Canadian Nanotechnology and Equity Challenges: Implications for Pro-Poor and Gender-Inclusive Policy

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ABSTRACT

Canadian Nanotechnology and Equity Challenges: Implications for Pro-Poor and Gender-Inclusive Policy

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Concordia University, 2018

Nanotechnology has been hailed as a disruptive technology that would revolutionize existing products and processes, open up new markets and business opportunities, as well as offer socio-economic benefits. Research and development (R&D) in this emerging technology presents great importance to many nations, offering a significant technological advantage that gears towards economic growth. However, despite the immense promise of societal benefits from nanotechnology applications, nanotechnology might expose societies to various forms of inequities. The main objective of this thesis is to examine two priority dimensions of equity concerns related to nanotechnology: the lack of R&D for nanotechnology applications that (predominantly) benefit developing nations (pro-poor R&D) and the scant representation of women in nanotechnology fields. This study adopts a combined use of bibliometrics, social network analysis, and survey results to perform both dimensional and cross-dimensional analysis, providing a better understanding of both issues and of how the two are related. The focus of this study is on Canada, a country who prioritizes nanotechnology research and development in its science and technology strategy, and actively practices gender fairness in the scientific system and is strongly involved in international development through its R&D efforts.

The findings reveal that only a narrow spectrum of Canadian nanotechnology articles and patents reflect pro-poor priorities, and acknowledge the importance of promoting and leading research and innovation in pro-poor areas, as it holds the potential to promote the economic development both within and between nations. However, these pro-poor scientific and innovative efforts tend to be highly male-dominated in terms of the scientific community and the workforce involved. Gender differences in citation and journal impact of papers published in the nano-pro-poor applications reveal the presence of the Matilda effect at the level of first-authorship and a strong selection effect at the level of last-authorship for women. While the majority of male authors and male inventors collaborate exclusively with men, those involved in a mixed-gender team outperform male-only teams. Therefore, it is important that policymakers pay attention to both gender and pro-poor initiatives simultaneously, because practices to promote pro-poor innovation might result in a wider gender gap and adversely affect social development. Furthermore, gender analysis of nanotechnology scientific reward system confirms that the gender productivity gap remains 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. The results of this study have strong implications for policy development (or reform) targeting both gender equality and poverty alleviation in emerging interdisciplinary areas, promoting a more equitable and inclusive society.

To all who live a life like “Maryam Mirzakhani”

All who with talent and grit have broken down barriers in science and paved the way for generations of women

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Lastly, I would like to dedicate this work to my beloved parents: to my father, whose loss looms large in my life over the last years, and to my mother, who, while pursuing her career as a university professor, also raised my two sisters and me. I owe my deepest gratitude to my sisters, Golsa and Saba, for their love and support which always warm my heart. If it wasn't for you, I would not have been standing where I am today.

PREFACE

This thesis is manuscript-based and is supervised under the co-direction of Dr. Matthew Harsh and Dr. Andrea Schiffauerova from Concordia University. The first manuscript entitled "A cross-dimensional analysis of nanotechnology and equality: Examining gender fairness and pro-poor potential in Canada's R&D landscape", is co-authored with Dr. Matthew Harsh and Dr. Andrea Schiffauerova. This manuscript is under review and was submitted to Research Evaluation in March 2018.

The Second manuscript entitled "Inequality and collaboration patterns of Canadian nanotechnology: Implications for pro-poor and gender-inclusive policy", is co-authored with Dr. Matthew Harsh and Dr. Andrea Schiffauerova. It is published in Scientometrics in February 2018.

The third manuscript entitled "What factors influence equity challenges of Canadian nanotechnology? Implications for pro-poor and gendered innovation", is co-authored with Dr. Matthew Harsh, Dr. Vincent Larivière, Dr. Catherine Beaudry, and Dr. Andrea Schiffauerova. This manuscript is under preparation and is to be submitted to PLOS One.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ACC	Average Clustering Coefficient
A-I	Author-Inventor
AMII	Alberta Machine Intelligence Institute
AUCC	Association of Universities and Colleges of Canada
CC	Clustering Coefficient
CES	Current Employment Statistics
CIDA	Canadian International Development Agency
CIFAR	Canadian Institute for Advanced Research
DFI	Development Finance Institution
EPO	European Patent Office
FP7	European Union's Seventh Framework Programme
ICON	International Council on Nanotechnology
IDRC	International Development Research Centre
IPC	International Patent Classification
ISIC	International Standard Industrial Classification
ISO	International Organisation for Standardisation
LFS	Labour Force Survey
MDGs	Millennium Development Goals
MILA	Montreal Institute for Learning Algorithms
MNCs	Multinational Companies
NAICS	North American Industry Classification System
NINT	National Institute for Nanotechnology
NNI	National Nanotechnology Initiative
NRC	National Research Council
NSERC	Natural Sciences and Engineering Research Council of Canada
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
RRI	Responsible Research and Innovation
S&T	Science and Technology

SCWIST	Society for Canadian Women in Science and Technology
SDGs	Sustainable Development Goals
SIC	Standard Industrial Classification
SJR	SCImago Journal & Country Rank
SNA	Social Network Analysis
SSHRC	Social Sciences and Humanities Research Council
STEM	Science, Technology, Engineering, and Mathematics
STI	Science, Technology, and Innovation
UIR	University-Industry Relationship
UN	United Nations
UNDP	United Nations Development Programme
USPTO	United States Patent and Trademark Office
WISE	Women in Science and Engineering

Chapter 1 - Introduction

Introduction

The term "nanotechnology" was coined in 1974 by Norio Taniguchi, a Japanese scientist to refer to the control of semiconductor processes on the nanometer precision. However, the concept was originated by Richard Feynman (Nobel Prize in Physics, 1965), in a visionary lecture titled 'There's Plenty of Room at the Bottom' which provided useful insights on manipulation of matter at atomic and molecular scales (Sandhu 2006). The term was not popularized until 1986 when Eric Drexler proposed the idea of molecular machines and their manufacturing in his book '*Engines of Creation: The Coming Era of Nanotechnology'*, which later was referred to as molecular nanotechnology (Collins 2007).

The term nano is originated from the Greek word "nanos" or "nannos" which refers to "dwarf", and is used as a prefix for units to represent a billionth of that unit. A nanometer (nm) is thus one billionth of a meter (10^{-9} meters). However, the wide use of the term "nanotechnology" as an all-encompassing reference to a broad range of research and development efforts to study matters at a nanoscale, reinforced the need for a rigorous definition of the term for the development and implementation of policies and initiatives in the field (Palmberg et al. 2009). Therefore, many agencies and governmental bodies have proposed definitions of nanotechnology, among which are National Nanotechnology Initiative (NNI), European Union's Seventh Framework Programme (FP7), European Patent Office (EPO), and International Organisation for Standardisation (ISO). The most widely used definition of nanotechnology in the policy context is "the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nano-scale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale." (NNI 2014).

Under this broad umbrella definition, nanotechnology is not confined to any specific technology or research but is an interdisciplinary pursuit, which draws on physics, chemistry, engineering sciences, material sciences, biology and other disciplines (Porter & Youtie 2009a). This interdisciplinary nature offers numerous potential benefits in a broad array of application areas, including but not limited to materials and manufacturing, electronics, aerospace and aviation, environment, energy, agriculture, water treatment and remediation, medicine and pharmaceutics (Mamalis 2007; Salamanca-Buentello, Persad, Martin, Daar, Singer, et al. 2005).

Nonetheless, the convergence of disciplines at the nanoscale greatly complicates the envisagement of the new prospects for nanotechnology and demarcation of its scope and scientific boundaries (Salamanca-Buentello & Daar 2016), and the societal impacts of nanotechnology development are largely unexplored (OECD 2014a). The analysis of publication and patent data provide a useful tool to assess the scientific, innovative and societal impact of nanotechnology, which could help address the challenges of tracking the development and use of nanotechnologies and serve to inform science and technology policies (Roco 2011).

1.2- Problem description

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 ranging from materials, medicine, and agriculture to research and development (Roco 2011). However, the possible economic benefits of nanotechnology could be undermined if nanotechnology negatively impacts the environment and public health, or reinforces inequalities (Cozzens 2010), stigmatization and discrimination (UNESCO 2014). Therefore, science and technology policymakers are challenged with the difficult task of 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, such as its environmental, health, social and economic outcomes, as well as how those outcomes will be distributed within and between countries (Hankin & Read 2016).

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 (Foster & Heeks 2013; Heeks et al. 2014) and responsible research and innovation (RRI) (Schroeder et al. 2016). The notion of inclusive innovation is widely embraced by international development agencies—such as World Bank, United Nations Development

Programme (UNDP), and Organisation for Economic Co-operation and Development (OECD)—and is built around innovations targeted directly at meeting the needs of the developing nations and low-income populations, offering scope for the introduction of "pro-poor" policies. RRI is a framework that is rooted in developed countries, and that aims at better align research and innovation (especially related to emerging technologies) with the societal needs and expectations. One articulation of RRI, offered by the European Commission, consists of six main themes, namely, public engagement, gender equality, science education, ethics, open access and governance.

This study sheds light on two important dimensions of inclusive and responsible research and innovation—gender equality and pro-poor innovation—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, such as establishment of several world-renowned research institutes (including National Institute for Nanotechnology and NanoQuebec), and involvement in several international policy collaborations (including collaborations with International Council on Nanotechnology (ICON) and Organization for Economic Co-operation and Development (OECD) Working Party on Nanotechnology) (NanoPortal 2014). It has also invested heavily in developing its nanotechnology capacity (139 million USD in 2005 (Palmberg et al. 2009)) and accounts for 1.3% of nanotechnology patents and 2.2% of nanotechnology publications (in 2017) globally (StatNano 2018)[1].

In June 2016, the Government of Canada launched an "inclusive innovation agenda"[2] 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 the RRI's gender inequality dimension and the shortage of women in Canadian science. Lack of women's participation in nanotechnology contributes to the general lack of women in science, technology, engineering and mathematics (STEM) fields. Furthermore, the underrepresentation of women in nanotechnology could exacerbate existing

[1] http://statnano.com/country/Canada
[2] https://www.ic.gc.ca/eic/site/062.nsf/eng/00014.htm

gender disparities in science by furthering the negative stereotype that women are less technology-adept (UNESCO 2014).

Pro-poor research and innovation have received scant attention in Canada's inclusive innovation agenda. This is likely due to the fact that the agenda has been launched by Innovation, Science and Economic Development Canada (formerly Industry Canada), the department responsible for industrial development, rather than by international affairs or development. However, Canada has been long involved in supporting pro-poor research and innovation through its International Development Research Centre (IDRC), an institution that particularly supports R&D related to improving the livelihood of poor and developing nations.

1.3- Scope and Objectives

The main objective of this study is to examine two priority dimensions of equity concerns related to nanotechnology, namely pro-poor potential and gender equity, to provide a better understanding of both issues and of how the two are related. For this purpose, this study provides both within- and cross-dimensional analysis, where the focus is on Canada, a country who prioritizes nanotechnology R&D in its S&T strategy (Minister of Industry 2014), and actively practices gender fairness in the scientific system and is strongly involved in international development through its R&D efforts. The importance of analyzing the pro-poor R&D dimension arises from the fact that it adds to Canada's years-long investment in knowledge and innovation to improve livelihood in developing countries, and the gender equity dimension is that it contributes to Canada's limited efforts to support and engage women in nanosciences. Cross-dimensional analyses add another layer to the understanding of the relationship between nanotechnology and inequity because it looks into the cross-cutting relationship between the two concerns, in the sense that a solution to one problem might positively or negatively affect another problem. For example, persisting equality and equity concerns of nanotechnology cannot be allayed if Canada's R&D efforts for pro-poor nano-innovation lead to a less gender-equal R&D workforce. Therefore, from an insight perspective, the main objectives of this study focus on three levels of analysis, including pro-poor dimension, gender dimension, and cross-dimension analysis.

The General Objectives

Pro-poor dimension:

1. Examine whether nanotechnology research and technological advancements in one of the most affluent countries, Canada, holds potent promises for poor in developing countries.
2. Identify scientific factors that influence scientific productivity and impact of Canadian researchers involved in nanotechnology pro-poor R&D.

Gender dimension:

3. Identify the key scientific, cultural and social attributes and factors that exacerbate or improve gender disparities in scientific production and impact.

Cross-dimensional analysis:

4. Provide a cross-gender analysis of scientific and technological performance, and collaboration patterns of researchers involved in advancements of pro-poor applications of nanotechnology, and pinpoint key challenges they face in their persistent publishing and patenting efforts in developing this breakthrough technology and applications.
5. Identify industries where companies involved in Canadian pro-poor nanotechnology R&D are poised for growth and examine where these industries stand in the Canadian economy in terms of the gender gap in wage and employment.

The Specific Objectives

1. Examine the quantity and quality of nanotech-related articles and patents of one of the most affluent and innovative countries, Canada, which can potentially bring benefit to the poor.
2. Investigate the role of female scientists (versus their male counterparts) in developing these applications.
3. Analyze gender differences in collaboration patterns among authors, inventors, and author-inventors and examine the distinct role of individual scientists in the innovative process.
4. Examine citation and journal impact of articles by authorship order for authors of each gender.

5. Explore the evolution of co-authorship and co-inventorship networks in time and the spread of knowledge through the scientific individuals of each gender in the networks.
6. Map gender diversity in co-authorship and co-inventorship collaboration teams of researchers of each gender and analyze scientific and technological productivity and impact of researchers involved in these scientific collaboration teams.
7. Provide visualization of networks to better understand the network structure and position of female researchers in their networks of collaborations.
8. Identify nanotech-related companies that are involved in pro-poor nano-innovation and determine where industrial sectors that are the primary focus of these companies stand in the Canadian economy in terms of gender employment and wage gap.
9. Determine influencing scientific factors on scientific productivity and impact of researchers involved in pro-poor nanotechnology research.
10. Identify scientific and demographic, and cultural factors that exacerbate or alleviate gender disparities in scientific productivity and impact.
11. Identify barriers and obstacles women face in their scientific community that impede their publishing and patenting productivity.
12. Propose policy and strategy implications for the promotion of gender equality and poverty reduction within nanotechnology innovation efforts.

1.4- Organization of the thesis

This thesis comprises five chapters and is organized as follows. Chapter 2 provides a cross-dimensional analysis of nanotechnology and equality, investigating whether Canadian nanotechnology R&D is addressing the needs of the poor and addressing gender disparities in research and innovative advancements of pro-poor applications of nanotechnology. This chapter uses bibliometric analyses of the Scopus article database over the period 1996-2011 and the United States Patent and Trademark Office over the period 1996-2009. Statistics Canada data are then used to map where the companies involved in the development of these applications stand in the Canadian economy in terms of gender equality in wages and employment. Chapter 3 complements Chapter 2 by applying social network analysis to explore differences in collaboration patterns of authors and inventors of each gender whose work is related to pro-poor applications of nanotechnology. Both of these chapters (chapter 2 and 3) call for development and implementation of pro-poor and gender-responsive policies to promote holistic equality in the emerging science and technology sectors. Chapter 4 looks into the two dimensions (gender equality and pro-poor innovation) separately and tries to articulate equity challenges of nanotechnology development in Canada with the use of survey results and the Scopus database. This chapter applies an exploratory approach to analyze how both bibliometric and sociodemographic indicators are linked to scientific, cultural and social factors influencing scientific productivity and impact of Canadian nanotechnology researchers from a pro-poor and gender perspective. This chapter concludes with several gender-related policy implications to support the involvement of women in nanotechnology research activities on the one hand. It also provides pro-poor policy implications to promote international development. Finally, chapter 5 presents concluding remarks and suggests several avenues for future work.

Chapter 2 - Article 1

A cross-dimensional analysis of nanotechnology and equality: Examining gender fairness and pro-poor potential in Canada’s R&D landscape

Abstract

Countries invest in nanotechnology primarily to increase economic growth and industrial development. However, nanotechnology might expose societies to various forms of inequalities, or at the same time, might be used as a tool to decrease existing inequalities. These inequalities fall along two dimensions, vertical and horizontal, where the former refers to economic inequalities (e.g., rich-poor gaps) and the latter indicates social inequalities (e.g., gender and ethnicity gaps). This study is a cross-dimensional analysis of nanotechnology and equality, investigating the relationship between the development and commercialization of nanotechnology applications that improve the livelihoods of the poor (pro-poor applications), and the gender gap in the scientific workforce. Cross-dimensional analyses are essential to more fully understand how emerging technologies affect equality—an effort to decrease inequality in one dimension (closing rich-poor gaps) might still increase overall global inequality if it also widens inequality in another dimension (widening gender gaps)—and to guide policy: many affluent countries, like Canada, aspire to use R&D to reduce inequality in both dimensions. Bibliometric analyses of the Scopus article database and the United States Patent and Trademark Office are used to explore if Canadian nanotechnology is addressing the needs of the poor and then to examine gender disparities in research and innovative advancements of pro-poor applications of nanotechnology (i.e., energy, agri-food, and water). Statistics Canada data are then used to map where the companies involved in the development of these applications stand in terms of gender equality in wages and employment. Only a small percentage of Canadian nanotechnology articles and patents reflect pro-poor priorities. Furthermore, Canadian workplaces that are producing pro-poor nano-applications are largely male dominant. Both pro-poor and gender-responsive policies are needed to promote holistic equality in emerging science and technology and foster economic growth.

Keywords: Nanotechnology; Gender; Pro-poor; Bibliometrics

2.1- Introduction

The application of nanotechnology[3] to a wide array of products and industries has potential to create enormous economic and societal benefits, and across the world, firms, governments, and universities are increasingly investing in this technology. There is a growing literature on the economic and policy dimensions of nanotechnology that documents these trends, focusing on how nanotechnology contributes to technological competitiveness (Forster et al. 2011; Mowery 2011; Shapira and Wang 2009). Nevertheless, these studies mostly reflect the viewpoint of affluent countries and focus on commercial payoffs of nanotechnology applications, leaving the debate about equity and nanotechnology – i.e. nanotechnology's potential to open gaps between developed and developing nations, between different racial groups, between men and women, etc. – open and intense (Cozzens and Wetmore 2011). Therefore, it is important to understand how nanotechnology might create new inequities, and how to use this breakthrough technology to alleviate existing inequities. For example, advances in nanoscale sciences related to medicine and nano-materials used for water purification (Hillie & Hlophe 2007), and for agricultural and energy production (Nature Nanotechnology 2007; Salamanca-Buentello, Persad, Martin, Daar, & Singer 2005), could improve the livelihoods of the poor and address inequity issues. And given that nanotechnology is still emerging and has not yet been fully entrenched in society, it is of utmost importance to gauge and define its effects on equity and equality[4] now.

Inequalities can be categorized along two dimensions, vertical and horizontal, where the former indicates the unequal distribution of wealth and income between counties or individuals (rich-poor), and the latter implies differences between groups in terms of culturally-defined categories (e.g., gender and ethnic inequalities). Both types of inequalities are among the factors that hinder social cohesion[5] and inclusion[6] (Cozzens et al. 2007; Cozzens and Wetmore 2011). Hence, science,

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[3] Nanotechnology is "the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, the size-scale between individual atoms and bulk materials, where unique phenomena enable novel applications" (NNI 2007).
[4] The term inequality explains a "given empirical distribution" while the term inequity describes "a normative judgment about a given inequality" (Cozzens and Wetmore 2011).
[5] Social cohesion refers to all efforts which "ensure that every citizen, every individual, can have within their community the opportunity of access: to the means to secure their basic needs, to progress, to protection and legal rights, and to dignity and self-confidence" (Council of Europe 2001, p.5).
[6] Social inclusion is "people's ability to participate adequately in society, including education, employment, and public services, social and recreational activities" (Litman 2003).

technology, and innovation (STI) policies aimed at reducing inequalities are important tools to help build a cohesive and inclusive society. Cozzens divides these policies into three categories, namely pro-poor (associated with poverty alleviation), fairness (associated with horizontal inequalities) and egalitarian (associated with vertical inequalities) (Cozzens 2008).

This study applies Cozzens's theory of equity and nanotechnology (Cozzens 2010) to provide the first quantitative, cross-dimensional analysis of nanotechnology and inequality. It investigates the relationship between the development and commercialization of nanotechnology applications that benefit the poor (pro-poor) and the gender gap in the scientific workforce. Cross-dimensional analyses are crucial to more fully understand the relationship between nanotechnology and inequality because exploiting nanotechnology's potential for the poor could lead to a less equitable global society if it widens inequalities at horizontal dimension while trying to rectify vertical inequalities.

Cross-dimensional analyses are especially important to inform policymaking in advanced economies, like Canada, that are actively trying to use R&D to promote equality in both vertical and horizontal dimensions: by improving gender fairness in the scientific workforce, and by using R&D as a tool to help international development. Increasing women's participation in STI has long been a goal in the science and technology (S&T) policy discourses of Canada, as part of the quest for gender equality and economic growth[7]. Organizations such as Society for Canadian Women in Science and Technology and Engineers Canada are devoted to promoting gender equality in science and engineering fields. However, within the national government, policies for gender inclusion in S&T only exist in the form of initiatives within the Natural Sciences and Engineering Research Council of Canada (NSERC). In terms of commitments to using R&D to help developing countries, Canada, has played a leading role through its International Development Research Centre (IDRC), a unique institution that focuses explicitly on STI in developing countries. Furthermore, in 2004, Canada set a target of using 5% of R&D investment to address challenges in developing countries (Salamanca-Buentello, Persad, Martin, Daar, & Singer 2005).

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[7] Given that women represent 50% of Canadian population (Urquijo & Milan 2011) but only 20% of the scientific workforce (Shendruk 2015), they represent a potential human capital asset that if tapped, could enhance the performance of S&T activities.

Therefore, if Canada can increase women's participation in research and development of the pro-poor applications of nanotechnology, this will contribute to many of its policy goals: it will not only help raise the level of innovativeness of the Canadian economy and improve gender equity, it will also create benefits for low-income and developing nations. Henceforth, this study has three main objectives. It (1) examines whether nanotechnology's scientific and technological advances in one of the most affluent countries, Canada, hold potent promises for poor and developing countries; it (2) provides an improved understanding of women's contribution to these advances over time and (3) further examines where potentially pro-poor nanotechnology-focused industries stand in the Canadian economy in terms of gender gap in wage and employment.

2.2- Literature Review

2.2.1- Nanotechnology and Millennium Development Goals

Potential applications of nanotechnology could have positive impacts on poor and marginalized communities. Fabio Salamanca-Buentello and his colleagues (2005) have ascribed the most promising nanotechnology applications with respect to the United Nations (UN) Millennium Development Goals (MDGs), arguing that nano-applications in energy, agri-food, and water are the most likely to benefit the poor, improve livelihoods, and contribute to achieving several of the MDGs: eradication of poverty, decrease in child mortality, improvement of maternal health, control of HIV/AIDS and other diseases, and environmental sustainability.

Nonetheless, none of the top pro-poor nanotechnology applications contribute to the third UN MDG, namely gender equality and empowerment of women. This underlines that it is not possible to reach global equity by introducing novel nano-applications that might reduce the gap between the poor and the rich while also increasing gender disparity. Hence, it is of great importance to look into the cross-cutting relations of both inequality dimensions and to understand how development and commercialization of these pro-poor applications affect gender equality. Invernizzi and Foladori (2005) found the Salamanca-Buentello's argument too 'optimistic' and claimed that new technologies are designed for the advantaged rather than the disadvantaged. Cozzens et al. (2013) thus further empirically tested the argument of Salamanca-Buentello (2005) by examining nanotechnology research advances in energy, agri-food, and water that have pursued the MDG-related priorities and argued that both developed and developing countries benefit from these applications. The last UN MDG which envisions creating a global partnership for development highlights the social responsibility of developed countries to address the needs of the developing countries and to ensure that developing countries can benefit from the new technologies. However, in the literature, there is still a research gap on the extent to which nanotech-related research and technological rise of affluent countries are in consonance with the needs of developing countries and MDGs (Harsh & Woodson 2012).

This study accordingly seeks to corroborate the work of Cozzens and her colleagues (2013) and specifies how nanotechnology research and development (R&D) in Canada (i.e., one of the top affluent countries) is relevant to the context of developing countries. Particularly it examines scientific and technological advances in the top potential 'pro-poor' nano-applications (energy, agri-food, and water).

2.2.2- Nanotechnology and Women

Issues related to women in science, technology, engineering and mathematics (STEM) are often seen as threefold (Schiebinger 2008). Firstly, there is a research focus on investigating women's participation in STEM at an individual level where the concepts of "glass-ceiling" and "leaky pipeline" have been coined to address gender barriers women face in their career path (Buré 2007). A second focus is on analyses of women's involvement in the cultures of STEM at an institutional level. An example here is the work of McAdam and Marlow (2008) which examines women's difficulties in founding technology-based start-ups. Third, there is a societal level focus on women and the outputs of STEM, to see how women are involved in bringing quantity (Bordons et al. 2003; Cole & Zuckerman 1984; Etzkowitz et al. 2000; Larivière et al. 2011, 2013a; Leahey 2006; Nakhaie 2002; Prpić 2002; Xie & Shauman 1998) and quality (Borrego et al. 2010; Long 1992; Peñas & Willett 2006; Whittington & Smith-Doerr 2005) to research and technological advances in various countries.

When it comes to nanotechnology specifically, there have been very few studies on women's participation and performance in nanotechnology science and innovation, despite the growing literature and focus on the capacity building in nanotechnology development. The works of Smith-Doerr (2011), and Meng and Shapira (2011) shed first light on nanotechnology and challenges of gender equity. By employing feminist theories and comparing the nanotechnology development to biotechnology, Smith-Doerr (2011) attempted to explore the probable place of women in nanotech-related research and production. Meng & Shapira (2011) further tried to explore one of the areas Smith-Doerr (2011) highlights, namely nanotechnology patenting by women, and concluded that there is a gradual reduction in the gap distance between female and male patenting. Smith-Doerr (2011) calls for further research into gender equity in the emerging nanotechnology sector, underlining nanotechnology's importance to policies that try to halt emerging gender inequity in STEM and promote equality. This paper, thereby, intends to fill this gap by tracing women's scientific and innovative productivity and impact in pro-poor nanotechnology applications.

2.2.3- Nanotechnology and Employment

Many have argued that nanotechnology's promise for job creation is huge (Palmberg et al. 2009). However, Stephan et al. (2007) and Freeman and Shukla (2008) found the number of nanotech-related jobs is 'few' and job growth in nanotechnology 'modest'. According to Roco and Bainbridge (2001), nanotechnology is expected to create around 2 million jobs by the end of 2015 and 6 million jobs by 2020 worldwide (Roco 2011). For Canada alone, the estimated nanotechnology market value will be around 100 billion dollars, and the sector will consist of approximately 600,000 jobs by 2020 (Alberta Advanced Education and Technology 2007).

However, these forecasts may vary based on different definitions of nanotechnology, the degree of optimism, and the degree that nanotechnology can add value to final products (Hullmann 2007). The majority of the nanotech-related workforce is formed by highly educated scientists and engineers (Invernizzi 2011). This could be due to the fact that nanotechnology is still in development stages and thus current jobs are related to R&D activities. However, the broad spectrum of nanotechnology creates the need for workers with a range of skills at different levels of the production chain (e.g., in manufacturing, sales, marketing, and distribution) (Invernizzi 2011). Hence, nanotechnologies might have a great potential to revolutionize the labor market in the near future, in terms of types of jobs and skills required, and these changes could affect various sectors. The research on how nanotechnology's promise of employment would affect different classes of people is very nascent. Thus, this study puts focus on the industries where companies involved in Canadian pro-poor nanotechnology R&D are poised for growth and identifies the gender gap in employment and wage.

2.3- Methods

2.3.1- Data

In this study, scientific publications are extracted from the Scopus database. Scopus accumulates and presents one of the largest article abstract and citation databases spanning science, technology, medicine, social sciences, arts, and humanities. Scopus provides an extensive coverage of data about peer-reviewed scientific publications in multiple disciplines including abstract, citation (per each year) and author information data (for each co-author), which gives Scopus significant advantages over other databases, as these data are very valuable and useful for assigning different attributes (e.g., gender and sector). Only peer-reviewed articles are analyzed in this study as they serve as the most commonly used measure of contributions to scientific knowledge (Moed 1996).

The patent data come from the United States Patents and Trademarks Office (USPTO) which has the largest coverage of patents registered in North America and provides patent data information, including inventor name, assignee name and location, international patent classification (IPC) code, application and grant date, and geographical location of the residence for each inventor.

The nanotechnology-related article and patent data are extracted using a full-text keyword search strategy. More details can be found in Barirani et al. (2013) and Tahmooresnejad et al. (2015). Our focus in this study is on articles published in 1996-2011 and patents granted over the period 1996 to 2009 because these are the years where the complete data are available to us. 1996 is the first year in which Scopus has full coverage, and 2011 was selected as the end year because it takes a lag of a few years to update all the publications after a given year is over.

Canadian nanotech-related articles involving water, energy, and agri-food applications are identified using the keyword filters proposed by Cozzens et al. (2013), and those where at least one author is affiliated to a Canadian institution are extracted. Similarly, patents are classified into those three applications using the same keyword filters while looking only into titles and abstracts. A total of 1,157 articles and 2,528 authors, and 365 patents and 608 inventors are identified. The gender is assigned to each author using the GenderChecker name and gender database[8]. For those authors where GenderChecker assigns a unisex designation or is not able to assign a gender

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[8] http://www.genderchecker.com

designation at all, gender is manually assigned based on author's academic, professional or Linkedin profiles. Note that gender is assigned to all the authors and inventors identified. Academic, governmental and industrial sectors are assigned to authors based on their affiliations. Similarly, provinces are assigned based on where affiliated institutions are located. For patents, different sectors are assigned based on the assignee sector type, i.e., whether it is a university, governmental agency or a company.

Canadian author-inventors (A-Is) are Canadian inventors whose names also appear in the Canadian nanotechnology articles database. In this study, A-Is are assigned to those who are involved only in publishing and patenting in pro-poor nanotechnology applications, and a total of 43 A-Is are identified in our databases. For validation, 1000 random authors and inventors were selected, and their gender and sector were independently identified and confirmed.

Created databases on nanotechnology publications and patents are further used to identify nanotech-related companies to which at least one publication is affiliated or to which at least one patent in water, energy or agri-food applications is assigned 185 unique companies are found in our article and patent databases). These companies are classified based on their North American Industry Classification System (NAICS) code using the Mergent Online database[9]and the identified industries are examined with regard to the number of female employees and wages by using the Labour Force Survey estimates (LFS) table of Statistics Canada. Statistics Canada's LFS data[10] table provides the list of industries and the data on the number of men and women employed in Canada and their hourly wages. These steps allow us to identify industries associated with nanotech-related companies in water, energy, and agri-food and categorize them under male-dominated and gender-balanced sectors (see below for more detail on how these designations are made).

2.3.2- Bibliometrics

The analyses are based on bibliometric indicators of scientific and innovative activities. Bibliometrics is a method commonly used to assess innovative and scientific research excellence

[9] http://www.mergentonline.com/

[10] Table 282-0071 5; Labour Force Survey estimates (LFS), wages of employees by type of work, North American Industry Classification System (NAICS), sex and age group, unadjusted for seasonality; Available at: http://www5.statcan.gc.ca/cansim/pick-choisir?lang=eng&p2=33&id=2820071

through quantitative analyses of patent and research publications. This study deploys quantitative bibliometric indicators to conduct large-scale analyses to measure the scientific excellence and innovative potential for pro-poor nanotechnology applications in Canada.

To evaluate the productivity of researchers or groups of scientists, this study uses the number of publications as the main indicator. Average number of citations per year is used to address the scientific impact and publication quality. The SCImago Journal & Country Rank (SJR) is also used as a journal quality indicator. SJR is a journal prestige metric, which uses Google's PageRank™ to rank nearly 17,000 journals based on Scopus data. SJR weights received citations based on the subject field, quality, and prestige of a citing journal (Guerrero-Bote & Moya-Anegón 2012). Due to its specific features, such as being subject-field normalized, exclusion of journal self-citations (maximum 33% of journal self-citations is counted), broader coverage of journals, and compatibility with Scopus data (García-Peñalvo et al. 2010; Guerrero-Bote & Moya-Anegón 2012), SJR is chosen in this study as a measure of journal quality.

All of these measures are used based on fractional counts of articles, assigning each author 1/x count of authorship where x represents the number of co-authors in an article. This means that if a paper with five authors has the same citation impact as a sole-authored paper, the author of the sole-author paper is considered to be involved in higher quality work than any of the five individuals of the co-authored paper.

A similar approach is applied to patents. The volume of patents is used as an indicator of technological output and quality of patents is evaluated based on average number of citations received per year and the number of claims. Each of these indicators is measured as a fractional count of patents where inventorship is measured as 1/y where y is number of inventors listed in a patent. Further, each of these bibliometric indicators is measured for female scientists and their male counterparts to map gender disparity in development of pro-poor technologies.

Table 2.1 shows the number of Canadian nanotechnology articles and patents with energy, agri-food, and water applications. Nanotechnology-related articles with energy applications represent only 3.7% of all the Canadian nanotech-related publications, which is the highest among the three pro-poor application areas of nanotechnology. Ontario has the highest share of nanotech-related publications in all the three applications followed by Quebec. As for patents, the shares of nanotech-related patents with energy and agri-food applications are higher (respectively, 5.8% and 2%) compared to their shares of publications (3.7% and 1.2% respectively). Ontario holds the highest share of patenting, and British Columbia and Saskatchewan show prominence in energy and agri-food patent applications, respectively. Given that the numbers of papers and patents are very small in Saskatchewan, the cross-province analysis in this research is confined to Ontario, Quebec, British Columbia and Alberta.

Table 2.1- Number and share of nanotech-related publications and patents with energy, agri-food, and water applications

		Energy	Agri-food	Water
Number of articles		726	244	271
% of nanotech-related papers		3.7%	1.2%	1.4%
Share of authorship of Canadian provinces	**Ontario**	45.9%	38.2%	49.2%
	Quebec	23.0%	25.0%	27.9%
	British Columbia	12.5%	9.5%	4.4%
	Alberta	11.6%	11.7%	10.2%
	Saskatchewan	2.8%	9.6%	2.6%
	Others	4.2%	5.9%	5.7%
Number of patents		241	82	53
% of nanotech-related patents		5.8%	2.0%	1.3%
Share of inventorship of Canadian provinces	**Ontario**	50.3%	51.2%	62.7%
	Quebec	17.8%	6.3%	11.3%
	British Columbia	24.0%	5.5%	9.4%
	Alberta	5.7%	13.3%	9.0%
	Saskatchewan	0.1%	15.8%	5.7%
	Others	2.1%	7.9%	1.9%

2.4- Results

2.4.1- Nanotechnology and Millennium Development Goals

Universities hold the highest share of publications across all the provinces. University of Alberta and University of Toronto are among the most active universities. Ontario has a high share of governmental publishing, which is due to the existence of the National Research Council (NRC) and Health Canada related laboratories in Ottawa, Ontario, the national capital (Fig. 2.1A). The laboratories include the NRC Institute for Microstructural Sciences, the Steacie Institute for the Molecular Sciences, the NRC Institute for Biological Sciences, Health Canada’s Healthy Environments and Consumer Safety Branch and Health Canada's Biologics and Genetic Therapies

Directorate. Agri-food applications hold the highest share of governmental involvement in scientific research, in which the NRC's Plant Biotechnology Institute (in Saskatchewan) and Agriculture and Agri-Food Canada's Saskatoon Research Centre play an important role (Fig. 2.1B). The private sector and hospitals are involved in low rates of publishing across different provinces for pro-poor nanotechnology applications. However, AB Sciex LP and Medicago Inc. are among the top firms involved in publishing.

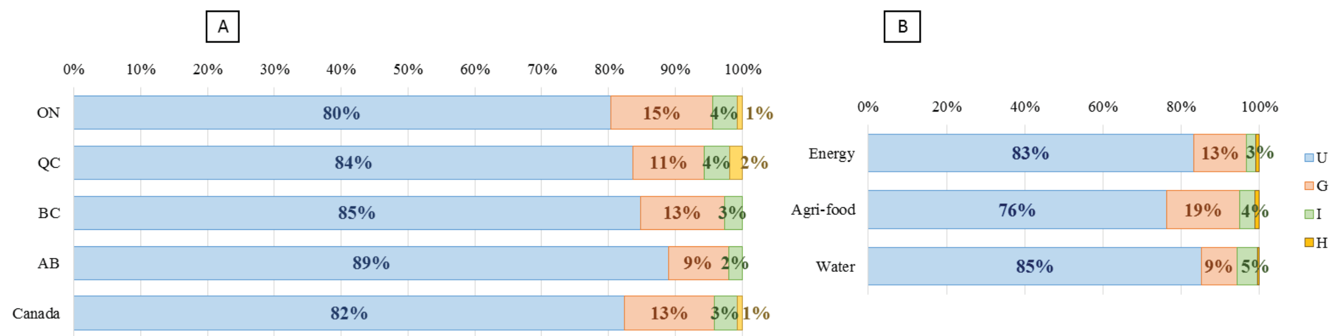


Figure 2.1- (A) Share of different sectors in pro-poor nanotechnology publications by province[11]; (B) Share of different sectors by field[12]

Nanotech-related publications with energy applications are the main focus across most of the dominant provinces. The number of publications in water and agri-food applications is similar but low across different provinces (Fig. 2.2A). Fig. 2.2B shows the cumulative volumes of articles across the years 1996 to 2011. The exponential trend line was chosen as it fits best to the cumulative number of articles (R squared more than 0.95). Fig. 2.2B reveals that the number of papers with the three pro-poor applications follows a trend-line with higher exponential growth rate than the one of the overall nanotechnology papers. Papers with the focus on water and energy applications have the highest exponential growth rate, explaining an accelerated focus on these specific application areas despite the fact that share of articles in these applications is low.

2.4.2- Gender Disparities in Publications

Authorship of pro-poor nanotechnology papers is largely male-dominated. Women hold merely 18% of total authorship (Fig. 2.4C) in all the pro-poor applications which is even lower than the share of women authorship across all the sciences and all the engineering, which are 30%

[11] Abbreviations for provinces are: ON=Ontario, QC=Quebec, BC=British Columbia, AB=Alberta
[12] Abbreviations for sectors are: U=University, G=Government, I=Industry, H=Hospital

(Larivière et al. 2013a) and 20% (Ghiasi et al. 2015), respectively. Fig. 2.3 shows that despite the growth in the number of articles and authors, the share of female authorship did not change noticeably over the 15-year period.

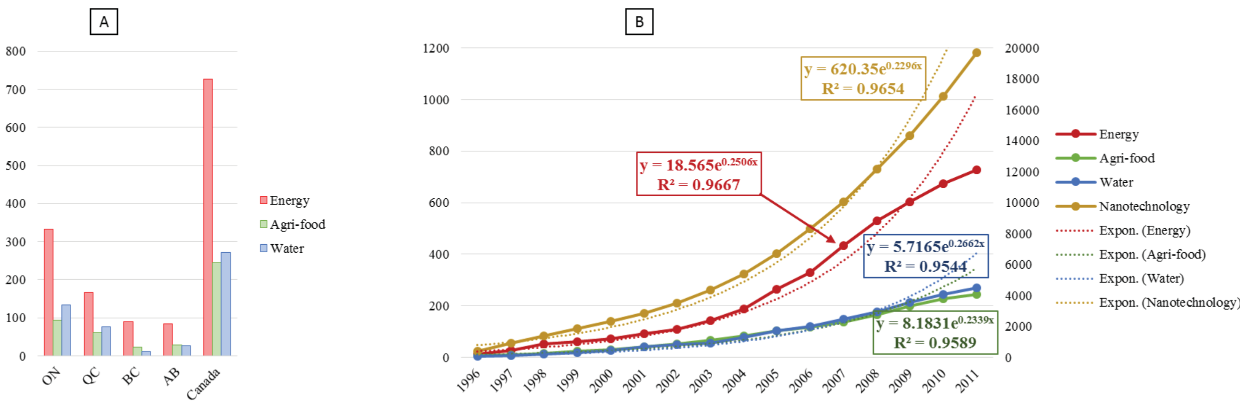


Figure 2.2- (A) Nanotechnology authorship by province in pro-poor applications; (B) Trend line based on cumulative number of publications in nanotechnology (right axis) and its pro-poor applications (left axis)

Narrowing the focus to disparities across different sectors, the share of women authorship has shown to be higher in universities and governmental agencies and is the lowest in industry. Women affiliated with governmental agencies have published in higher ranked journals, and their publications have received higher numbers of citations compared to their male counterparts. Women in academia, despite the higher overall quality of papers compared to other sectors, were involved in papers which had lower citation impact and were published in lower quality journals in comparison to their male peers.

It might seem that authorship in industry favors women in the sense that on average they have published in only slightly lower quality journals and their publications received more citations, however it should be noted that the share of industry in pro-poor nanotechnology authorship is very small (~3%) and involves only 57 papers with only 17 female authors. Therefore, the findings on paper quality for women in industry are biased due to the small number of women involved.

Nanotechnology authorship with energy applications is the most male-dominated application where women published articles with lower scientific impact. This may be due to the fact that research in energy occurs largely within the highly male-dominated fields of engineering and physics, whereas agri-food and water applications are associated with less male dominant fields, namely earth sciences, biology, biotechnology, chemistry and health sciences, according to the work of Larivière (2014), who mapped the level of male dominancy in scientific authorship of different disciplines in Quebec, Canada and worldwide. Authorship in agri-food and water applications was less male-dominated, and women have published in journals with the same quality as their male peers. However, women received lower citation rates. This finding might correspond to the "Matilda effect in science" (Rossiter 1993) at the citation level, where the number of citations of papers published by women is lower than the number of citations expected to be received by papers published in a given journal. A similar interpretation is discussed in engineering (Ghiasi et al. 2015) and all sciences (Larivière 2014).

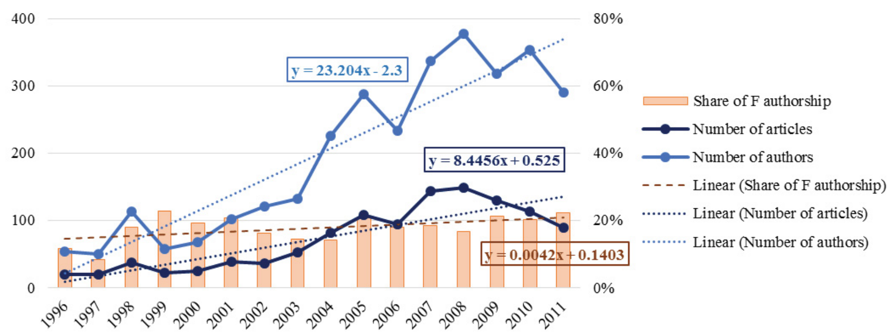
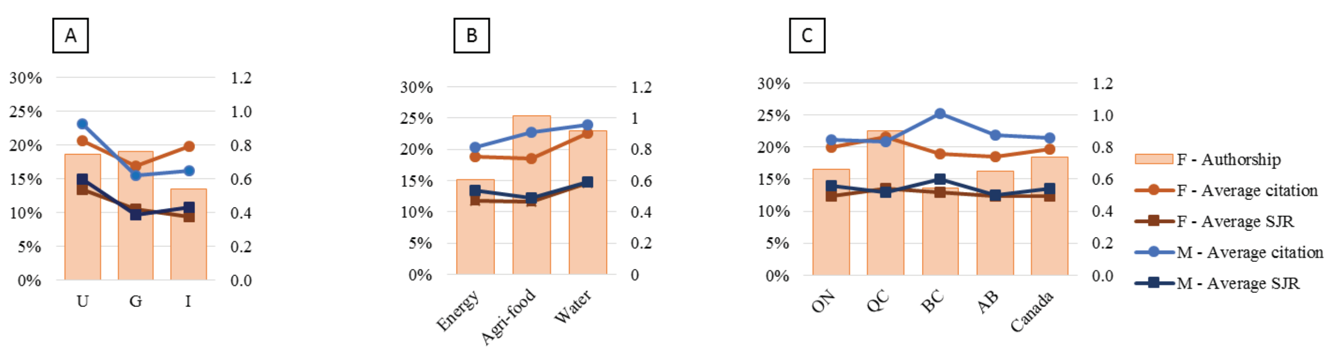


Figure 2.3- Number of articles and authors (left axis) and share of female authorship (right axis) over years in pro-poor nanotechnology applications[13]

Women in Quebec have proved to be dominant, given that their share of authorship is higher than the authorship share of Canadian women. This is in line with the analysis of Larivière (2014) across all scientific fields. Moreover, Quebec women were involved in papers published in higher ranked journals that also received higher numbers of citations than their male peers from Quebec.



[13] Abbreviations for gender: F=female, M=Male

Figure 2.4- Share of women authorship (left axis) and citation and journal impact (right axis) of the papers published by female and male authors (A) by sector (B) by application and (C) by province

2.4.3- Patent Analysis

As one might expect, industry holds the lion share of patent inventorship (73%), followed by universities (16%) and governmental agencies (9%). In terms of provinces, Ontario holds the highest share of patent inventorship followed by British Columbia and Quebec (Table 2.1). British Columbia has the highest share of industry patenting, and universities play a major role in Quebec and Alberta (Fig. 2.4A). Government plays a large part in the development of nanotechnology patents in agri-food applications compared to the other applications (Fig. 2.4B). Top governmental agencies involved in pro-poor nanotechnology patenting are the NRC, the Ministry of Natural Resources, and top companies are the Xerox Corporation, Nortel Network limited and Zenon Environmental Inc. Top universities are the University of Saskatchewan and Laval University.

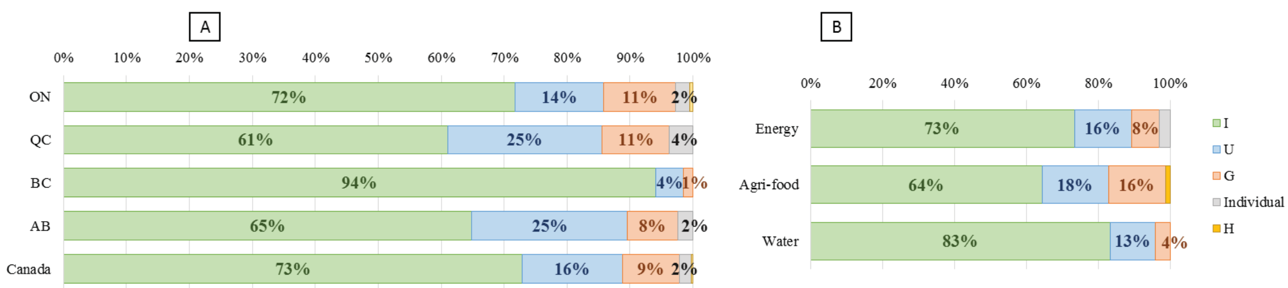


Figure 2.5- (A) share of different sectors in pro-poor nanotechnology patents by province; (B) Right share of different sectors by field

Similar to the publication analysis, the volume of patents with energy applications is the highest among dominant provinces, and the patent inventorships with agri-food and water applications are almost the same. However, the power trend lines (the best-fit trend lines in this case) on cumulative number of patents suggest that the growth rates of energy and agri-food patents are higher than the overall nanotechnology patent growth rate. Water has the lowest growth rate, which implies that technological advancements with water applications are very undeveloped in Canada.

2.4.4- Gender Disparities in Patents

Similar to authorship, despite the growth in the number of patents and inventors, the share of female inventorship only slightly increased overtime (Fig. 2.7). Women were involved in only 11% of inventorship in pro-poor applications of nanotechnology (Fig. 2.8C). This share is similar to the findings of Sugimoto et al. (2015) who analyzed all technological fields worldwide and found a proportion of 10.3% in 2013. It is also higher than the findings of Mauleón et al. (2013) who focused on Spain and found that women were involved in only 9% of patents. This could be due to the interdisciplinary nature of the nanotechnologies, based on which Meng and Shapira (2011) justified the narrower gender gap they found in nanotechnology patenting in the US.

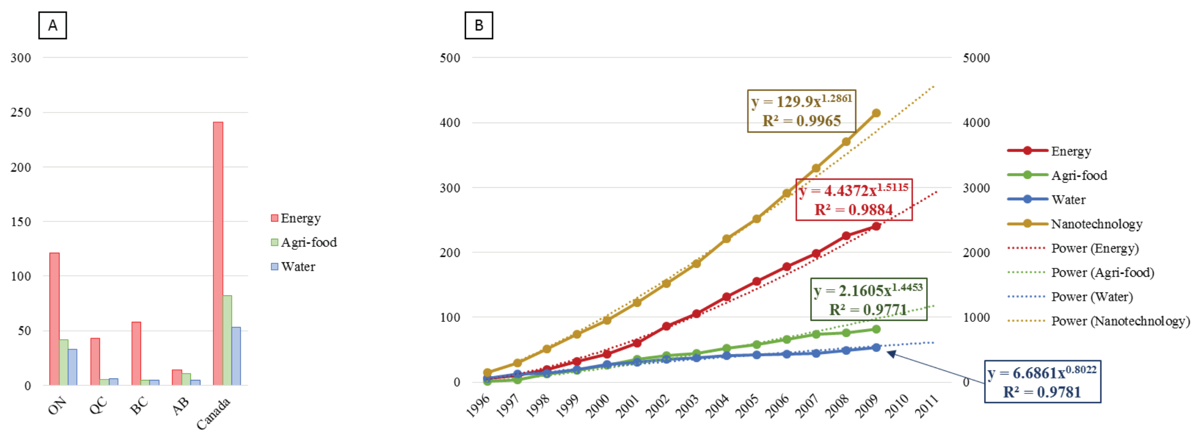


Figure 2.6- (A) Nanotechnology inventorship by province in pro-poor applications; (B) Trend line based on cumulative number of patents in nanotechnology (right axis) and its pro-poor applications (left axis)

When focusing on women participation in patenting across different sectors, one sees that women's share of inventorship is slightly higher in industry compared to universities and governmental institutions. Women were involved in industry patents with the same citation impact as their male counterparts, however, at universities and government institutions, there was a gender gap in the citation impact (Fig. 2.8A). Contrary to female authorship, the share of women inventorship is slightly higher in the energy and agri-food sectors (12%) than in the water (7.5%) (Fig. 2.8B). Women contributed to patents with a lower number of claims in all the sectors, applications, and provinces. The quality of nanotech-related patents with energy applications, in general, is higher than the ones with agri-food and water applications, and women have also proved to have almost the same citation impact as their male peers in this specific application area. The share of women inventorship is highest in Alberta, and female inventors contributed to patents with the same citation impact as their male peers in Quebec and Alberta (Fig. 2.8C). This also corresponds to the publication analysis where papers published by women in Quebec and Alberta have shown to have the same impact as the papers by their male counterparts.

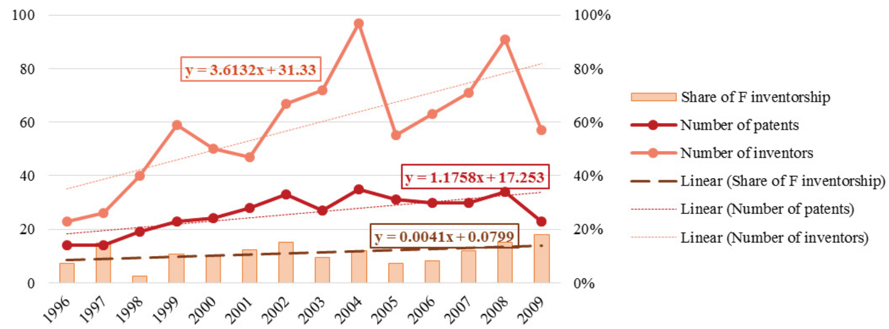


Figure 2.7- Number of patents and inventors (left axis) and share of female inventorship (right axis) over years in pro-poor nanotechnology applications

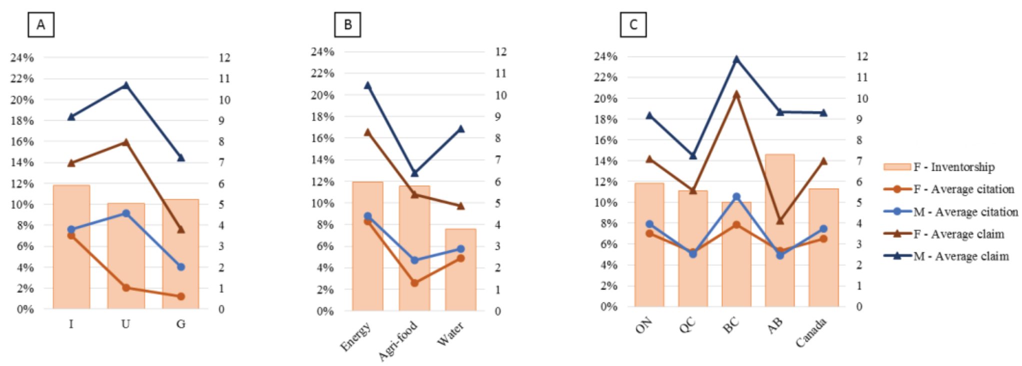


Figure 2.8- Share of women inventorship (left axis) and citation impact and patent claim (right axis) of the patents granted to female and male inventors (A) by sector (B) by application and (C) by province

This study also provides cross-gender analysis for the production, performance, and quality of Author-Inventors (A-Is). Author-inventors are here Canadian-affiliated individuals who published at least one paper and registered at least one patent in subfields of water, agri-food, and energy. Women account for only 5% of A-Is. However, women A-Is have shown on average to be involved in articles published in higher quality journals and articles receiving more citations. They were also involved in patents with almost the same number of claims and with even higher number of citations than men. Therefore female A-Is have contributed to more quality work compared to the male A-Is.

2.4.5- Employment Analysis

Industries which are comprised of at least one company contributing to the scientific and technological development of pro-poor nanotechnology applications are identified. 52% of the companies are focused primarily on manufacturing, followed by professional services (24%) (Fig. 2.8A).

For this study, industries are assigned as gender-balanced where the employment gap or wage gap in that specific industry is lower than the gender gap across all the industries in Canada (Orange bars in Fig. 2.9) and as male-dominated where the employment and wage gaps are higher (blue bars in Fig. 2.9). In Canada, the employment gap in the share of women and men across all industries is 1.9%, and the gender wage gap is 16.4%. Among the identified industries, only the educational services industry has shown to be pro-women in terms of both employment and hourly wages.

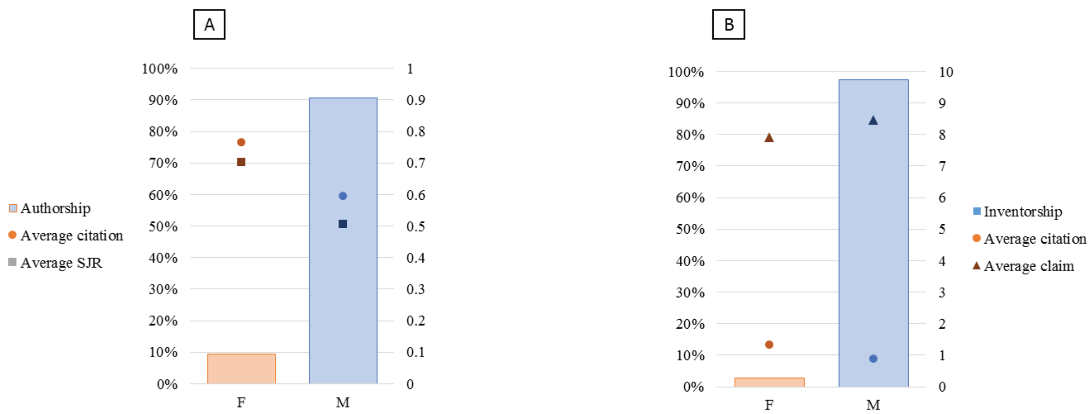


Figure 2.9- (A) Share of female A-Is authorship (left axis) and citation and journal impact of papers published by female and male A-Is; (B) Share of female A-Is inventorship (left axis) and citation impact and patent claim (right axis) of the patents granted to female and male A-Is

Looking into industries representing the three pro-poor applications of nanotechnology, all the three application areas have shown to be largely male-dominated in terms of both wages and employment. However, the agri-food industry shows a lower gap in comparison to energy and water applications. Energy and water subfields are almost equally male-dominated in terms of both employment and the gender wage gap.

As discussed above, nanotechnology authorship and inventorship in agri-food applications are less male-dominated. Together with the employment analysis, this implies that women in this application area are subject to less inequality in comparison to the other two subfields.

However, it should be noted that publishing and patenting activities in all the pro-poor applications are highly male dominant, and women face high wage gaps and employment gaps in workplaces in these areas. These findings represent a clear call for integration of gender-responsive policies across the development of these application areas, as discussed more in the conclusion below.

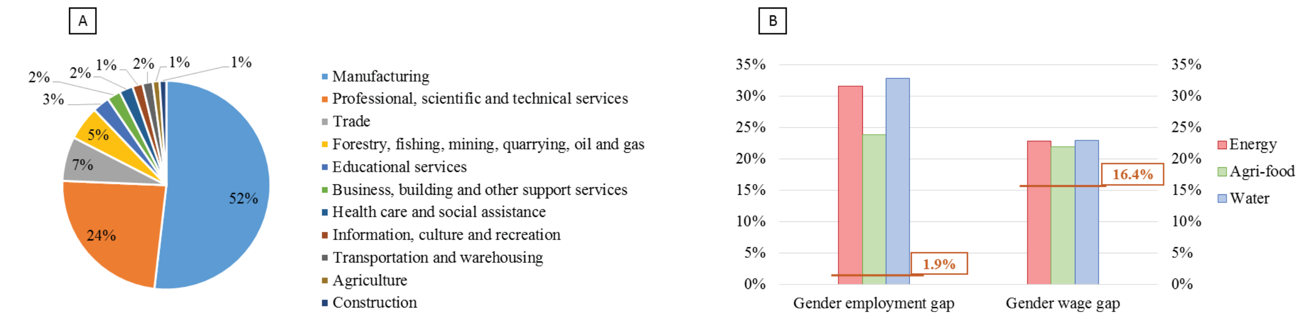


Figure 2.10- (A) Share of companies contributed to scientific and technological development of pro-poor nanotechnology applications by industry; (B) Gender gap in employment and wage by different applications (bars) compared to average gap in Canada (brown line)

Figure 2.11- Gender gap in employment (left) and wage (right) in Canadian industries

2.5- Discussion and Conclusions

The findings reveal that only a narrow spectrum of Canadian nanotechnology articles and patents reflect pro-poor priorities for energy, agri-food and water applications which is significant because these are the three application areas of nanotechnology that have been identified as having the most potential to create pro-poor technologies. However, this study found a higher share of nanotechnology publications in these three pro-poor applications for Canada than the shares found by Cozzens et al. (2013) in their global analysis. This shows that Canada has a larger focus on the development of pro-poor nanotechnologies than the worldwide average, even if only slightly so.

Ontario has the largest share of governmental publishing and patenting activities, which is due to the fact that many of the governmental agencies—including NRC related agencies—are located in Ottawa, the capital. The share of governmental involvement is the highest in scientific and technological advancements in agri-food applications. Among the three application areas, Canada puts more focus on publishing and patenting on energy applications, which is in line with the worldwide analysis of pro-poor nanotechnology applications (Cozzens et al. 2013). The growth rate of publications in these applications is higher than the development of all Canadian nanotechnology papers, which corresponds to an accelerating focus on publishing on pro-poor technologies. However, in terms of patents, the growth rate of nanotechnology patents with water applications is very slow and is lower than that of all nanotechnology patents, which is contrary to the case of energy and agri-food applications.

Canadian women researchers account for only 18.45% of total nanotechnology authorship in the three application areas, and they have shown higher dominance across governmental and university sectors, leaving industry as the most male-dominated sector. Women in governmental agencies contribute more to higher quality work than their male peers. Authorship in agri-food applications is less male-dominated in comparison to the other applications. Female researchers in Quebec have proved to be the most dominant compared to other provinces in terms of authorship and quality of work.

The patent analysis in this study reveals that the share of Canadian women inventorship is only 11.3% and the share of women inventorship across different sectors is quite similar. Inventorship in water applications is the most male dominant. Women in Alberta have shown to be involved in a higher share of inventorship, and patent citation impact reveals that inventions by women are equally important as those created by men in that province. Female A-Is have contributed to higher quality publications and patents than male A-Is. It has been shown that all the companies involved in R&D for all three application areas are active in highly male-dominated industries in which women are subject to lower rates of employment and lower hourly wages.

These findings can help inform Canada's decades-long process of determining how to best help developing countries. In 1968, the Canadian International Development Agency (CIDA) – which was folded into the Department of Foreign Affairs, Trade and Development (DFATD) in 2013 – was established to alleviate poverty and support sustainable development in poor countries. Along with Canada's allocation of 0.7% of GDP to foreign aid in 1970, the IDRC was created by the Parliament of Canada to help developing counties by the use of science, technology, and innovation, and provide support and formation of a local research community whose research provides long-term solutions to socio-economic and environmental issues facing developing countries (Marcus 2013). In 2004, the government of Canada affirmed the importance of research associated with addressing the needs of developing world and devoted 5% of its R&D budget to address the challenges faced by developing countries (Salamanca-Buentello, Persad, Martin, Daar, & Singer 2005). In 2006, the collaboration between the Association of Universities and Colleges of Canada (AUCC) and IDRC was formed to support scientific and technological advancements which bring benefits to developing countries and help solve development problems (AUCC 2006). Currently, there is a debate on the establishment of a Development Finance Institution (DFI) (Laverdière 2015) to facilitate investments in private sector companies that promote development. Despite of all these efforts and all of the nanotechnology's promises in revolutionizing the Canadian market, only a narrow spectrum of nanotechnology research and development efforts in Canada contribute to the success of the UN MDGs and the needs of developing countries. This shows there is a clear need for the integration of pro-poor policies into the existing science and technology priorities in Canada. However, this is not sufficient. Because these pro-poor scientific and innovative efforts tend to be highly male-dominated in terms of both the scientific community and the workforce, the incentives to develop pro-poor nanotechnology applications might widen the gender gap and hinder social development. Therefore, it is of utmost importance for Canada to focus on the establishment of both gender-related and pro-poor policies concurrently.

Canada's effort to mainstream gender in S&T policies is largely confined to NSERC initiatives and gender-related programs on women in nanotechnology is nonexistent at national, organizational and institutional level. Although NSERC shows policy concerns for underrepresentation and repression of women in sciences, its gender-related initiatives seem not to be very effective. According to Shendruk (2015), the share of women working in the STEM fields barely changed since 1987, and they are still underpaid (7.5% less than their male peers).

With the right gender-responsive policies that help attract and support more women in these nano-application areas, Canada might be able to reach a higher level of gender equality in its workforce and broaden its knowledge capacity and research performance in addressing developing world's challenges. The results of this study are thus of great importance to policy makers to gain insight into the identification of leverage points to promote both gender equality and poverty alleviation in emerging science and technology policies, enhance success in new interdisciplinary environments (such as nanotechnology) and consequently foster economic growth.

Chapter 3 - Article 2

Inequality and collaboration patterns of Canadian nanotechnology: Implications for pro-poor and gender-inclusive policy

Abstract

Policymakers and scholars are increasingly concerned with how nanotechnology can reduce inequalities and provide benefits for underprivileged, disadvantaged, and poor communities. This paper simultaneously addresses two concerns related to nanotechnology and equity: the lack of research and development (R&D) focused on nanotechnology applications that benefit developing nations (pro-poor R&D) and the lack of women in nanotechnology fields. The paper focuses on Canada, an affluent country that is committed to both pro-poor and gender responsive policies. Social network analysis is used to examine collaboration patterns of authors and inventors whose work is related to pro-poor applications of nanotechnology. Differences in collaboration patterns of scientists of each gender are then examined to better understand how they are involved in networks of authorship and inventorship. The findings reveal that female first-authored papers receive a lower rate of citations and are published in higher ranked journals compared to those papers first-authored by men. Nevertheless, when women are last or corresponding authors, their papers receive equal or higher citation rates and are published in lower or similar ranked journals. Women are as, or more, collaborative as their male peers in their co-authorship and co-inventorship networks. While the majority of male authors and male inventors collaborate exclusively with men, those involved in a mixed-gender team outperform male-only teams. Women, as both authors and inventors, are involved in more gender-balanced collaboration teams. The study calls for development and implementation of gender-related policies in Canada to increase the prevalence of female scientists in collaboration networks, and to support the participation of women in pro-poor areas.

Keywords: Nanotechnology; Gender; Pro-poor; Social network analysis

3.1- Introduction

Nanotechnology is a multidisciplinary field at the intersection of engineering, biology, physics and chemistry that involves manipulation and control of matter at a molecular level (NNI 2014). Nanotechnology has gained momentum in various application areas—such as energy generation and supply, water treatment and remediation, agriculture and food production, medicines and healthcare, manufacturing, and environment—which evinces a great potential to benefit both developing and developed nations (Salamanca-Buentello, Persad, Martin, Daar, & Singer 2005). Research and development in this groundbreaking technology has been supported by large national investments worldwide because it is seen to offer a great technological advantage and fuel economic growth (Palmberg et al. 2009).

However, many nations have grappled with the challenge of policy making for nanotechnology. Because applications are complex and uncertain, and because the hyped promise of job creation (Roco, 2011) and the rapid commercial payoff (Hobson 2009) distort delineation of the scope of nanotechnology development (Schummer 2007). Debates about nanotechnology's benefits not only complicate economic analysis, but they also reveal the complexities of nanotechnology's ethical, environmental, legal, and social implications (Muchie & Demissie 2013).

This makes nanotechnology a difficult, yet critical case, for science and technology (S&T) policy scholars and practitioners who are increasingly interested in understanding how innovation alleviates or exacerbate inequality, and whether new technologies provide benefits for underprivileged, disadvantaged and poor communities and groups (Cozzens 2012; Cozzens & Wetmore 2011; Harsh & Woodson 2012; Pidgeon et al. 2009; Wiek et al. 2012; Zehavi & Breznitz 2017). Recent policy initiatives at the United Nations (UN) have highlighted the equity issues connected to nanotechnology and what is at stake (UNESCO 2014). Unequal access to the latest discoveries in nanotechnologies and stark disparities in resources and opportunities for nanotechnology research, development and innovation could bring forth a "nano-divide" (Daar et al. 2004) between nations and communities. UNESCO (2014) argues that this may perpetuate and exacerbate the gulf between privileged and marginalized groups across the globe, increase the vulnerability of poor and disadvantaged communities to environmental and health problems, and could lead to discrimination and stigmatization.

At the same time, nanotechnology could serve as an impetus for sustainable development in poorer countries; it could help create so-called pro-poor technologies (Salamanca-Buentello, Persad, Martin, Daar, & Singer 2005). For instance, nanotechnology could lead to clean, inexpensive, efficient and reliable devices to harness renewable resources and providing new solutions for energy generation and storage, water treatment and desalination and disease diagnosis (UNESCO 2014). Nanotechnology could thus be a tool to help meet the UN's Sustainable Development Goals (SDGs) – the successor to the Millennium Development Goals (MDGs) – to end poverty, reach equality, and fight climate change by 2030. The 17th goal of UN SDGs specifically highlights revitalization and implementation of global partnership and calls for development and transfer of pro-poor technologies, acknowledging the importance of advanced emerging technologies to help reach the SDGs. UNESCO (2014) also raises an additional important concern about potential discrimination, stigmatization, and marginalization connected to nanotechnology – the male dominancy in nanotechnology fields. This gender disparity could preclude women from participating in and benefiting from nanotechnology advances. In addition, as a further negative consequence, women might be seen as less adept and qualified compared to men, and suffer prejudice that hampers their career development.

This paper simultaneously examines both of these critical equity issues connected to nanotechnology as identified by the UN, namely pro-poor potential and gender equity, to better understand both issues, and how the two are related.[14] An important starting point to tackle these issues is examining the characteristics of nanotechnology R&D systems in affluent countries, where the bulk of nanotechnology R&D occurs (OECD 2013). It is here where gender inequality in the scientific workforce can be most significantly manifested, and where research priorities and patenting may or may not align with the needs of developing nations. For instance in 2013, 56.5% of nanotechnology patents were filed in North America, 19.5% in Western Europe and 27.8% in East Asia and all by developed nations and multinational companies (MNCs), focusing mainly on the computers and electronics sector (Jordan et al. 2014) and on concerns of affluent communities, particularly decreasing the size for computers and laptops.

[14] For instance, a policy that focuses on economic inequality and increasing investments in pro-poor areas, alone, might exacerbate the underrepresentation of women and gender inequalities in STEM fields as an unintended consequence.

This paper focuses on Canada, a country that has a strong focus on pro-poor technologies and on gender equality in the S&T workforce. Canada's International Development Research Centre (IDRC)—established by Parliament of Canada in 1970—has been long involved in supporting research and development related to improving lives and livelihoods in developing countries, and through IDRC, Canada allocates no less than 5% of Canada's R&D investments to international development issues. In terms of gender, the Natural Sciences and Engineering Research Council of Canada (NSERC) has a research chair program for Women in Science and Engineering Program, which along with Society for Canadian Women in Science and Technology (SCWIST), helps implement and support initiatives to increase the participation of women in S&T fields (NSERC 2010). However, Canada does not have gender-related policies designed to engage women in nanotechnology specifically.

In order to understand how the characteristics of Canada's nanotechnology R&D are connected to pro-poor applications and to gender equity, social network analysis (SNA) is utilized. After briefly reviewing the literature on nanotechnology collaboration networks, collaboration patterns of researchers and inventors involved in the development of pro-poor nanotechnology applications are analyzed. For this analysis, this paper uses the top three potential pro-poor applications of nanotechnology identified by Salamanca-Buentello (2005) who correlated nanotechnology applications with the UN MDGs: (1) energy storage, production, and conversion (2) agricultural productivity enhancement (3) and water treatment and remediation. The paper then further investigates differences in collaboration patterns of scientists of each gender and provides a better understanding of how they are involved in their network of authorship and inventorship. Our results show that women are as, or more, collaborative as their male counterparts and are involved in more gender-balanced scientific collaboration teams in their co-authorship and co-inventorship networks. The paper concludes with a discussion of the implications of the findings for Canada's policies.

3.2- Literature Review

3.2.1- Nanotechnology Collaboration Networks

Analysis of collaboration networks helps us understand the interactions among researchers, inventors, and their behavior. Scientific collaborations are formed through joint efforts to reach a common goal, enabling continuous interaction of knowledge, skills, and resources (Katz & Martin 1997) and thereby enhancing of scientific productivity. These collaborations are generally in the form of co-authorship, co-inventorship and university-industry relationships (UIRs). Researchers are increasingly motivated to collaborate because of many recent trends in science: research problems are becoming more varied and complex, expertise is more specialized, the amount of scientific knowledge is growing exponentially, research funding sources are more competitive and varied, and technologies that support science are changing rapidly (Hara et al. 2003). On the one hand, there is some empirical evidence that collaboration among scientists leads to higher research productivity (Lee & Bozeman 2005; Pravdic & Oluic-Vukovic 1986; Price & Beaver 1966) and quality (Aksnes 2003). On the other hand, some studies found no significant impact of an increase in co-authorship collaborations on publication productivity, and argue that productivity is dependent on the background of the individual scientific collaborators (Duque et al. 2005; Pravdic & Oluic-Vukovic 1986). For example, the presence of prolific scientists (known as star scientists) (Zucker & Darby 1995, 1996), or of so-called gatekeepers – individual scientists at the network's frontier who play a key role in negotiating the inflow of external knowledge (Schiffauerova & Beaudry 2012) – can both be important factors linked to productivity. For nanotechnology, various patterns of co-authorship collaboration are mapped and analyzed in the works of (Meyer & Persson 1998) and (Tang & Shapira 2011). Similarly, co-invention collaborations are analyzed in the study of Schiffauerova & Beaudry (2012) with a specific focus on stars and gatekeepers.

UIRs, also known as public-private collaborations, stimulate innovation and scientific capacity by providing industries with novel ideas to exploit the commercial potential of new discoveries, and by enabling universities to enhance their know-how through sharing knowledge with firms (Nikulainen & Palmberg 2010). It is generally accepted that collaboration between university researchers and industry scientists emerge in the form of co-patenting and co-publishing and this type of collaboration has a positive effect on the innovative productivity (Schultz 2011). Some publication and patent-based indicators are introduced in the literature to map UIRs, including, but not limited to, citations to non-patent literature, papers published by authors affiliated to industry, patents filed by universities, papers with at least one author from industry and one author from university, patents invented by academics but filed by industry, lexical linkage between articles and patents, and author-inventor links (Bassecoulard & Zitt 2004; Cassiman et al. 2007; Maraut & Martínez 2014). More specifically for the field of nanotechnology, many studies show a propensity of industries to employ university researchers (Kim et al. 2010), an increase in UIRs in general (Zucker & Darby 2005) and increased productivity for university researchers involved in patenting (Meyer 2006). This study also pays attention to the distinct role of Author-Inventors (A-Is) of each gender, researchers involved in the production of knowledge as well as development of a technology, who are associated to most productive and highly cited researchers in nanotechnology (Meyer 2006) and maps gender differences in scientific and technological production and collaboration patterns of the A-Is.

Regarding the collaboration patterns of female scientists (versus their male counterparts), some studies found that women are more inclined than men to collaborate via co-authorship based on the number of sole-authored articles (Hunter & Leahey 2008; Ozel et al. 2014). While some other studies have found the opposite (Kyvik & Teigen 1996; Prpić 2002). Long (1990) found no significant difference between men and women in their co-authorship collaboration patterns. These inconsistencies stem from the use of various samples and different measures of collaboration. Nevertheless, it is important to note that these studies overlook one key issue, namely scientific and technological productivity. Gender differences in scientific and technological productivity have been addressed in several other studies (e.g., in (Davarpanah & Moghadam 2012; Meng & Shapira 2011; Miller et al. 2012; Ozel et al. 2014)). However, there have only been a few studies that specifically looked at how the collaboration patterns of female scientists impact their productivity (Bentley 2012; Kyvik & Teigen 1996; Long 1992), which found a positive impact of collaboration on women's productivity. On the gendered collaboration patterns of researchers in nanotechnology, it is shown that women are more likely not to be included in collaborations, as patents with only-male inventors are more likely to be the result of scientific collaborations while patents with only-female inventor(s) are possibly the result of individual scientific activity (Meng & Shapira 2011). Accordingly, Villanueva-Felez et al. (2015) found that women acquire less information from collaborations and tie strength is lower for women's scientific collaborations.

Although, a nanotechnology R&D strategy conducive to pro-poor growth might benefit developed nations by promoting SDGs in developing countries and creating new markets in developed nations (Rodrigues et al. 2007), studies focusing on collaboration and productivity of nanotechnology researchers in pro-poor areas is nascent and only limited to energy sector and country-level analysis (Guan & Liu 2014). This study tries to fill this void and look into differences in collaboration patterns of researchers whose focus of research is on the top pro-poor areas of nanotechnology.

Social network analysis (SNA), as a specific tool for collaboration analysis, is used to identify crucial factors which influence the motivation for and behavior of scientific collaborations, and how these are connected to productivity (Abbasi et al. 2011; Catherine Beaudry & Schiffauerova 2011; Eslami et al. 2013; Newman 2001; Uddin et al. 2012). The use of social network theories in the cross-gender analysis of collaboration networks and their productivity is still nascent in the literature, and as yet, is largely undeveloped in nanotechnology and its pro-poor areas. Henceforth, this research not only intends to trace women's scientific and innovative productivity performance but to study how their involvement in various collaborative teams and networks affects scientific and innovative productivity.

3.3- Methods

3.3.1- Data

This paper uses an all-nanotechnology article and patent dataset developed by researchers at Concordia University and École Polytechnique de Montréal (Barirani et al. 2013; Moazami et al. 2015; Tahmooresnejad et al. 2015), which is comprised of nanotechnology-related articles indexed in the Scopus database and nanotechnology patents in the United States Patent and Trademark Office (USPTO) database. Since Scopus offers full coverage on publication data from the year 1996, and usually after a lag of few years, full publication data of a given year become available, this study focuses on papers published from 1996 to 2011. Complete patent data was available to this study for patents granted over the years 1996-2009. Articles and patents with at least one author affiliated with a Canadian institution are further identified. Canadian nanotechnology-related articles and patents with pro-poor applications in energy, agri-food and water (top pro-poor applications of nanotechnology) are further extracted using the set of keyword filters introduced for each of these three areas in (Cozzens et al. 2013) applied to abstract, title, and keywords (where applicable) of the nanotechnology-related articles and patents. The order of authors is further identified to address gender differences in the contribution of first, corresponding, and last author of a paper.

The province and the sector (university, government, and industry) of an author's publishing activities are identified based on the author affiliation. For patents, the province of an inventor is given information. However, the sector is identified based on the type of assignee, whether it is a firm, governmental agency, university or an individual. The gender of each author and inventor is further assigned based on author first names using GenderChecker.com name-gender database, which was developed from 2011 UN Census data. For those scientists whose gender is unknown or unisex after using GenderChecker.com, their academic, LinkedIn, or any other online profile is used to determine their gender, so that that gender can be assigned to all authors and inventors. Appendix A lists most common given names of identified authors and inventors and their gender.

Author-inventors (A-Is) refer to those researchers who are involved in both patenting and publishing in pro-poor areas. Inventors and authors are paired based on their first names and last names, and A-Is are further selected as those pairs with patent(s) and article(s) similar in title(s) and abstract(s), or those pairs whose province(s) listed on their patents matches province(s) of their current and previous affiliations in the Scopus database. The productivity of scientists is further defined as the total number of their publications and patents. Average number of citations per year as a measure of scientific impact, together with the SCImago Journal & Country Rank (SJR) – a journal prestige metric, which uses field-subject weighted citations to rank journals according to Scopus data and classifications (SCImago Research Group 2007) – as the measure of journal impact, is used to measure research quality of an author. For inventors, average number of citations received per year is used as a measure of impact. The number of patent claims, a series of numbered expressions describing the invention in technical terms and defining the extent of the protection conferred by a patent, is used as an indicator of broad application and potential profitability of an innovation, or innovation quality (Lanjouw & Schankerman 2004). Since extracted articles and patents are within the same field and same country, field and country-specific normalizations are not applied in this study. A total of 2,528 authors, 608 inventors, and 43 A-Is which are involved in publishing 1,157 articles in years 1996-2011 and 365 patents in 1996-2009 are identified.

3.3.2- Social Network Analysis

Collaboration networks are a type of complex network – irregular structured networks whose nodes or vertices dynamically evolve in time (Boccaletti et al. 2006)– within which knowledge creation, diffusion, and utilization can occur. In these networks, nodes represent actors of a knowledge system (e.g. individuals, firms, institutions) and links imply their collaborations in developing a product. This study focuses three specific types of networks: co-authorship network, co-inventorship network and combination of the two (being referred to as co-innovation network in this study), and examines collaboration patterns among scientists and innovators of each gender through the use of created databases on patents and publications. Given that actors and their interactions form networks, SNA is a useful tool to examine how dense, cohesive, and complex a network – as a whole – is. While at an individual level, SNA helps to understand the relationship between the ways an actor is embedded in a network and actor's behavior, influence, power, and accessibility to different resources and opportunities (Wei et al. 2011). Hence, network analyses are used in this study to help identify connections between authors and inventors of each gender and to track cooperation patterns and flows of knowledge based on co-publication and co-patenting activities.

The connectedness of a network's nodes can be measured in terms of network density and the network's clustering coefficient. The importance of nodes and links is analyzed using centrality measures. Since networks are disconnected, network degree centrality and clustering coefficients are deployed in this study to characterize innovation network structures and assess the role of individual scientists (actors) in the scientific and innovative productivity of a network.

Network density is the ratio of the number of observed links in a network to the total number of possible links in the same network and shows how fast information diffuses among the scientists. Degree centrality is the measure of a node's total number of connections and represents collaborativeness and popularity of a node and its advantaged position for catching information. The clustering Coefficient (CC) is the ratio of the total number of links that could exist for an actor to the number of real existing links and is a measure of the transitivity of a network. It shows how well neighbors of a node are connected to one another and how well direct collaborators of one node are connected to one another if the node is removed from the network. Therefore, a lower CC value indicates that the node plays a more important role the in the network, compared to a different node with a higher CC value. The closer average clustering coefficient (ACC) of a network is to 1, the more connected the network is (a network with a high degree of 'cliquishness') (Zweig et al. 2014).

In this research, co-authorship and co-inventorship networks are created for nanotechnology's three top pro-poor applications: water, energy, and agri-food. The network of scientists is generated based on the database of the co-authored scientific articles, and similarly, the inventorship network is built using the database of co-inventors from the patents in the related fields. Afterwards, article authors who are also assigned as an inventor to at least one patent within the same application – known as Author-Inventors (A-Is) – are identified in the network, and the links between author-inventors and other authors and inventors are studied. Finally, networks of scientists and inventors are put together, presenting what is referred to as "co-innovation network" in this study. A 5-year temporal window is adopted to assess the dynamics of innovation over time. Networks are created based on 5-year windows starting from 1996 to 2011 for publications and 1996-2009 for granted patents. In this research, collaboration team of a researcher is defined as all the distinct authors and inventors who co-published or co-patented with the researcher.

Collaboration networks are visualized in Gephi (Bastian et al. 2009), an open source software which enables analyses and visualization of large networks and facilitates calculation of network properties. Visualization helps better understand the network structure, along with the calculation of network measures, including number of nodes, number of links, network density, degree centrality and clustering coefficient. Networks comprise of several connected components, which are known as clusters. The giant component is the largest connected component of a network.

Edges of the network are classified into FF, FM, and MM collaboration, which identify whether the authorship or inventorship collaboration is between a female scientist with another female scientist (FF collaboration), a female and a male scientist (FM collaboration) or between two male scientists (MM collaborations). The team structure is further analyzed in terms of whether a given scientist has only female, only male or mixed gender collaborators.

The weight of edges network represent the extent that researchers who have already collaborated together (on papers or patents) repeat their collaboration by authoring another paper or patenting another patent—which is sometimes referred to as loyalty (Zamzami & Schiffauerova 2017) and in this research, it is referred to as the collaboration repetition rate. This rate helps to understand better how strong collaboration ties are among researchers of each gender in their both publishing and patenting activities.

3.4- Results

3.4.1- Publication analysis

3.4.1.1- Authorship order

The order of authors in the byline provides an approximate measure to evaluate the contribution of each author. The declining rate of alphabetical ordering in authorship (i.e., usually used in articles published in the field of mathematics, economics, and high energy physics) (Waltman 2012) has led to the use of contribution-based ordering as a common practice (Clement 2013). Here, the first position is typically allocated to younger researchers with lower professional rank and last position is given to the principal investigator with a high rank (West et al. 2013). This has been studied in the experimental fields of materials science and chemical engineering (Costas & Bordons 2011; Ho 2012), which are the main fields of nanoscience. Moreover, the correspondence is often assigned to the senior author (e.g., programme director, principal investigator) (Nahata 2008) who is mostly responsible for the initial conception and supervision of the research conducted for the paper (Mattsson et al. 2011). Consequently, first, last, and corresponding authored publications play a major role in hiring and promotion in the field of nanotechnology. Analysis of authorship order can, therefore, help us understand in/equality in the field.

The findings reveal a drop in the share of first author positions that are assigned to women (female first authors) and an increase in the share of female last authors over time (Fig. 3.1), noting that a 5-year moving window is used to assess trends. Average number of authors per paper is slightly higher when women are listed as first authors in the byline, and is lower when they sign their names as corresponding or last authors. The number of authors of a paper is shown to be positively correlated with the citation impact of the paper in several studies (Aksnes 2003; Beaver 2004; Bornmann & Daniel 2008; Lawani 1986). When women are listed as first authors, their papers receive lower citation rates than their male peers, despite having a similar number of authors (Table 3.1) and published in journals with higher SJR rankings (Fig. 3.2). This might be related to the well-known Matilda effect (Rossiter 1993)—women receive lower credit and recognition than expected compared to their male counterparts, which in this case means the expected rate of citations received by signing papers with higher number of co-authors and publishing papers in journals with the same SJR as journals in which male first-authored papers are published (Ghiasi et al. 2015; Knobloch-Westerwick & Glynn 2013; Larivière 2014). One important aspect to consider is that the average number of citations per paper varies greatly in different subject areas (Marx & Bornmann 2015). The proportion of female-authored papers that are published in engineering and physics subject areas is low compared to that of male-authored papers (Fig. 3.3). These fields were identified as two of macro-disciplines that are highly cited by nanotechnology-related papers (Porter & Youtie 2009a). Therefore, the lack of participation of women in engineering and physics fields might also partly contribute to differences in citation impact of female and male first-authored papers.

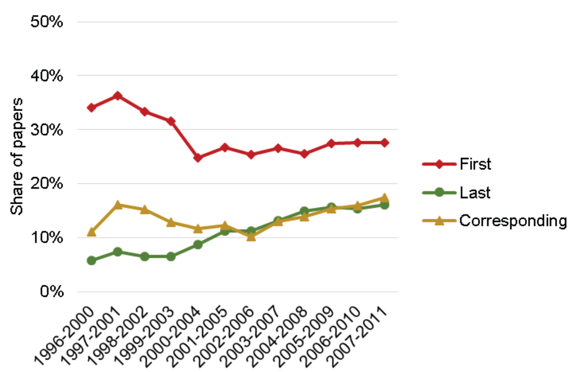


Figure 3.1- Fraction of first, last and corresponding authored papers by women

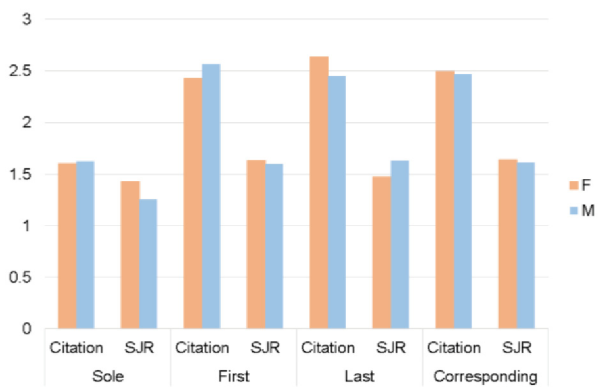


Figure 3.2- Citation and journal impact of papers sole-, first-, last-, and corresponding- authored by each gender

However, regardless of differences in subject areas, equal (or higher) citation impact is found among papers in which women are listed as the corresponding (or last) authors, and these papers are published in journals with equal (or slightly lower) SJR rankings. This shows that when women sign their names as corresponding or last authors – positions which are usually signed by the principal investigator and the supervisor of research project (Tscharntke et al. 2007) – their papers receive equal or higher recognition compared to papers where men are the last authors. This might be due to a correlation between the low fraction of female corresponding or last authors and the low fraction of women in senior STEM academic positions (a result of the so-called 'leaky pipeline'(Berryman 1983) which could lead to a strong selection effect in science and engineering fields: unless being highly competent and qualified, women tend to leave the field. While women first authors receive lower recognition for their scientific work, women as corresponding (or last) authors might represent a small proportion of female researchers in senior positions who are exceptionally qualified in the field and hence, their research group attracts scientific attention.

Table 3.1- Average number of authors per paper when women and men are first, last and corresponding authors

	First	Last	Corresponding
F	3.48	3.29	3.06
M	3.44	3.42	3.29

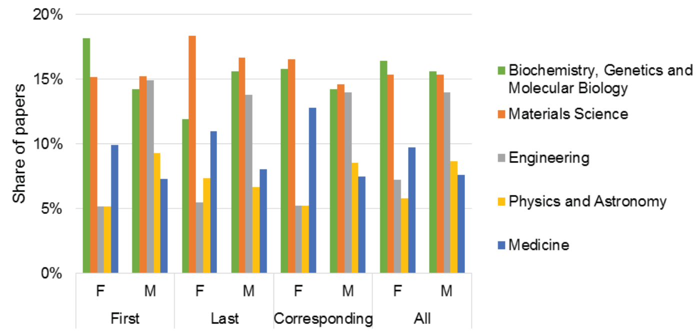


Figure 3.3- Proportion of papers that are first-, last-, corresponding-, and all- authored by women and men in most productive subject areas

3.4.1.2- Co-authorship network analysis

The co-authorship network is mapped to evaluate gender difference in the collaboration patterns of researchers. In this network, nodes represent authors, and two nodes are connected if two authors have collaborated on a paper together in the 5-year temporal window. Table 3.2 shows network properties over time. Average clustering coefficient (ACC) is high (close to 1). This represents a tightly connected network and shows that it is highly probable that two researchers that have co-authored a paper with the same researcher, are connected themselves. The network is becoming less dense over time as the number of authors and connections increases—a common pattern when the number of authors increases: more collaboration opportunities lead to a sparser network.

Table 3.2- Properties of co-authorship network

	1996-2000	1997-2001	1998-2002	1999-2003	2000-2004	2001-2005	2002-2006	2003-2007	2004-2008	2005-2009	2006-2010	2007-2011
Nodes (#)	314	361	426	438	589	770	880	1062	1275	1345	1387	1471
Edges (#)	563	669	867	777	1040	1373	1497	1687	2140	2228	2376	2713
Density	0.011	0.01	0.01	0.008	0.006	0.005	0.004	0.003	0.003	0.002	0.002	0.003
ACC	0.958	0.955	0.952	0.944	0.943	0.942	0.938	0.937	0.938	0.937	0.937	0.944
Degree	3.586	3.706	4.07	3.548	3.531	3.566	3.402	3.177	3.357	3.313	3.426	3.689

To map gender differences in co-authorship collaboration patterns, degree centrality and productivity of authors of each gender are measured (Fig. 3.4). The average productivity of researchers of each gender is not significantly different in a 5-year temporal window (it is slightly lower for women). However, women, on average, are more collaborative (have higher degree centrality) than their male peers from the period 2000-2004. Canada implemented several nanotechnology initiatives starting in 1997 by introducing a Centre for Advanced Nanotechnology at the University of Toronto, followed by other National Research Council (NRC) institutes in Alberta, British Colombia, Quebec and Ontario, including large institutions such as National Institute for Nanotechnology (NINT) and NanoQuébec (established in 2001). In addition, the Natural Sciences and Engineering Research Council of Canada put forward the Women in Science and Engineering (WISE) Chair program in 1996 to boost participation of women in STEM fields. These national initiatives might be the reason behind the changes in trends from the period 2000-2004.

As stated in the methodology, the higher the clustering coefficient (CC) of an author, the more well-connected the co-authors of the author are to one another. CC of a node, therefore, shows to what extent an author is important – nodes with a lower CC play more important linking roles in the network (Zweig et al. 2014). The analysis shows that the gap between the CC of female and male authors has decreased over time. Male authors hold lower CC over time, revealing their important positions in the co-authorship networks (Fig. 3.5).

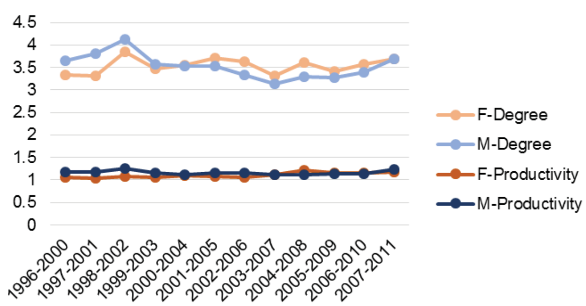


Figure 3.4- Average degree centrality and productivity of authors of each gender

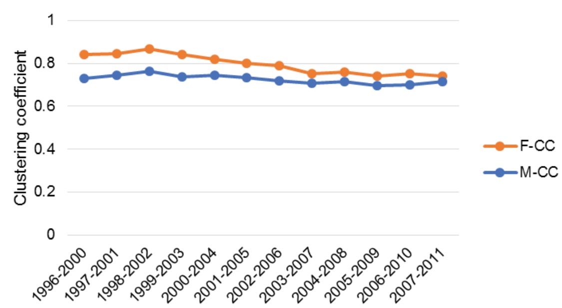


Figure 3.5- Average clustering coefficient of authors of each gender

Our analyses of collaborations (the edges of co-authorship network) show that the share of male-male (MM) collaboration is the highest in all the years and small changes are detected in these shares over time: MM collaborations slightly decreased and collaborations of researchers (of any gender) with female authors slightly increased (Fig. 3.6). Fig. 3.7 shows that women repeat their co-authorship collaborations with their female peers at a very low rate, whereas men are highly loyal to their male co-authors and repeat their collaboration with men at a higher rate. However, the trend shows an incline toward repeating co-authorship with women (as the weight of FF and FM collaborations is increasing).

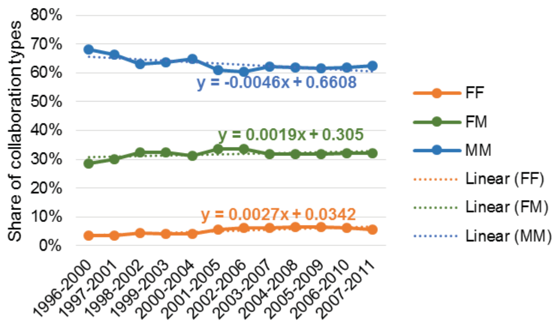


Figure 3.6- Share of different types of co-authorship collaboration overtime

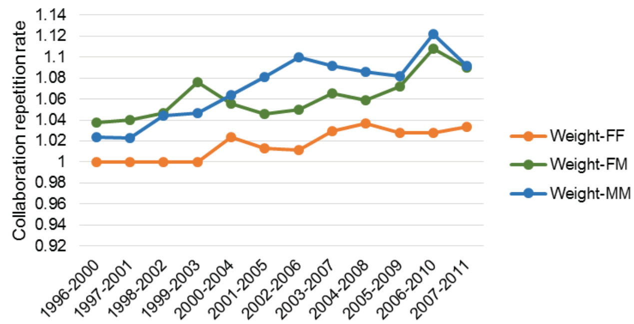


Figure 3.7- Repetition rate of co-authorship collaboration types (edge weights) overtime

3.4.1.3- Co-authorship collaboration teams

The analysis of the full network for the whole period provides insights into how researchers form their co-authorship collaboration network. MM collaborations represent the highest share and highest level of loyalty for collaborations on authoring papers, which attests that the scientific system (of pro-poor nanotechnology) is not only dominated by men but also favors them (Table 3.3) in the sense that the repetition rate of collaboration with men is the highest for both genders.

Table 3.3- Share and repetition rate (weight) of collaboration types in the full co-authorship network

Collaboration type	Share	Repetition rate
FF	5.43%	1.026
FM	32.03%	1.085
MM	62.54%	1.1

To better study the scientific system and the structure of collaborative teams, authors are classified into authors who only published by themselves, and authors who have collaborated only with men, only with women, and who have formed mixed gender teams in which at least one author of each gender is present. Around 50% of female authors included both genders in their teams of collaborators, and less than 40% only collaborated with male authors. However, the share of men who exclusively collaborated with men is slightly higher than the share of male researchers who included both genders in their authorship collaboration network (Fig. 3.8). Researchers, regardless of their gender, are more productive when they collaborate with both genders. These results are in line with a study of the engineering community (Ghiasi et al. 2015), which is expected as nanotechnology is an interdisciplinary field, comprising of engineering, physics, and chemistry (Porter & Youtie 2009a). Women who collaborated only with men published in higher ranked journals and their publications received a higher number of citations compared to women involved in mixed gender teams. Nevertheless, male researchers who collaborated with both genders published in journals with higher SJR, and the same citation rate is found among male researchers involved in only male, only female and mixed-gender collaboration teams (Fig. 3.9).

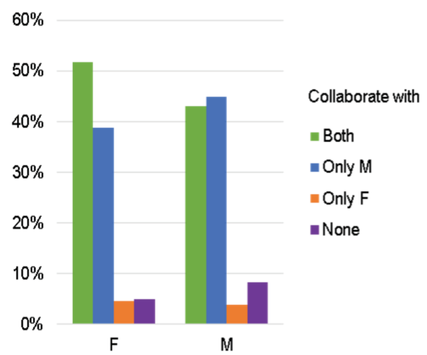


Figure 3.8- Share of authors of each gender who collaborated with no one, only male authors, only female authors and both genders

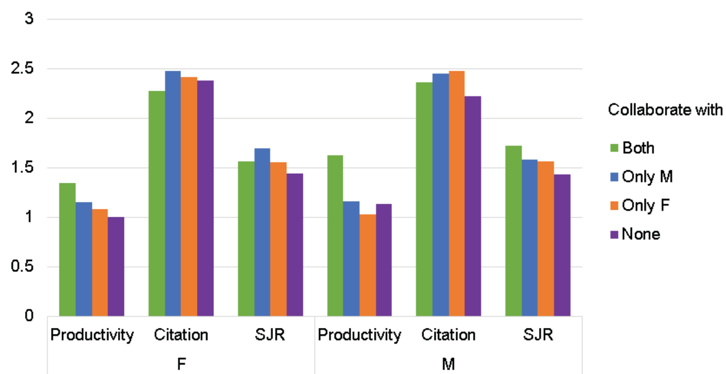


Figure 3.9- Productivity of authors (of each gender) involved in collaboration with no one, only female, only male, and both genders- and the citation and journal impact of their publications

The analysis of collaborators of authors of each gender shows that women tend to include more female researchers and lower numbers of male researchers in their co-authorship teams, compared to their male peers, representing a lower gender gap in women's co-authorship collaboration teams (Fig. 3.10). Men also tend to collaborate exclusively with men over time, and the share of researchers who are sole authors and did not collaborate with anyone is greater than the share male researchers collaborating only with female authors (Fig. 3.11). However, female authors collaborate with both genders at the highest rate over time and the share of female scientists who sole-authored their papers and those who collaborated only with women are very similar (Fig. 3.12). This shows a lower level of gender differences in the formation of collaborative networks of female scientists.

Fig. 3.13 presents the visualization of the co-authorship network in years 1996-2011. Blue nodes represent male authors, and orange nodes are female authors. The size of each node corresponds to its degree centrality. Clusters represent authors who work closely because their research subject and their expertise are similar (or complementary), or they work in the same geographical location (Parveen & Sreevalsan-Nair 2013).

The network visualization is based on Gephi's *Force-Atlas 2* algorithm. In this layout, nodes stay closer if they are connected, and the distance is defined based on the weight of edges (Bastian et al. 2009). The visualization shows that women are more central when they are located in small clusters, whereas men are highly central when located in the giant component. Hence, collaboration with women is higher when they are located in smaller clusters. This might be due to the lower availability (lower numbers) of male authors to participate in co-authorship collaborations. In other words, researchers in these clusters are specialized in a very specific topic, and options for choosing collaborators are very limited. Therefore, there are higher chances for women to be selected as collaborators. Consequently, specializing in a very specific topic might lead to the lower gender gap in the team of collaborators.

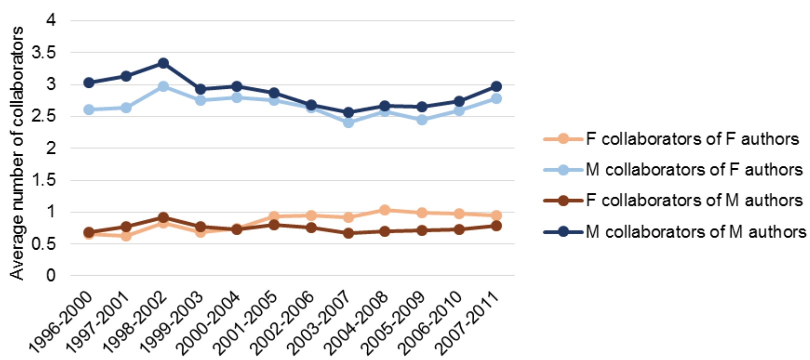


Figure 3.10- Average number of female and male collaborators of authors of each gender

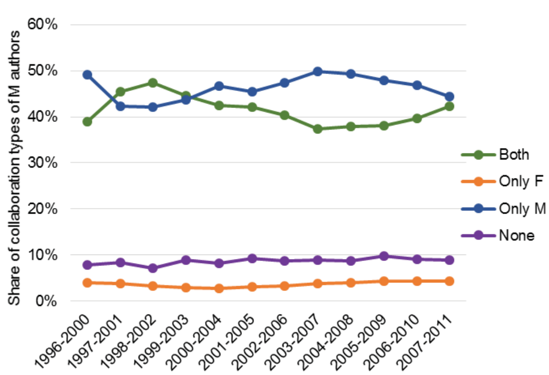


Figure 3.11- Share of collaboration types of male authors

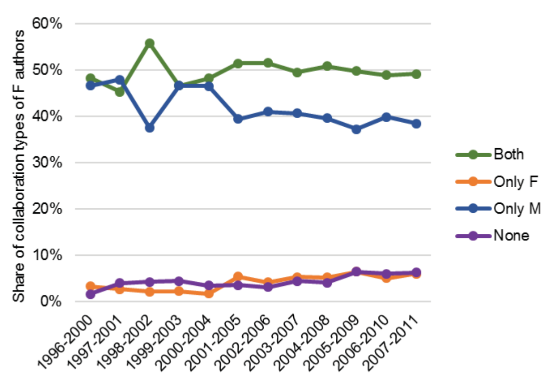


Figure 3.12- Share of collaboration types of female authors

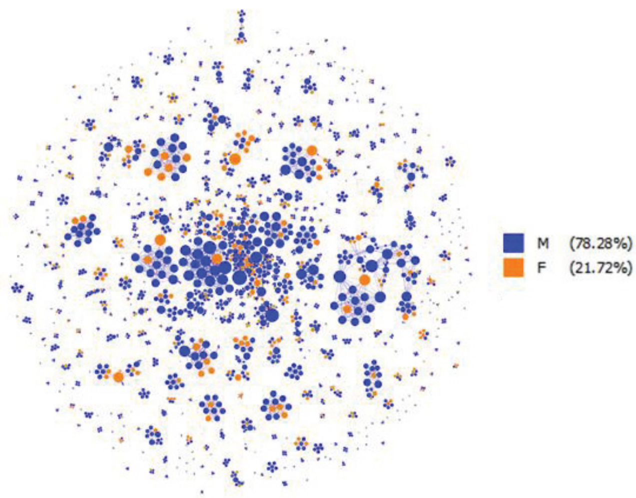


Figure 3.13- Visualization of co-authorship network (1996-2011)

3.4.2- Patent analysis

The sequence of inventors' names in a patent does not follow a particular order, and it has no bearing on the amount of contribution of an inventor to the invention. Therefore, the analysis of authorship order is very different from that of inventorship.

3.4.2.1- Co-inventorship network analysis

This study provides a gendered analysis of co-inventorship and collaboration patterns in patenting to map differences in the scientific and technological system of pro-poor nanotechnologies. The findings show that inventors tend to have higher degree centrality and are more collaborative than inventors. Average clustering coefficient is high and close to 1, which again shows a tightly connected network (Table 3.4). Therefore, two inventors that have collaborated on a patent with the same author are very likely connected to one another.

Table 3.4- Properties of co-inventorship network

	1996-2000	1997-2001	1998-2002	1999-2003	2000-2004	2001-2005	2002-2006	2003-2007	2004-2008	2005-2009
Nodes	170	189	215	250	280	284	298	298	303	277
Edges	188	205	226	299	333	343	368	393	407	375
Density	0.013	0.012	0.01	0.01	0.009	0.009	0.008	0.009	0.009	0.01
ACC	0.957	0.962	0.973	0.96	0.943	0.949	0.957	0.965	0.969	0.983
Degree	2.212	2.169	2.103	2.392	2.379	2.415	2.47	2.638	2.686	2.708

Female inventors are more collaborative than male inventors overtime, and are more than, or as productive as their male peers over different periods (Fig. 3.14). The average clustering efficient of male inventors is lower than for their female peers, representing the higher impact of removing male inventors from the network (Fig. 3.15).

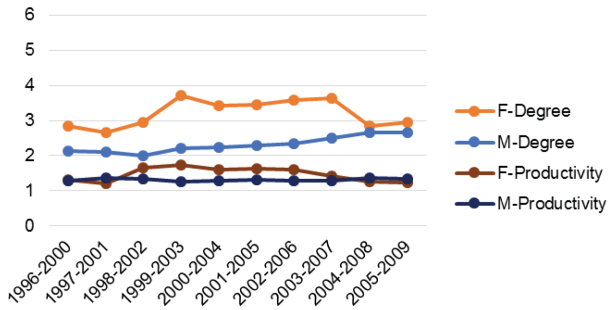


Figure 3.14- Average degree centrality and productivity of inventors of each gender

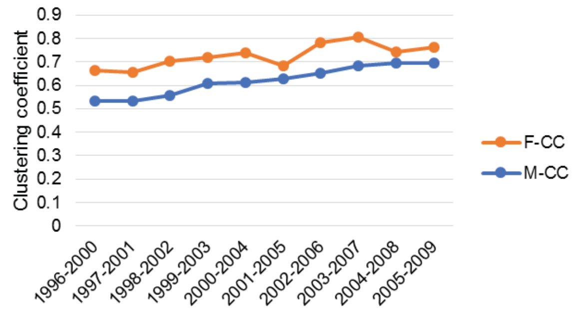


Figure 3.15- Average clustering coefficient of inventors of each gender

The share of MM collaborations is the highest in inventorship collaborations. However, trend analysis shows that the share of different co-inventorship collaboration types did not change dramatically over the years. However, there is a slight decrease in FM collaboration and increase in FF and MM collaboration over time, showing that co-patenting collaboration among inventors with the same gender is slightly increasing (Fig. 3.16). Looking into repetition of co-patenting collaborations and loyalty of inventors to their peers of each gender, FF collaborations are repeated more often than other types of collaboration from the period 1998-2002 to 2003-2007. This anomaly in the data is due to the unique collaborations of specific female scientists at Xerox Research Centre of Canada (Fig. 3.17).

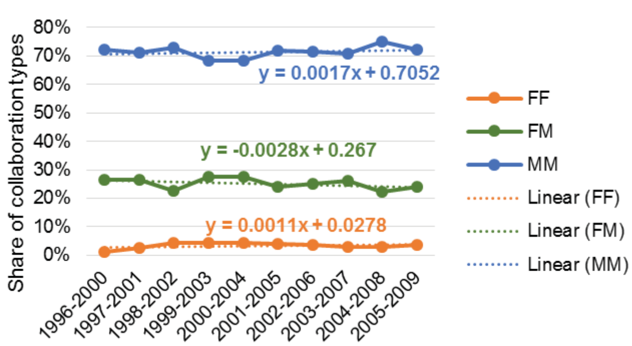


Figure 3.16- Share of different types of co-inventorship collaboration overtime

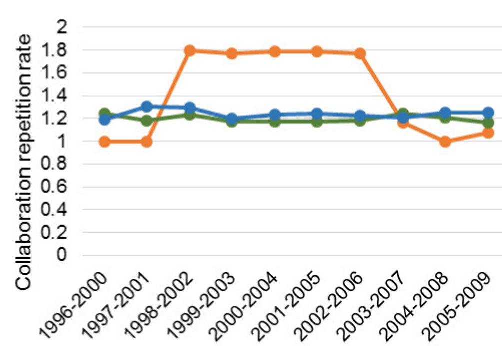


Figure 3.17- Repetition rate of co-inventorship collaboration types (edge weights) overtime

3.4.2.2- Co-inventorship collaboration teams

On average, MM collaborations form the lion share of co-inventorship collaborations (Table 3.5). However, FF collaborations outweigh other types of co-inventorship collaborations, due to the aforementioned productive team of female inventors at Xerox Canada.

Table 3.5- Share and repetition rate (weight) of collaboration types in the full co-inventorship network

Collaboration type	Share	Repetition rate
FF	3.74%	1.4
FM	26.15%	1.24
MM	70.11%	1.32

The analysis of collaboration patterns of inventors sheds light on the extent of gender-balance in the structure of collaborative teams. The share of male inventors who exclusively collaborated with men is greatly higher than male inventors who participated in mixed-gendered teams. Whereas, the share of female scientists who collaborated only with men and those involved in mixed-gender teams is very similar. Looking into female-only and male-only collaboration teams, women involved in female sole-inventorship outnumber women involved in only-female collaboration teams, whereas the higher share of men is involved in single-gender collaboration teams than in sole patenting (Fig. 3.18). According to Meng and Shapira (2011), this implies that single-gender patenting for male inventors is mostly the result of collaborations while for female inventors, it is more due to their individual inventive activities. Similar to the authorship analysis, productivity of researchers involved in mixed-gender invention collaboration teams is higher for researchers of both gender. The impact and quality of patents held by female inventors involved in teams of both genders, and of those held by male inventors involved in single-gender teams is higher (Fig. 3.19).

The analysis of collaboration patterns reveals that women on average include a higher number of women in their collaboration teams over time. However, they also include higher numbers of male collaborators. The average gender gap in the team of co-inventorship collaborations of female inventors is lower, and their teams are more gender-balanced (gender gap= 73%) than the teams of their male peers (gender gap= 82%) (Fig. 3.20). The share of male inventors who include only male scientists in their networks of inventorship collaboration is greatly higher than other male inventors forming collaborations with at least one female researchers (Fig. 3.21). On the other hand, differences in the proportion of female inventors forming collaborations with only men and those with both genders decrease over time (Fig. 3.22). These results conform with the gendered analysis of the U.S. nanotechnology patents (Meng & Shapira 2011), which found that women are more likely to be part of a mixed-gender collaboration team.

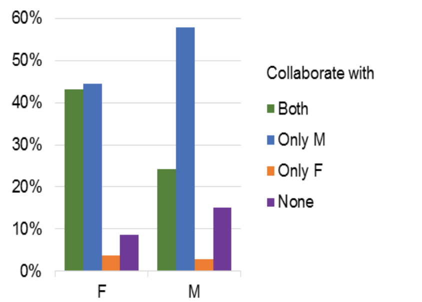


Figure 3.18- Share of inventors of each gender who collaborated with no one, only male inventors, only female inventors and both genders

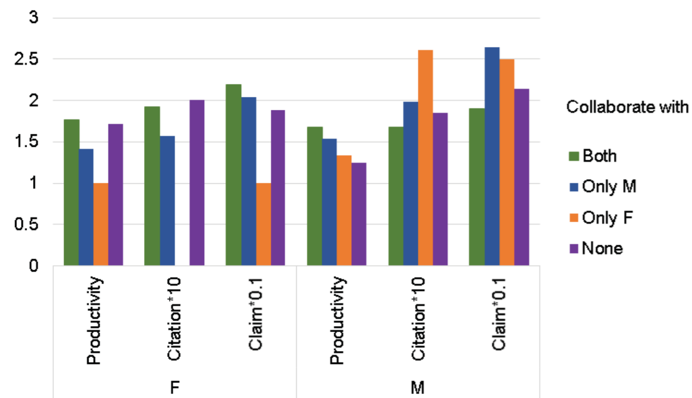


Figure 3.19- Productivity of inventors (of each gender) involved in collaboration with no one, only female, only male, and both genders, and average citation (impact) and claims (quality) of their patents

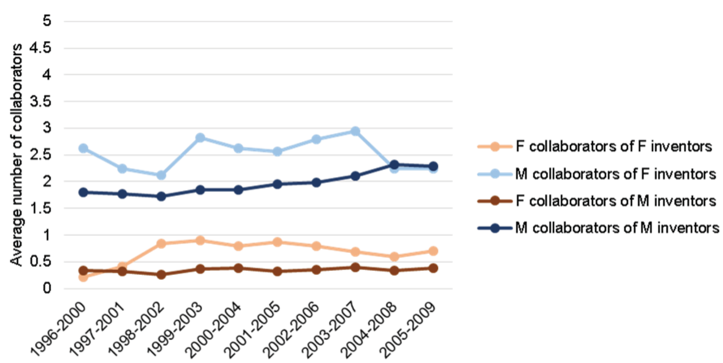


Figure 3.20- Average number of female and male collaborators of inventors of each gender

The visualization of co-inventorship collaborations, in which each node represents an inventor, and the links represent a collaboration of two inventors on a patent, is presented in Fig. 3.23. The size of each node is associated with its degree centrality. Female inventors are orange nodes, and blue nodes are male inventors. The network is composed of several disconnected clusters due to a higher degree of technological specialization of patents. In patents, as opposed to publications, dominant women are located in the center and giant component (biggest cluster) of the network, working with dominant male scientists.

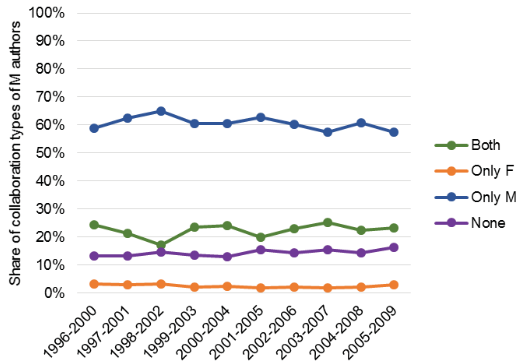


Figure 3.21- Share of collaboration types of male inventors

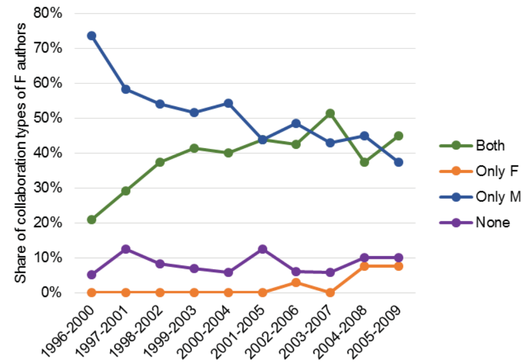


Figure 3.22- Share of collaboration types of female inventors

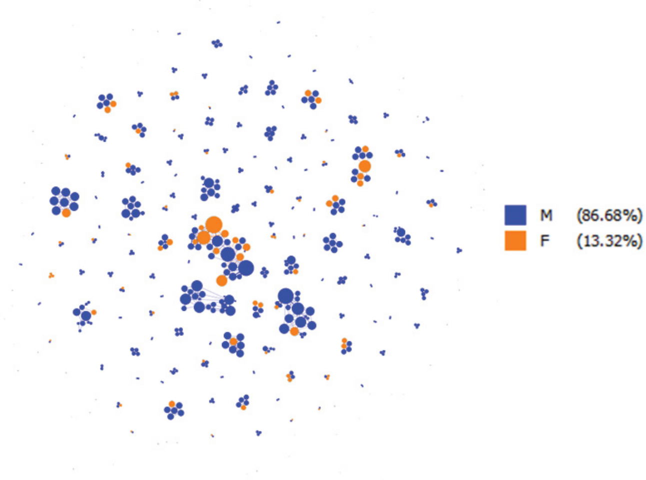


Figure 3.23- Visualization of co-inventorship network (1996-2011)

3.4.3- Author-Inventors

The co-innovation network, in this study, is composed of co-authorship and co-inventorship collaborations that are connected by scientists who are involved in both publishing and patenting (known as A-Is). A-Is are important researchers and are usually considered as the channels of scholarly communication between university and industry (Cassiman et al. 2007; Maraut & Martínez 2014). A-Is present different collaboration behaviors as authors and as inventors, which can shed light on differences seen in comparing scientific and technological systems. Therefore, this paper analyzes A-Is and their distinctive role in the co-innovation network as a separate category, noting that, earlier in this study, A-Is were included as inventors in the patent analysis and as authors in the publication analysis.

Results show that A-Is are the most collaborative scientists, however, female A-Is are less collaborative than male A-Is (Fig. 3.24a). The clustering coefficient of A-Is is the lowest, highlighting their important role in the network (Fig. 3.24b). Although being low in number, female A-Is are more productive in publishing articles and less productive in patenting than male A-Is (Fig. 3.24c). This might be related to the conductive environment of academia for female patenting (Sugimoto et al. 2015). Therefore, women A-Is are mostly affiliated to academic institutions, in which publishing is more of a priority than patenting.

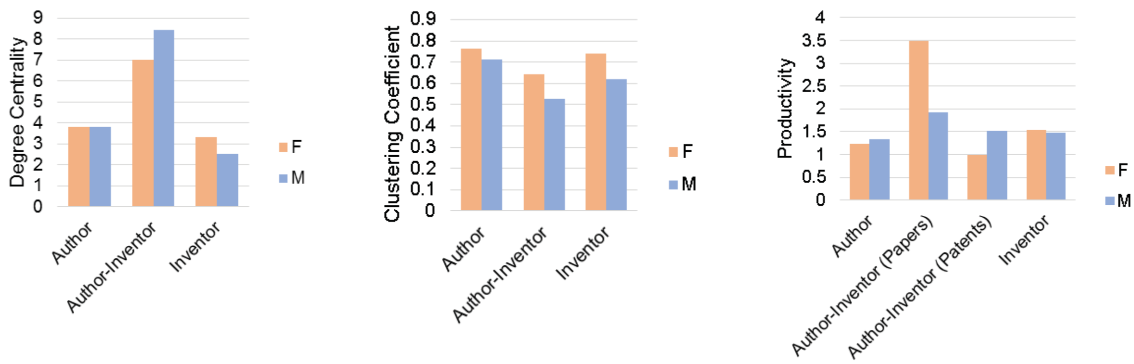


Figure 3.24- (a-left) Average degree centrality, (b-middle) clustering coefficient and (c-right) productivity of authors, Author-inventors, and inventors

Comparing collaboration teams of the three types of actors, this study shows no large difference between the number of female collaborators and the number of male collaborators of authors of each gender in their networks of collaboration. As for A-Is, male collaborators and female collaborators of male A-Is outnumber those of female A-Is. Conversely, for inventors, female collaborators and male collaborators of female inventors, outnumber those of male inventors (Fig. 3.25).

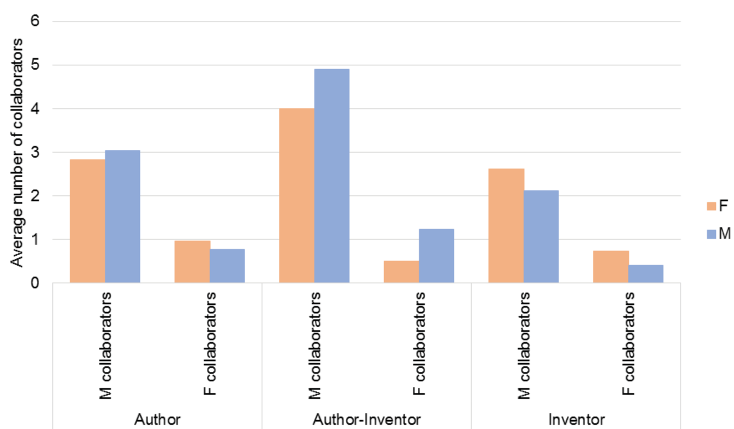


Figure 3.25- Average number of female and male collaborators of authors, A-Is and inventors of each gender

Fig. 3.26 maps the co-innovation network in three deferent classifications: actor type, gender, and sector. Dominant A-Is are located in small clusters where collaboration between industry and university is conspicuous, which might be due to their specialization in very specific nano-related subjects that also attract industry attention.

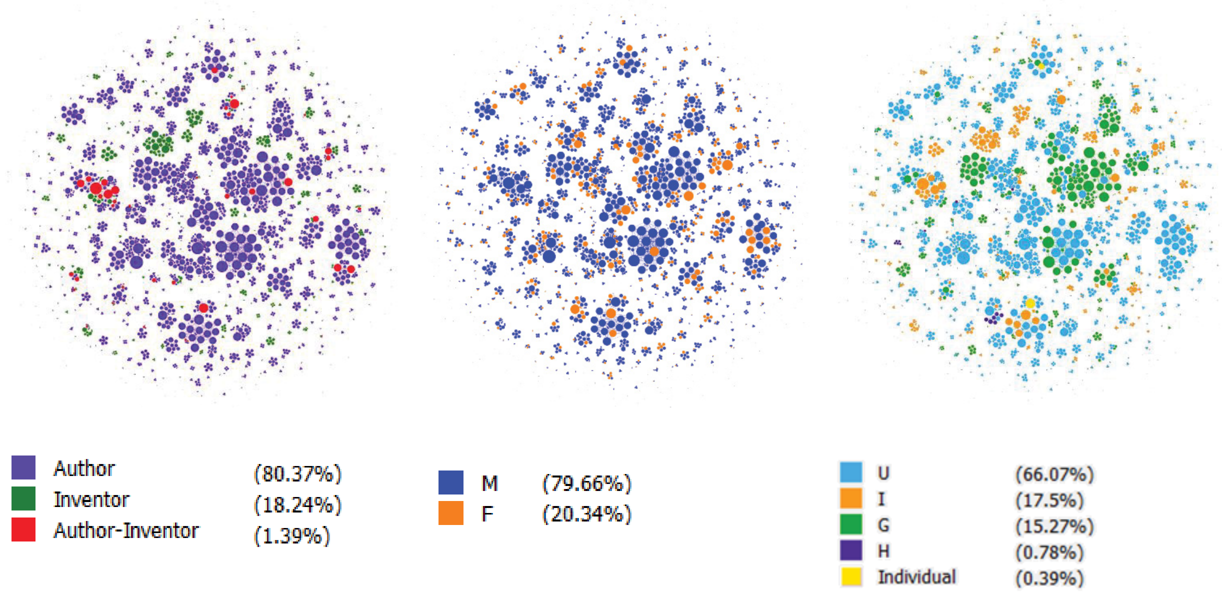


Figure 3.26- Visualization of co-innovation network in three deferent classifications: (left) scientist type, (middle) gender and (right) sector (1996-2011)

3.5- Discussion and Conclusions

This study examines collaboration patterns of authors, inventors, and author-inventors involved in Canadian nanotechnology, whose research is in line with the UN SDGs and likely to benefit developing countries. The cross-gender analysis reveals different collaboration patterns among authors, inventors, and A-Is. For this purpose, the paper first examined citation and journal impact of articles by authorship order for authors of each gender. Female first-authored papers receive lower numbers of citations, include a slightly higher number of authors and are published in higher ranked journals, whereas gender differences in citation rates are not conspicuous when women are corresponding or last authors. Female corresponding and last-authored papers receive equal or higher numbers of citations, while being published in equal or slightly lower-ranked journals with a lower number of co-authors. The former might be related to the well-known Matilda effect—systematic repression of women's contribution to science, which is often accredited to their male counterparts—which has been identified in science and engineering (Ghiasi et al. 2015; Knobloch-Westerwick & Glynn 2013; Larivière 2014). Moreover, scant representation of female-authored papers in engineering and physics fields might account for lower citation rates for women as first-authors, as these fields are among highly-cited macro-disciplines by nanotechnology-related papers (Porter & Youtie 2009b).

However, this study also examines this issue when women are listed as corresponding or last authors, authorship positions often held by the principal investigator of the research project (or the researcher of senior rank), and shows that female corresponding or last authored papers have similar (or more) scientific impact, despite being published in lower or equal ranked journals with lower number of co-authors. This might be due to the fact that a very low proportion of women authors are listed as last or corresponding authors, and a similar low proportion of women are able to reach high ranking positions in academia due to the glass ceiling (Tang 1997) and leaky pipeline (Berryman 1983) phenomenon in academia. The concept of a 'glass ceiling' addresses gender barriers that preclude women from being promoted to high-level positions, and the 'leaky pipeline' concept refers to more women than men leaving their scientific professions at each stage of career development. Therefore, these limited numbers of women were subject to a strong selection effect, according to which women who reach higher ranked positions are required to be extremely qualified, competent and accomplished. Therefore, the research of these women becomes well-known in the field and has higher citation impact regardless of the journal in which it is published. At the inventorship level, the order of inventors does not follow any specific sequence and is not based on contributions, status or other characteristics of inventors.

Female authors are as central as their male peers in their authorship network and are more central than their male peers in their inventorship network, showing that women in both networks are as or more collaborative than their male peers. Moreover, the share of collaboration with women (FF and FM collaborations) is increasing over time in the co-authorship network, whereas single-gender collaborations (FF and MM collaborations) are increasing in the inventorship network. Women are forming more gender-balanced teams in their authorship and inventorship collaborations. More than 52% of female authors include at least one female researcher in their co-authorship teams, while 45% of male authors collaborate exclusively with their male peers. The fraction of female inventors who form mixed-gender collaborative teams is similar to that of female inventors who collaborate only with men. 58% of male inventors collaborate only with men and do not include any female inventors in their collaborative teams. However, actors, regardless of their gender and their type (author, inventor, or A-I) are more productive when involved in a mixed-gender team.

The visualization of networks of co-authorship and co-inventorship reveals that women authors are more central when they are located in small clusters in a co-authorship network, whereas they are more central when located in the giant component in the inventorship network. Hence, collaboration with women is higher when they are located in smaller clusters and collaborate with highly central male authors. This could be explained by the degree of specialization of the researchers. In the co-authorship network, when women are highly specialized and located in small clusters, the number of potential collaborators is very limited, and therefore, it might be more likely that women are selected as collaborators for co-authored papers. However, the co-inventorship network is more male-dominated and patents are more specialized and technical than articles. Therefore, women are more central when located in the giant component where the highest share of researchers is involved. This might give women a higher chance of collaborating with central male inventors, which might lead to more recognition and therefore more opportunities for collaboration.

These results can inform Canada's (still limited) policies to support women in science and technology, like NSERC's focus on the development and implementation of strategies to increase participation of women in STEM fields as students and professionals. These policies tend to overlook collaboration issues. Supporting female scientists in their collaborations is not a specific focus area, and is only incorporated into policies in terms of general national and regional networking strategies for female scientists (NSERC 2010). Moreover, there is no specific policy in Canada (at national, regional or institutional levels) which focuses on gender equity in nanotechnology. This study can serve as an input for data-driven analyses by policymakers to prioritize actions that correct the gender imbalance in collaborative teams working on pro-poor nanotechnologies. If policies can be implemented that encourage researchers to form collaborations with female scientists and that support participation of women in pro-poor areas, then Canada can contribute to its R&D investments in terms of both economic and social development by simultaneously addressing two of the main equity concerns connected to nanotechnology.

3.5.1- Research limitations and prospects for future research

Authorship order is only a proxy for contribution and seniority of authors. For example, the last author might mistakenly receive credit as a primary investigator of the research project, while in reality, that author might actually be the person who made the least contribution. In some authorship practices, a lead (first) author or a middle author is responsible for correspondence, who might be a graduate student or a junior researcher. Hence, in these cases, the corresponding authorship is not necessarily associated with seniority or directorship of a project. Therefore, there is no common indicator to consistently identify and evaluate the characteristics of a group leader on a given scientific publication, but authorship order is the best proxy we have. Another limitation of this research is that women only account for 13% of all inventors involved in pro-poor nano-papers, which results in a low share of FF inventorship collaborations. Therefore, the repetition rate for this type of collaboration is influenced by the strong collaboration ties of specific female scientists at the Xerox Research Centre of Canada.

This research focuses on two main equity challenges of Canadian nanotechnology (gender and pro-poor potential). It thus provides a baseline for future studies addressing equity concerns in other emerging technologies and in other national contexts. As this body of work expands, it can serve policymakers and research managers to help ensure that emerging technologies lead to more just societal outcomes.

3.6- Appendix

Table A- List of most common given names of authors and inventors and their gender

Authors			Inventors		
First Name	**Gender**	**Authors (#)**	**First Name**	**Gender**	**Inventors (#)**
David	M	36	David	M	21
John	M	33	John	M	17
Michael	M	30	Michael	M	12
Peter	M	27	Robert	M	11
Jean	M	25	Richard	M	9
Jean	F	1	James	M	8
Robert	M	24	Steven	M	7
Paul	M	23	Peter	M	7
Daniel	M	23	Paul	M	7
Richard	M	20	George	M	5
Andrew	M	16	Kenneth	M	5
Pierre	M	16	Daniel	M	5
Marc	M	15	Mark	M	5
Thomas	M	15	Jeffrey	M	4
Christine	F	6	Jean	M	4
Susan	F	6	Joseph	M	4
Angela	F	5	Pierre	M	4
Jennifer	F	5	Dave	M	4
Sylvie	F	5	Yves	M	4
Marie	F	5	Rene	M	4
Anne	F	4	Leslie	F	3
Stephanie	F	4	Maria	F	2
Isabelle	F	4	Susan	F	2
Joan	F	4	Sophie	F	2
Patricia	F	4	Alicja	F	2

*First or middle initials are removed from given names.

Chapter 4 - Article 3

What factors influence equity challenges of Canadian nanotechnology? Implications for pro-poor and gendered innovation

Abstract

Gender equality and pro-poor innovation are important dimensions of inclusive and responsible research and innovation. Based on bibliometric and survey data of nanotechnology researchers in Canada, this paper analyzes how gender interacts with key scientific, cultural and social factors to influence scientific productivity, and how these same factors influence the degree to which Canadian nanotechnology research is targeted towards issues facing poor communities. The findings show that the gender productivity gap remains 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 acknowledges the importance of leading and promoting research and innovation in pro-poor areas, as it holds the potential to promote the economic development both within and between nations.

Keywords: Nanotechnology; Gender; Pro-poor; Scientific reward

4.1- Introduction

Researchers generally use the term “gendered innovations” 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 (Schiebinger 2014). Gender equality is becoming a high priority in responsible research and innovation (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 (2007) introduces three separate but interrelated levels of analysis to understand gender issues in science, which also represent three approaches to try to achieve gender equality: (1) Fix the numbers of women: participation of women in science; (2) Fix the institutions: gender in the cultures of science and engineering; and (3) Fix the knowledge: gender in the results of science.

Our theoretical framework utilizes these three levels of analysis to better understand current gender inequalities within the nanotechnology workforce of a nation, whether the current culture and structure of nanotechnology research will alleviate or deepen these gender inequalities. This paper applies a gender dimension to questions of who are the drivers of nanotechnology scientific innovations and who are most likely to profit from scientific reward system in nanotechnologies, on the assumption that providing more equitable context for women to engage, retain and thrive in nanotechnology sciences, help to thrive gendered innovations and improves nanotechnology sciences.

In addition, our framework also considers the concept of nano-divide (Smith 2001) used in the inclusive innovation framework[15], which signifies that unequal access to nanotechnology innovation could precipitate a divide between countries and individuals, exacerbating existing disparities between poor and rich countries, and between privileged and marginalized groups. If the nano-divide can be overcome, nanotechnology has the potential to drive sustainable development in poor nations and could greatly contribute to the development of pro-poor technologies.

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[15] Inclusive innovation is defined as any innovation that “seeks to expand affordable access to quality basic goods and services for excluded populations – primarily those at the “Base of the Pyramid” (World Bank 2013 p. 8).

The rest of the paper is structured as follows. First, the literature on gendered and inclusive innovations is reviewed in order to provide a theoretical 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 explore gender disparities in scientific productivity and impact; and identify factors that exacerbate or alleviate these disparities, and are followed by a discussion and a conclusion on the policy implications of these results.

4.2- Literature Review

4.2.1- Fix the numbers of women: Participation of women in science

Schiebinger's (2007) first level of analysis looks into increasing 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 & 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) associates (1) the occurrence of these concepts and lack of representation of women in senior positions with cultural factors such as work-life balance and (2) gendered approaches to the scientific reward system, including productivity, performance, and promotion. These factors emanate from traditional masculine discourse prevalent in the academic career system, where (3) women consistently need to work harder to compensate for being a women and to be recognized as professionals (Dryburgh 1999) and to overshadow the in/visibility paradox (Faulkner 2006)—whereby women are visible as women but invisible as professionals. The aforementioned three points (1, 2, and 3) are incorporated in this study as follows:

4.2.1.1- Level of seniority, and the phenomenon of leaky pipeline and glass ceiling

Academic positions and level of funding are often postulated as factors associated with promotion and level of seniority in science, and the underrepresentation of women in senior roles (both in terms of ranking and funding) are often explained by the challenges of the leaky pipeline and the glass ceiling (Bowman & Ulm 2009; McDowell et al. 1999). Studies confirm the lower propensity of women to reach high-level academic ranks (Besselaar & Sandström 2017; Mayer et al. 2017; McDowell et al. 1999) and an increased gender gap in productivity as academic rank increases (van den Besselaar & Sandström 2016). However, no significant gender differences in citation impact have been shown across academic positions (van den Besselaar & Sandström 2016). Higher association of women to lower academic positions negatively affects their productivity, initiating a vicious cycle which finally leads to the lower rank and status for women (van den Besselaar & Sandström 2017).

These differences are also observed at the level of funding. Women, in general, receive lower research funding than men (Bowman & Ulm 2009; Larivière et al. 2011), while funding positively influences the productivity of researchers (Ebadi & Schiffauerova 2016; Tahmooresnejad & Beaudry 2015) and scientific impact of publications (Jowkar et al. 2011; Wang & Shapira 2015). Therefore, women's lower funding performance might result in lower productivity and impact, which reinforces attainment of lower levels of funding for women. In accordance, academic ranking and level of funding are factors that can illuminate or debilitate women's progression in science.

4.2.1.2- Gendered approaches to productivity, performance, and promotion

The persistence of gender differences in scientific productivity despite the numerous efforts to alleviate these differences is referred to as the 'productivity puzzle' (Cole & Zuckerman 1984). Women account for less than 30% of scientific authorships (Larivière et al. 2013b), and their papers receive fewer citations when controlling for disciplines, journal impact factor (Larivière & Sugimoto 2017), authorship order, and different types of collaborations (Larivière et al. 2013b). Productivity and citation rates are of particular importance as they indicate a baseline according to which a researcher is awarded among his/her scientific community, regarding hiring, reappointment, tenure, promotion, funding allocation (Holden et al. 2005) and salary (Toutkoushian 1994). Gender differences in these attributes highlight the disadvantaged position of women in their scientific community and their struggle to receive adequate recognition for their work, and indicate how being a woman can be a contributing factor to cumulative disadvantages in a scientific career. This study takes into account scientific output (number of publications per active year) as the measure of *productivity* of a researcher, and scientific impact (number of citations per active year) to better analyze to what extent a scientist is influential and is recognized among his/her scientific community. Scientific productivity and impact are considered in this study as determinants of *scientific performance.*

While self-citations are an inevitable part of scientific research that reflects the cumulative nature of ones' research, they can also artificially inflate citation rates and raise the position of authors among their scientific community (Costas et al. 2010; Glänzel et al. 2006) and might, in turn, positively influence productivity. Gendered studies on self-citations have shown that men cite themselves at a higher rate than women (Ghiasi et al. 2016; Hutson 2006; King et al. 2015). These trends have been associated with gender differences in *self-promotion*. Our analysis looks into gender differences in self-citations to see whether it can affect the gender gap in productivity and impact. We use self-citation indicators introduced in Costas et al. (2010), which classifies indicators into share of internal (vs. external) citations and share of author (vs. co-author) self-citations.

4.2.1.3- Additional level of effort in research

Achieving a higher rate of patenting and of first-author production both represent involvement in higher prestige research and leadership roles, and thus account for accomplishments of a researcher (Azoulay et al. 2007; Wilson et al. 2012), but with one major difference: there are fewer opportunities for women to be socialized into networks that lead to being a patentee (Murray & Graham 2007) and women patent at significantly lower rates than men (Ding et al. 2006). On the other hand, first-authorship is more coveted by women: when a female scientist contributes to a paper, she is more likely to be the first author than the last-author (Pierson 2014), which might relate to the fact that women lead the papers that they author. The gender gap is also higher in inventorship (~89%) (Sugimoto et al. 2015) than in first authorship (~60% to ~70%) (Filardo et al. 2016; Rexrode 2016). Therefore, women need to work considerably harder to reach the same opportunities as their male peers in patenting (Mongeon 2017). Following the argument of (Dryburgh 1999; Faulkner 2009), this study shares the assumption that women in male-dominated fields are required to work harder and devote extra efforts than men to compensate being a woman and prove their competency. Hence, a higher rate of first-authored publications and a higher rate of patenting are associated with a researcher's additional level of effort. This study assumes that authorship order in nanotechnology is contribution-based, according to which first-position authors are often leading the experimental work (Larivière et al. 2016; H. Moed 2000). This assumption is derived from the fact that contribution-based ordering in authorship is becoming a common practice in experimental sciences (Clement 2013), whereas alphabetical ordering is declining and is merely confined to some disciplines such as mathematics, economics or high-energy physics (Costas & Bordons 2011; Waltman 2012).

4.2.2- 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 inequality 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 & 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 (1) networking and social capital, (2) proportion of men and women in teams, (3) work-life balance, (4) support and gender inclusive policies. This research also considers these workplace cultural factors (1, 2, 3, and 4).

4.2.2.1- Networking and social capital

Networking and collaboration among researchers can be measured through co-authorship patterns. The number of co-authors is shown to be highly associated with the productivity (Fanelli & Larivière 2016) and citation count (Biscaro & Giupponi 2014; Uddin et al. 2013) of a researcher. Gender differences in collaboration patterns have shown that women are less involved in sole-author publications and thus have a higher propensity to collaborate (Hunter & Leahey 2008; Ozel et al. 2014). However, women are shown to have a fewer number of distinct collaborators than men (Bozeman & Corley 2004; Cole & Zuckerman 1984). Furthermore, women are more involved in interdisciplinary research collaborations (Rhoten & Pfirman 2007; Van Rijnsoever & Hessels 2011) and have fewer international collaborators (Rosenfeld & Jones 1987). Nanotechnology, as an interdisciplinary field, might provide more collaboration opportunities for women than established engineering fields, physics or chemistry. Therefore, gender differences in co-authorship collaborations present an important factor when considering social capital and networking opportunities of researchers, and the networking rate is measured by distinct number of co-authors (per active year) in this study.

4.2.2.2- Proportion of men and women in teams

Researchers, regardless of their gender, form their collaborations around men (Bozeman & Corley 2004; Ghiasi et al. 2015; Knobloch-Westerwick & Glynn 2013) and the repetition rate for these collaborations are lower for women than men (Ghiasi et al. 2015; Villanueva-Felez et al. 2015). However, women include a higher share of other women in their teams compared to their male peers (Bozeman & Corley 2004; Ghiasi et al. 2015). Since researchers who collaborate largely with women are less cited and less recognized among their scientific community (Catherine Beaudry & Larivière 2016), this share drops as women's academic rank increases (Bozeman & Corley 2004). Hence, this study considers share of female co-authors to indicate the proportion of men and women in teams.

4.2.2.3- Work-life balance

The scholarly literature on work-life balance suggests that academics of both genders face similar challenges. However, because of the pressure created by social norms around motherhood, women curtail their career prospects more readily and experience more stress related to a work-life balance compared to men (Conley & Carey 2013; Mason et al. 2013; Ward & Wolf-Wendel 2012; Wilton & Ross 2017). Female academics are often saddled with more domestic and childcare responsibilities, and their careers—when measured by their publication records—are slowed down or even halted (Forster 2001). However, childrearing is shown to have no effect (Cole & Zuckerman 1987; Long 1990; Reskin 1978; Sax et al. 2002) or positive effect (Astin & Davis 1985; Beaudry & St-Pierre 2016; Fox & Faver 1985) on the productivity of women academics.

These results are further explained by the association of childrearing with a degree of maturity that cannot successfully be captured by the age of the researcher (Beaudry & St-Pierre 2016), and incorporation of other factors, including age and dependency of children (Fox 2005; Sax et al. 2002; Stack 2004). However, compared to male academics, the increase in productivity is significantly lower for female academics (Beaudry & St-Pierre 2016).

Along these lines, the issue of dual-career couples is one of the main focuses of studies on work-life balance in academia, as more women than men are in dual-career relationships (Tzanakou 2017). Employment within close geographical proximity or in the same institution is one of the primary concerns for dual science career couples (Obakeng Mabokela 2011). However, women are more challenged to secure their career advancement, career mobility and work-life balance, and are more likely to interrupt their careers to follow a spouse or a partner, considering jobs that do not suitably align to their qualifications (Becker & Moen 1999; Ferber & Huber 1979; Rusconi & Solga 2008; Cooke 2007). Therefore, partnering—which is lamentably not often considered in science and technology policies—is at least as crucial a factor as parenting in women's career progression, because being in a dual career household disfavors women's careers in academia (Ackers 2004). This paper determines the level of work-life balance by examining parenthood stage and by using scales for difficulties a researcher faces in balancing work and personal life, and in managing his/her career because of his/her spouse/partner career.

4.2.2.4- Support and gender inclusiveness

The growing representation of women in male-dominated professions does not necessarily imply greater integration of women into organizations. Because of their scant representation in certain fields and professions, women are often excluded from informal ties and relationships (Kanter 1977). The exclusion of women affects their social integration, which is often measured by the level of support and encouragement from their colleagues (Wallace 2014). This is provided by Kanter's (1977) concept of tokenism, which emphasizes the additional stresses experienced by those in a minority group (i.e., tokens) due to their numerical or proportional underrepresentation in certain organizations or professions, including isolation and exclusion from social and professional networks. In this regard, Taylor (2010) found that women in male-dominated occupations receive lower levels of support from colleagues and supervisors, highlighting structural barriers that hinder women's career progression and success. The creation of a gender-inclusive culture can help overcome these barriers and encourage career progression of both genders (Cartwright & Gale 1995; Sharma & Sharma 2012). Hence, this paper incorporates positive treatment from colleagues, women's representation in the workplace, and lack of gender-inclusive culture as crucial factors to better understand the culture of the nanotechnology research system.

4.2.3- Fix the knowledge: Gender in the results of science

The third level 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, which is being referred to as gendered innovations. (Schiebinger 2008) considered this level *crucial* for efforts to recruit and retain women in science, in the sense that, increasing the number of women in scientific professions opens the way to reconceptualize science and engineering research.

This paper incorporates the third level in the sense that it advocates a more comprehensive definition of nano-divide than is generally adopted in the context of inclusive innovation: divides between who will and will not have *access to, profit from, benefit from, and control* the nanotechnologies (Sparrow 2007). Nano-divide is conventionally studied to address the concerns around divides between developed and developing nations, or poor and rich communities/individuals (Daar et al. 2004; Moore 2002; The Royal Society 2004). This study looks into this concern not only from an inclusive innovation (more specifically, economic development) perspective, but also from a gender perspective and pays attention to two questions relevant to the nano-divide: (1) how developed and developing nations *benefit from* nanotechnology R&D differently, and (2) how men and women *profit from* nanotechnology R&D differently.

In sum, the approach of this study is informed by (Schiebinger 2008) framework of gendered innovations, and incorporates its three approaches to gender inequality to provide a comprehensive cross-gender analysis of Canadian nanotechnology scientific publications and impact. It further identifies the most important scientific, cultural and social attributes and factors that exacerbate or reduce gender discrepancies in scientific production and impact, considering both bibliometric and sociodemographic indicators. This study applies the exploratory approach to further develop and contribute to gendered aspects of science, technology and innovation policy discourse. This study also considers the inclusive innovation framework and determines influencing scientific factors on scientific productivity and impact of researchers involved in pro-poor nanotechnology research.

4.3- Methods

4.3.1- Data

In this paper, 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 a comprehensive coverage of scientific publication data from 1996 (Elsevier 2016) and provides a larger journal coverage compared to Web of Science (Mongeon & 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 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 website, etc.). In the end, the questionnaire was sent to 6,606 valid email addresses, and 523 valid responses (out of 674 total) were collected. 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. Data on patents was further collected through a manual search of 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, similarity between abstract, title and subject area of their patents and their scientific papers are verified. Data for funding is collected through 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 the governmental funding awarded to the researchers in their scientific careers.

Gender is further assigned to respondents using the gender-checker name and gender database[16]. For those whose gender remain unidentified or unisex, gender was assigned manually, using online academic or professional profiles. The numbers of female and male respondents are, respectively, 92 and 431. The maximum number of co-authors recorded in Scopus is 150, and most of the respondents had high numbers of co-authors (mean=91.56 and median=93), 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 main co-authors of the selected author. Scopus lists co-authors by the number 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 top 15 loyal co-authors of a selected author to cover, at a minimum, the top 10% of major co-authors.

The questionnaire entails two dimensions to understand nanotechnology equity challenges: (1) facts and (2) perceptions. The former involves attributes and demographic information of active nanotechnology researchers, including their level of funding, academic ranking, parenthood and the like. The latter addresses inequalities through perceptions of researchers by posing six Likert-type questions, ranging from 1 (strongly disagree) to 5 (strongly agree). The first question directly addresses the nano-divide and the pro-poor aspect of Canadian nanotechnology and the other questions highlight both gendered and general aspects of workplace culture that can hinder the scientific development of nanotechnologies.

4.3.2- Model

This paper has two dependent variables: traditional research output measured by the number of peer-reviewed documents (indexed in Scopus) per career age, as well as the total number of citations per career age. The former is a measure of scientific productivity of a researcher, whereas the latter is associated with the research impact and indicated to what degree a scientist is influential and recognized by his/her scientific community. The two dependent variables present

[16] http://genderchecker.com/

two criteria by which researchers are rewarded. In this study, career age is measured by the number of years between last and first publications of a scientist. 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 4.1 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 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:

$$\binom{nbPub/Careerage}{nbCit/Careerage} = f\left(\begin{array}{c} nbPat, \dfrac{nbCoaut}{Careerage}, \dfrac{nbFAPub}{Careerage}, shareofFcoaut, \\ shareofAASelfCit, shareofSASelfCit, Propoor, Balancediff, \\ TreatPositive, WomenFew, GenderExclusive, Spousediff, \\ dFemale, dChildmorethan1, dAcademicRank, dFund \end{array}\right)$$

All explanatory continuous variables in the models are transformed using the z-scores in order to minimize the multicollinearity problems. Table 4.2 verifies that the correlation coefficient among independents variables is very low, and variables are not correlated. The moderating effects of gender and questionnaire measures of facts and perceptions are also analyzed. More specifically, this study looks into interactions of *dFemale, dChildmorethan1, dAcademicRank, dFund* (facts) and *Propoor, Balancediff, TreatPositive, WomenFew, GenderExclusive, Spousediff* (perceptions) with other continuous variables. These moderating effects help explain whether determinants and contributing factors of nanotechnology scientific reward of researchers differ for men and women (of different academic rank or funding), and what differences a more equitable context (mainstreaming of gender and pro-poor perspectives) exhibit in this reward system.

Table 4.3 and Table 4.4 reveal robust regression results with significant interaction terms through all models. 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, 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 (or effect) of an independent variable on a dependent variable does not imply any causality and merely refers to the degree of association between an dependent and an independent variable.

4.4- Descriptive results

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 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 higher rate of lead (first) author production. Both internal citations and author self-citation rates were not different between the two genders (Table 4.1). The perception of nanotechnology culture (Table 4.1) 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 4.1). To better understand the underlying reasons behind differences in perceptions for men and women, gender differences in related sub-factors listed in the questionnaire in the form of close-ended statements are analyzed. Fig. 4.1 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.

Table 4.1 - List of variables, descriptions, gender means and comparison tests.

Dimension	Variable	Description	Men (n=431)	Women (n=92)	M-W[a]
Facts (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 careerage	4.60	4.51	0.60
	nbFAPub/Careerage	total number of first-authored publications divided by careerage	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
Perception (Propoor)	Propoor	a five-point Likert scale showing the degree to which research application of a scientist can benefit developing countries	3.33	3.38	0.84
Perception (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*
Facts (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 4.2- Correlation table.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
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	Propoor	.056	.043	-.074	.043	-.043	-.097*	-.001	.106*	1										
10	Balancediff	-.011	-.021	.113**	.065	.042	-.070	-.023	-.056	.034	1									
11	TreatPositive	.017	.059	-.004	.064	.046	.014	.046	-.044	-.013	-.123**	1								
12	WomenFew	-.004	-.052	.024	-.038	-.057	.122**	-.070	.069	-.110*	.089*	.018	1							
13	GenderExclusive	-.086*	-.110*	.004	-.056	.001	.022	.021	.017	.019	.143**	-.248**	.196**	1						
14	Spousediff	-.107*	-.128**	.021	.036	-.013	-.002	-.082	-.079	-.071	.259**	-.183**	.137**	.252**	1					
15	dFemale	-.158**	-.060	.071	-.015	.114**	-.145**	.062	-.061	.017	.141**	-.073	.103*	.196**	.104*	1				
16	dChildmorethan1	.106*	.101*	-.130**	-.048	.032	.028	.093*	.140**	.090*	-.071	.011	-.018	-.054	-.148**	-.161**	1			
17	dFullProf	.347**	.299**	-.164**	.049	-.020	.008	.139**	.311**	.105*	-.023	.071	.034	-.108*	-.099*	-.126**	.155**	1		
18	dAProf	-.084	-.035	.149**	.006	-.023	-.046	-.056	-.007	.011	.083	-.043	.066	.116**	.000	.152**	-.039	-.419**	1	
19	dOtherRes	-.279**	-.272**	.041	-.054	.039	.030	-.093*	-.307**	-.115**	-.046	-.036	-.088*	.013	.100*	.001	-.124**	-.660**	-.406**	1
20	dFund	.230**	.194**	-.136**	.022	.069	-.027	.096*	.299**	.019	-.003	.047	.114**	-.086*	-.152**	.017	.140**	.439**	.097*	-.522**

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

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 the 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 majority of decisions on their academic status and progress is 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.

4.5- Regression results

The OLS regression results for the various factors associated with productivity (number of publications per career age) of a researcher are presented in Table 4.3, and Table 4.4 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. However, a higher share of female co-authors has a negative impact on the productivity of researchers (Table 4.3). Yet, as a standalone variable, it does not have a significant effect on research impact of a researcher (Table 4.4). This finding is in accordance with the effects of gender: being a woman significantly affects research productivity (Art-3) but presents no significant effect on the citation impact of a researcher. Therefore, as women are significantly less productive, researchers who collaborate mainly with a higher share of women are also associated with lower scientific productivity. These gender disparities represent one of the main gender equality issues in the nanotechnology field that, if not addressed, might form a vicious circle that excludes women from the nanotechnology scientific community.

Share of internal citations has no significant effect[17] on productivity and a negative significant effect on the total scientific impact of a researcher (Table 4.4). A higher share of author self-citations is associated with higher productivity (Table 4.3) and scientific impact of a researcher (Table 4.4- (Cont'd[18])). 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 high 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.

This study also confirms that higher rate of internal citations does not play a positive role in inflating a scientist's overall citation impact. However, it shows that author self-citations do. Therefore, author self-citations are associated with an author's citation impact and could present a considerable challenge to decision making for rewarding nanotechnology researchers. A higher percentage of author self-citations among productive and more established researchers might occur because these authors have more publications to cite.

However, these aforementioned independent variables show different patterns of effects when interacting with gender, academic rank and the questionnaire measures.

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[17] Note that share of internal citations becomes significant in Table 4.3 when academic rankings of researchers of each gender are added to the model (Art-1, Art-4).
[18] Note that share of author self-citations becomes not significant in Table 4.4 when academic rankings of researchers of each gender are added to the model (Cit1-Cit8).

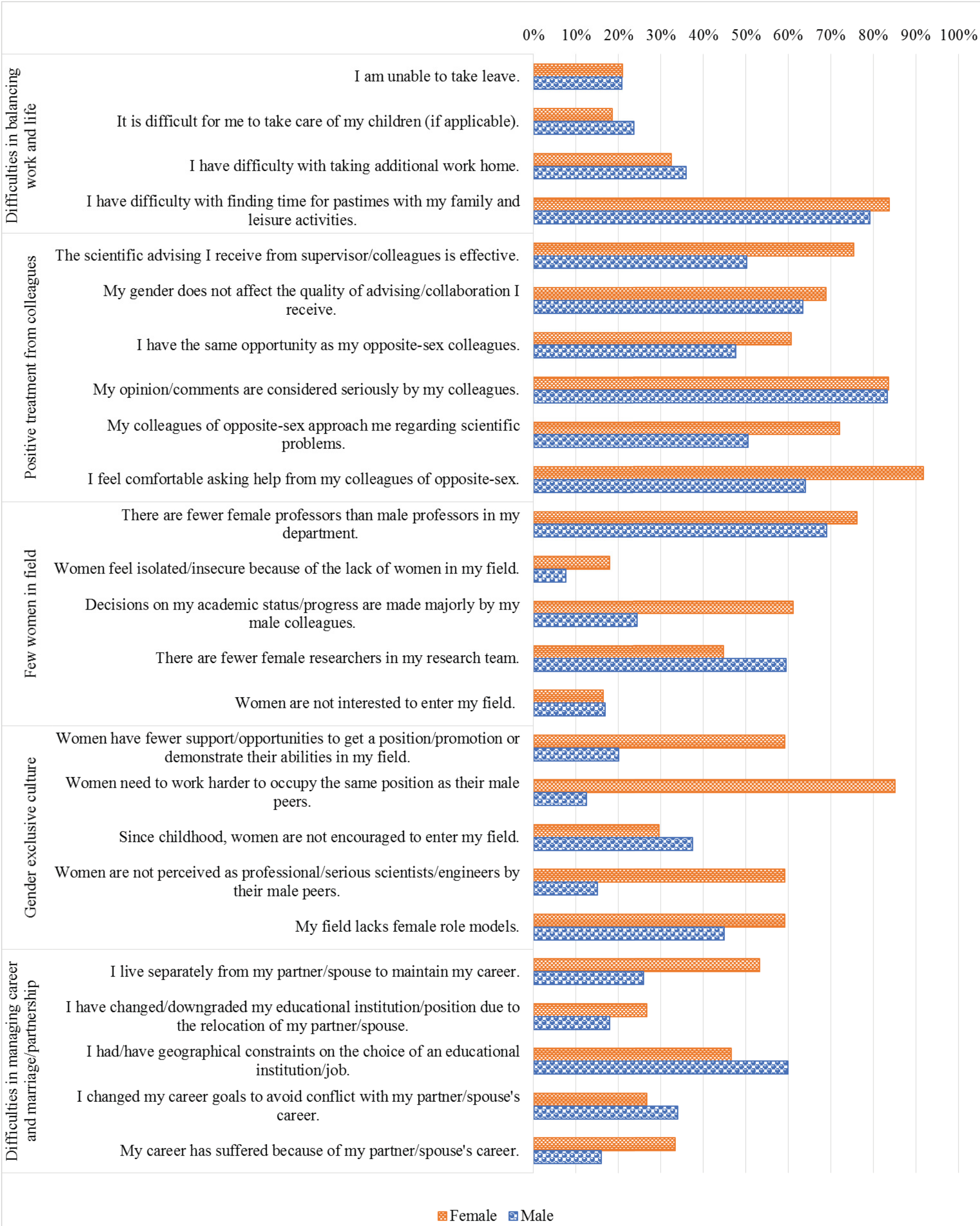

Figure 4.1- Share of respondents of each gender who chose the selected sub-factor to the number respondents of each gender who chose 'agree' or 'strongly agree' for the selected Likert-scale category.

4.5.1- Questionnaire results: Facts

4.5.1.1- Academic ranking

Male full professors publish significantly more than men and women of any academic ranking. Moreover, the regression results reveal that female researchers who are not professors publish significantly less than male and female full professors[19] (Art-1). The differences in scientific impact are not significant between the research impact of women in tenured or tenure-track positions and male full professors (Cit-1). Moreover, there is no significant difference between the overall scientific impact of female and male researchers who are not in tenured (-track) positions (Cit-1).

Although women in tenured or tenure-track positions are significantly less productive than male full professors (Art-1)[20], the scientific impact of their research is not different from that of male full professors (Cit-1). This finding complies with the selection effect, according to which in male-dominated disciplines where women face greater career risk to pursue their academic career, female faculty have equal or higher publication impact (Duch et al. 2012; Ghiasi et al. 2015) and the gender gap in impact is less conspicuous than in productivity.

The lower productivity of female researchers shows that women 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, are less productive (weakly significant) than their male peers (men of the same ranking). While no significant difference is found for the publication impact of researchers of each gender, when these female researchers become involved in patenting, they surpass their male peers (men who are not in tenured or tenure-track positions) in terms of scientific impact (Cit-2). On the other hand, although higher first-author productivity positively affects the scientific impact of researchers of any gender and academic ranking, it benefits female researchers who are not in tenure-track professorship positions at a weakly significantly lower rate than that of male full professors (Cit-4). These types of differences might affect the opportunity of women to get into the tenure-track faculty positions. Because although higher rate of the first-author

[19] Male full professors and men with high level of funding are considered as the reference category in the regression results included in this study. However, the significance level has been verified for other cohorts being considered as the reference category.
[20] The significance level for female full professors is weak.

production and patenting, both, are associated with making extra effort in scientific activities in this paper (which was addressed in section 2), it is more difficult for women to become involved in patenting activities in nanotechnologies (Meng 2016)—as gender disparities in patenting is more conspicuous than in first-author publications. Female assistant and associate professors are less productive than male full professors. However, a higher rate of patenting and first-author productivity exacerbates this productivity gap (at a weak significance level) (Art-1). The impact of patenting is even negative for female junior faculty. This highlights the disadvantaged position of female junior professors, in the sense that they benefit less from first-author productivity and there is a productivity payoff for being an inventor.

Although a higher number of co-authors positively affect the total impact of nanotechnology scientists, it favors publication impact of female junior professors less than men of any academic rankings (Cit-3)[21]. This also confirms another hindrance for female junior professors: networking and collaboration privilege female junior professors significantly less than male researchers of any academic ranking in terms of recognition and scientific impact. On the other hand, when female junior professors co-author more papers with a higher share of female researchers, their research becomes more recognized and presents more impact (Cit-5) (at a weak significance level). This might be associated with women's propensity to collaborate with other female scientists (Ghiasi et al. 2015; Ozel et al. 2014) and shows that high impact junior professors include a higher share of female researchers in their co-authorship collaborations. However, as women climb in academic ranks, they might comply with the male-dominated system and share of female co-authors, thus, exhibits no impact on the total impact of the female full professors.

Female full professors who are involved in patenting are significantly more influential than men of any academic ranking (Cit-2)[22].This also can be explained by the selection effect. Women need to be highly competent in their work in order to break the glass ceiling to reach top positions in academia and also become involved in patenting, a male-dominated scientific activity.

[21] This difference is weakly significant for male assistant and associate professors.
[22] This difference is weakly significant for male full professors.

Internal citations are associated with the lower scientific impact of a researcher. However, it significantly disfavors female full professors more than any other cohorts (except male assistant and associate professors) (Cit-6)[23]. 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. 2016). However, their recognition at the full-ranked position could be fragile and dwindle as share of internal citations increases. Therefore, this can be interpreted to mean that although women have to work harder and longer and exude extreme competency in order to climb in the academic hierarchy (Toren 1988), their recognition in top academic positions in the field is fragile, and women are most susceptible to the disadvantages internal citations bring to research impact of scientists.

4.5.1.2- Funding

In this study, men with high levels of funding (more than 100K) are most productive (Art-2) and their research has a higher impact compared to other cohorts[24], 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 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 to boost recognition of women and help 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. Collaboration with higher number of researchers is associated with higher productivity and scientific impact of highly-funded female scientists. This notwithstanding, these networking activities (weakly) significantly benefit highly funded men at a higher rate. Hence, this disadvantage might play out as a hindrance for women to receive recognition and raise further funding. Women on average receive less funding than men (Larivière et al. 2011) and often are required to put extra effort to fill the same position and ranking as their male peers (Dryburgh 1999; Faulkner 2009). However, their title as a highly funded researcher might be altered because they are less productive and influential than men of the similar title.

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[23] These results are weakly significant for male full professors and female assistant/associate professors.
[24] The difference is weakly significant for women with high level of funding.

4.5.2- Questionnaire results: Perceptions

4.5.2.1- Pro-poor research

The impact of internal citations on productivity is more positive for research activities with strong pro-poor orientation (Art-3) (Fig. 4.2a). This is associated with the low number of nanotechnology papers in pro-poor areas. The share of nanotechnology-related papers which focus on top three pro-poor applications—i.e., energy, agri-food, and water (Salamanca-Buentello, Persad, Martin, Daar, Singer, et al. 2005)—to the total number of nanotechnology papers worldwide is less than 5% (Cozzens et al. 2013). Therefore, scientific discoveries and networks in pro-poor areas are limited and highly specialized and productive researchers are more prone to receive citations from their direct co-authors (internal citations). However, the impact of author self-citations is positive but lower on productivity (Fig. 4.2b) and is negative on scientific impact for researchers involved in nanotechnology pro-poor areas (Cit-9) (Fig. 4.3a). This might be due to the differences in the scientific reward system of research in pro-poor areas. In pro-poor areas, the focus is more on the discovery's potent promises for developing countries and enforcement of policy reforms (Cozzens 2010). Traditional indicators, such as citations, might be less important in pro-poor areas and author self-citations, therefore, play a trivial role in inflating a researcher's productivity and impact.

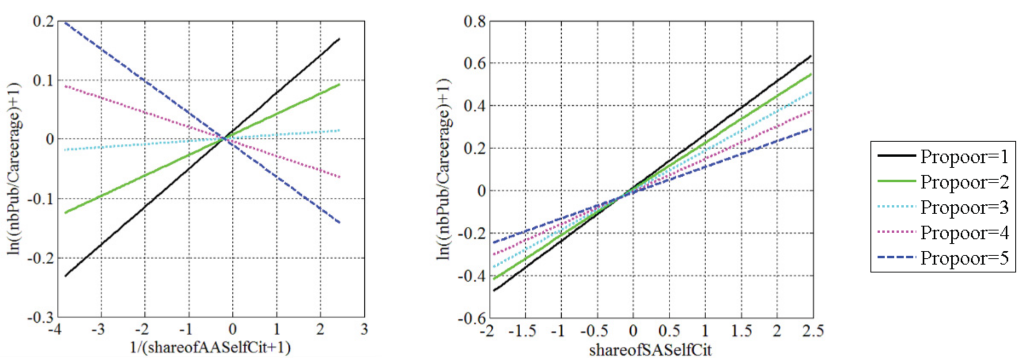

Figure 4.2- Impact of research with pro-poor orientation on scientific production with respect to (a: left) all authors' self-citations (internal citations) and (b: right) author self-citations.

The effect of the number of patents on scientific impact of a researcher is more positive (at a weak significance level) for those involved in pro-poor application areas (Fig. 4.3b). Patents are means of successful translation of a technology from research into commercialization and product development. Patenting in pro-poor areas might help introduce products that have the potential to ameliorate the economic gap both within and between nations. Patenting in pro-poor areas thus might represent more prestigious research and innovation, which could positively influence the scientific impact of a researcher. Since the share of nanotechnology research with pro-poor focus is very limited, first-author publications have great importance in conducting high prestige research and is associated with a researcher's higher impact in pro-poor (Fig. 4.3c).

4.5.2.2- Work and life balance

The effect of patenting is higher (at a weak significance level) on the productivity of a researcher when he/she has difficulties in balancing her/his professional and personal life (Art-4) (Fig. 4.4). Patenting, as an additional scientific activity to publishing, is associated with hard work and more applicable research, which could potentially result in higher production of research. However, it is more difficult for women to enter the patenting process due 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 difficulties in work-life balance affect women in non-tenure track positions the most. Their research impact is significantly lower compared to men of any ranking (Cit-10)[25].

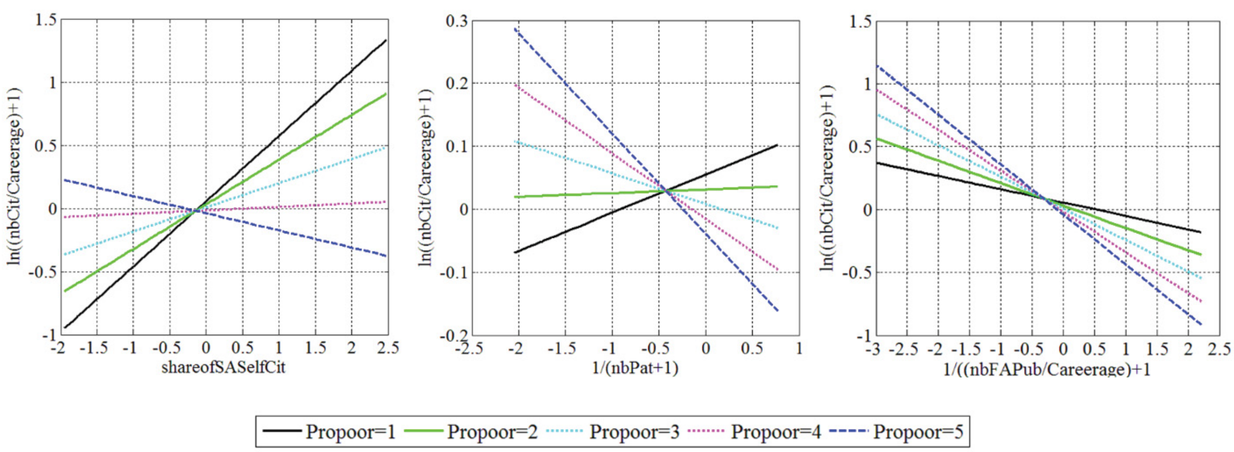

Figure 4.3- Impact of research with pro-poor orientation on scientific impact with respect to (a: left) author self-citations, (b: middle) patents, and (c: right) first-author production.

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

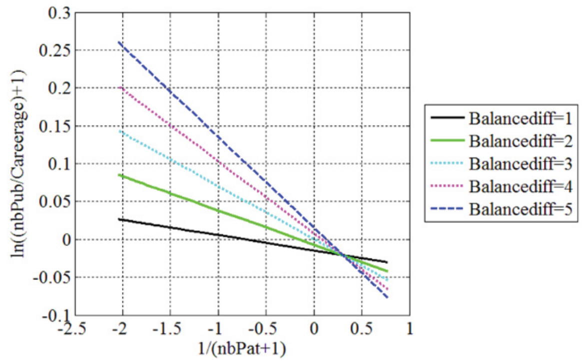

Figure 4.4- Impact of difficulties in work-life balance on scientific production with respect to patents

4.5.2.3- Positive treatment from colleagues

Receiving positive treatment from colleagues is associated with a researcher's higher scientific impact (at a weak significance level). However, gender plays a moderating effect on the relationship between the receipt of positive treatments from colleagues and researcher's total impact, and this effect is adverse for women (Cit-11) (Fig. 4.6a). This also shows that highly cited female and male researchers are not treated equally by their colleagues. The receipt of positive treatment from colleagues is adversely associated with highly cited women, which might result in lower levels of attention and recognition in the longer term, and therefore might leave women more vulnerable to retain their recognition as highly cited researchers. The positive impact of the first-author production on productivity (Fig. 4.5a) and citation impact (Fig. 4.6b) is lower for a researcher who is receiving positive treatments from his/her colleagues (Art-5; Cit-11). In a 'positive treatment' environment, researchers might be less required to devote extra effort to lead projects in order to boost their productivity and impact, as opposed to the environments in which a researcher is not treated properly. Moreover, the negative impact of share of female co-authors on the productivity of a researcher is lower in a positive environment (Art-5) (Fig. 4.5b). This means that a positive environment might provide the basis for forming more gender-balanced authorship teams—an important factor that might help to break the vicious circle around collaboration with women and productivity.

The positive effect of author self-citations on productivity (Art-5) (Fig. 4.5c) and the negative effect of internal citations on scientific impact are stronger (Cit-11) (Fig. 4.6c) in the workplace environments where colleagues treat each other positively. This could be associated with the fact that positive relationships with colleagues might result in more repetitive collaborations or more loyalty with co-authors and 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 adversely affect the knowledge transmission (Zamzami & Schiffauerova 2017), which might only promote internal citations rather than receiving external citations and recognition from the scientific community. Therefore, the higher share of internal citations is highly associated with lower citation impact.

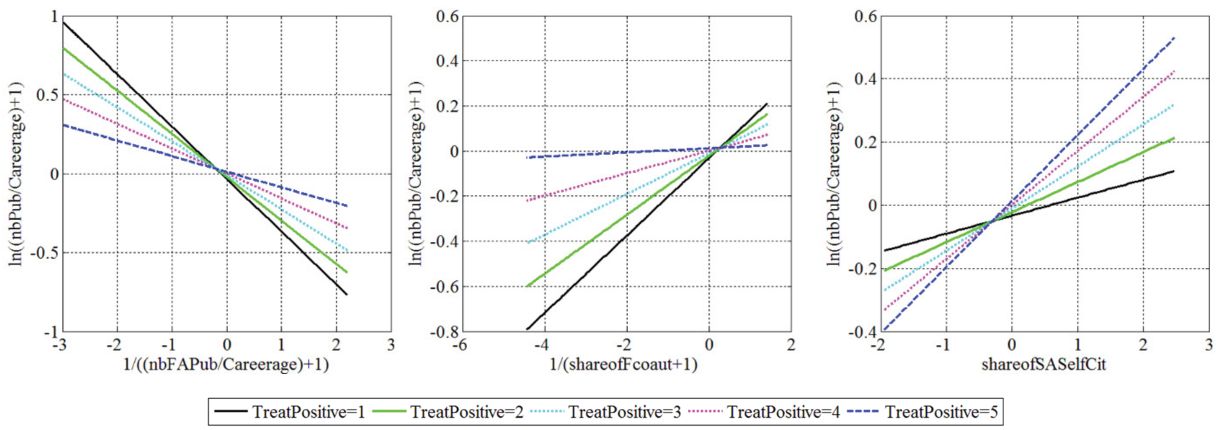

Figure 4.5- Impact of positive environment on scientific production with respect to (a: left) first-author production, (b: middle) share of female co-authors, and (c: right) share of selected author self-citations.

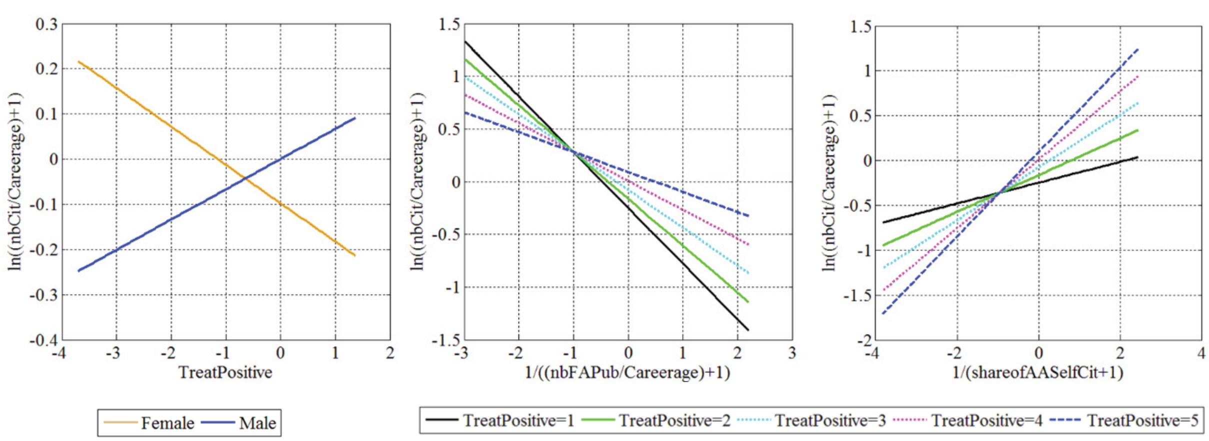

Figure 4.6- Impact of (a: left) gender, and impact of positive environment with respect to (b: middle) first-author production, and (c: right) share of all authors' self-citations (internal citations) on scientific impact.

4.5.2.4- Women's representation in the field

Given the interdisciplinary nature of nanotechnology, one can posit that it has inherited gendered scientific system from various disciplines, ranging from highly male-dominated fields (including physics, engineering, and chemistry) to more gender-balanced fields (including health and medicine). However, Nanotechnology scientific system is highly male-dominated and women represent only 18.9% of nanotechnology authors (Mihalcea et al. 2015). The analyses 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 fields might be able to delegate more while researchers in gender-balanced fields might be required to work harder and lead more research (higher first-author productivity) to boost their productivity (Art-6) (Fig. 4.7a). This could be explained by the fact that R&D in nanotechnology is intrinsically male-dominated and for those researchers who are in a more gender-balanced field, it is required from them to work harder to compensate for the differences they are facing in the gendered cultural aspects of their workplace and their research community. The highest share of nanotechnology papers is published in journals in the fields of materials science, chemistry, physics, biomedical and engineering sciences (Porter & Youtie 2009b). 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. 2013b; Porter & Youtie 2009b). Therefore, researchers in less male-dominated disciplines are located in smaller and denser co-authorship and citation networks where the share of nanotechnology papers produced in these disciplines is limited. Internal citations are inevitable in these fields (because there exists only limited relevant of publications to cite) and thus are highly associated with productivity of researchers. Therefore, the impact of internal citations is more positive and higher for less male-dominated fields (Fig. 4.7b). The positive impact of author self-citations on productivity decreases as the researcher's field become less male-dominated (Fig. 4.7c). This is likely related to the fact that men cite their own work at a higher rate than women (Ghiasi et al. 2016; Hutson 2006; Molly M. King et al. 2016) and women receive a higher self-citation rate from their immediate co-authors (Ghiasi et al. 2016). Nanotechnology is thus not unlike other scientific fields in this way. Therefore, author self-citations play a more important role in male-dominated fields than in more gender-balanced fields.

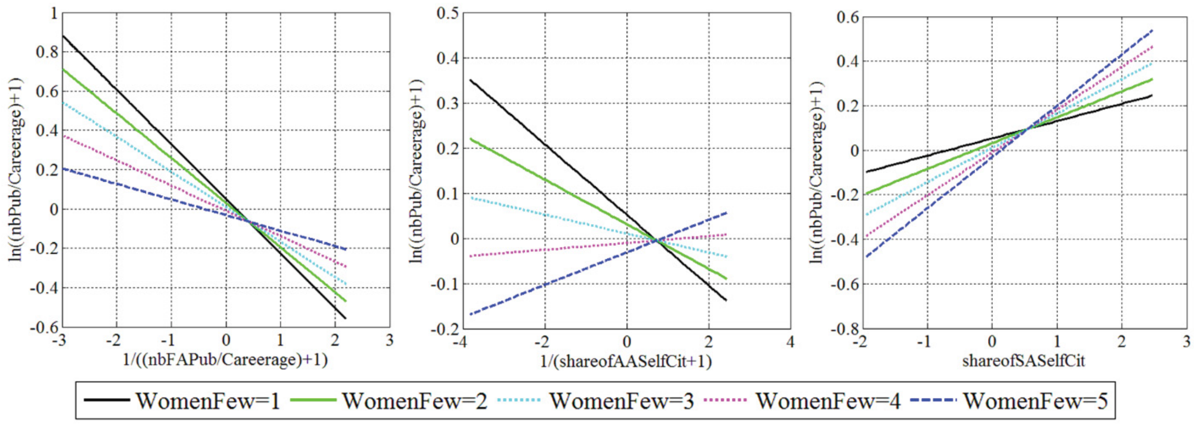

Figure 4.7- Impact of male-dominated fields on scientific impact with respect to (a: left) first-author production, (b: middle) share of all authors' self-citations (internal citations), and (c: right) share of selected author self-citations.

4.5.2.5- Gender exclusive culture

The effect of gender-exclusive culture on scientific impact of a researcher is negative (Cit-13). The existence of 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. The positive impact of patents on productivity is highest (at a weak significance level) for researchers with gender-exclusive workplace culture (Art-7) (Fig. 4.8a). In this culture, equitable measures are not considered to help women access the same opportunities, therefore patenting might be more rewarded and boost researchers' productivity. However, for researchers with gender-inclusive workplace culture, first author production presents the strongest impact (at a weak significance level) on productivity (Art-7) (Fig. 4.8b). This culture might consider the fact that it is easier for women to be involved in the first-author production rather than patenting, and therefore represents a more equitable pathway to achieve the scientific reward.

4.5.2.6- Difficulties in managing career and life partnership

Difficulties in managing career and life partnership (marriage) significantly negatively affects productivity and impact of a researcher (Art-8; Cit-14). Women are facing this difficulty more than men in this study (Table 4.1). Therefore, there exists the need to introduce gender-related policies to facilitate relocation and employment of the partner/spouse, ensuring that neither the career of the scientist nor that of his/her partner/spouse, suffers because of the other's career.

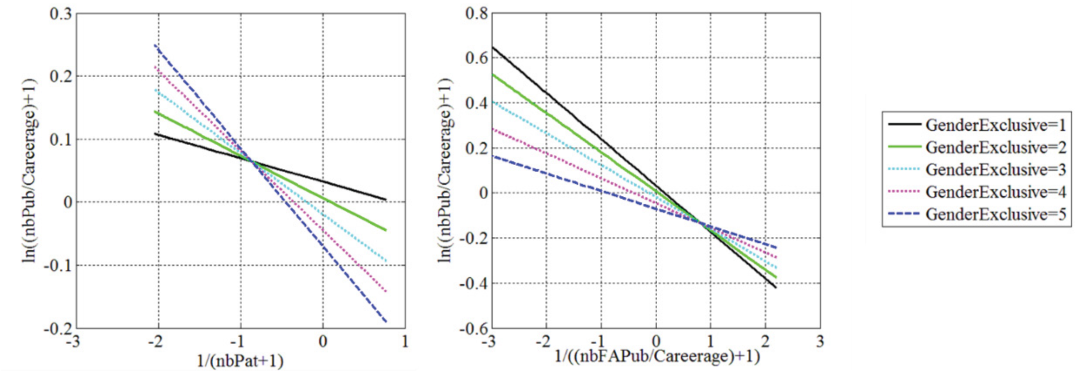

Figure 4.8- Impact of gender-exclusive culture on scientific production with respect to (a: left) patents and (b: right) first-author production.

The impact of patenting on scientific production of a researcher is higher (at a weak significance level) for researchers facing difficulties in managing their career and partnership/marriage. This again highlights the fact that these researchers might be required to work harder and get involved in patenting in order to be involved in more collaborations and thereby could potentially increase their scientific productivity. However, as discussed earlier, it is easier for men to become involved in patenting and therefore, the situation could worsen for women without appropriate policy actions. On the other hand, the impact 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. These findings are similar to those on gender-inclusive culture (section 5.2.5), in the sense that, the introduction of policies to support dual career couples might open up a more equitable context (weighting the roles of first-author productivity and collaborations rather than patenting) for a researcher to boost his/her productivity.

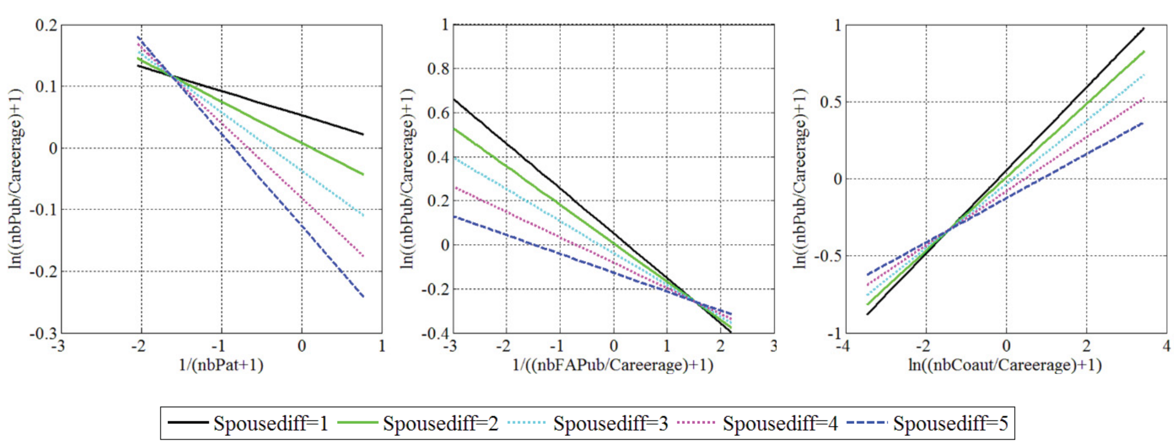

Figure 4.9- Impact of difficulties in managing career and marriage/partnership on scientific impact with respect to (a: left) patents, (b: middle) first-author production, and (c: right) number of co-authors.

Table 4.3- 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)	-0.073***	-0.056***	-0.071***	-0.069 ***	-0.069 ***	-0.067***	-0.075 ***	-0.072 ***
	(0.024)	(0.016)	(0.016)	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)
ln((nbCoaut/Careerage)+1)	0.210***	0.280***	0.226***	0.211 ***	0.231 ***	0.224***	0.230 ***	0.232 ***
	(0.016)	(0.028)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
1/((nbFAPub/Careerage)+1)	-0.232***	-0.186***	-0.161***	-0.181 ***	-0.162 ***	-0.152***	-0.165 ***	-0.169 ***
	(0.025)	(0.017)	(0.017)	(0.017)	(0.017)	(0.018)	(0.017)	(0.017)
1/(shareofFcoaut+1)	0.057***	0.056***	0.058***	0.056 ***	0.053 ***	0.056***	0.053 ***	0.058 ***
	(0.015)	(0.015)	(0.016)	(0.015)	(0.015)	(0.016)	(0.015)	(0.015)
1/(shareofAASelfCit+1)	-0.077**	-0.021	-0.005	-0.031 **	-0.006	-0.006	-0.009	-0.012
	(0.031)	(0.016)	(0.016)	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)
shareofSASelfCit	0.120***	0.161***	0.175***	0.119 ***	0.168 ***	0.174***	0.157 ***	0.164 ***
	(0.018)	(0.025)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Propoor			-0.006					
			(0.016)					
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			-0.101 **		-0.112 ***	-0.113***	-0.096 **	-0.092 **
			(0.041)		(0.040)	(0.041)	(0.041)	(0.041)
dChildmorethan1	0.049	0.060**						
	(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) × FemaleAProf	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) × FemaleAProf	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) × FemaleAProf	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)						
1/(shareofAASelfCit+1) × *Propoor*			-0.030**					
			0.014					
shareofSASelfCit × *Propoor*			-0.033**					
			0.015					
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	1.550***	1.480***	1.429***	1.581 ***	1.461 ***	1.430***	1.443 ***	1.426 ***
	(0.032)	(0.031)	(0.017)	(0.025)	(0.018)	(0.017)	(0.017)	(0.017)
Nb observations	523	523	523	523	523	523	523	523
F	33.613***	51.342***	73.399***	67.472 ***	52.478 ***	69.503***	65.156 ***	70.216 ***
R^2	0.647	0.619	0.589	0.633	0.624	0.599	0.605	0.602
Adjusted R^2	0.628	0.607	0.581	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 4.4- 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) × FemaleAProf			-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) × FemaleAProf					-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 4.4- (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)	-0.068**	-0.067 **	-0.078 **	-0.080**	-0.081 **	-0.081 **
	(0.033)	(0.033)	(0.034)	(0.034)	(0.034)	(0.034)
ln((nbCoaut/Careerage)+1)	0.456***	0.438 ***	0.463 ***	0.458***	0.453 ***	0.462 ***
	(0.034)	(0.034)	(0.035)	(0.035)	(0.034)	(0.034)
1/((nbFAPub/Careerage)+1)	-0.276***	-0.310 ***	-0.281 ***	-0.288***	-0.290 ***	-0.291 ***
	(0.036)	(0.036)	(0.037)	(0.037)	(0.037)	(0.036)
1/(shareofFcoaut+1)	0.002	-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)	0.372***	0.329 ***	0.375 ***	0.367***	0.370 ***	0.358 ***
	(0.033)	(0.033)	(0.034)	(0.034)	(0.033)	(0.033)
shareofSASelfCit	0.135***	0.034	0.128 ***	0.124***	0.125 ***	0.111 ***
	(0.035)	(0.037)	(0.035)	(0.036)	(0.035)	(0.035)
Propoor	-0.024					
	(0.032)					
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	-0.085		-0.098	-0.077	-0.036	-0.055
	(0.086)		(0.088)	(0.088)	(0.089)	(0.087)
dChildmorethan1						
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)				
1/(nbPat+1) × Propoor	-0.056*					
	(0.033)					
1/((nbFAPub/Careerage+1)× Propoor	-0.074**					
	(0.034)					
1/(shareofAASelfCit+1)× Propoor	0.021					
	(0.030)					
shareofSASelfCit × Propoor	-0.166***					
	(0.035)					
dFemale× TreatPositive			-0.152 *			
			(0.089)			
1/((nbFAPub/Careerage)+1)× TreatPositive			0.067 **			
			(0.033)			
1/(shareofAASelfCit+1)× TreatPositive			0.070 **			
			(0.034)			
1/(nbPat+1)× shareofSASelfCit	-0.090***					
	(0.033)					
Constant	3.983***	4.251 ***	3.977 ***	3.984***	3.977 ***	3.980 ***
	(0.035)	(0.055)	(0.036)	(0.036)	(0.036)	(0.036)
Nb observations	523	523	523	523	523	523
F	42.635***	34.473 ***	46.738 ***	61.998***	63.839 ***	64.630 ***
R^2	0.521	0.537	0.502	0.491	0.498	0.501
Adjusted R^2	0.509	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.

4.6- Discussion and conclusions

The purpose of this study is to provide a gender analysis of nanotechnology research and development. It develops a model for examining how nanotechnology R&D structures and cultures are gendered and might establishe a baseline from which policy changes can be initiated to tackle emerging inequities and/or foster equality—all of which are priorities for nanotechnology fields (Smith-Doerr 2011).

<u>Gender differences in the perceptions of scientific culture</u>

The descriptive results of this study reveal that men were more productive. However, the scientific culture of nanotechnology was perceived as more masculine by women than by men. Women reported a 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/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 nanotechnology female 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 majorly 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 fill 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 coherent with previous studies on gender differences in perceptions of workplace climate and career development (Brainard et al. 2014; Bronstein & Farnsworth 1998; Gunter & Stambach 2005), according to which the climate of science is described as '*chilly*' for women and that a smaller share of women relate their workplace to a positive environment, because they experienced negative attitude and exclusion by colleagues, and unfairness in progression processes.

Influencing factors of the reward system of nanotechnology scientists

The regression analysis reveals the positive association of number of patents, number of co-authors per career age, and number of first-authored publications per career-age on scientific productivity and scientific impact of a nanotechnology researcher.

Gender

Being a woman is associated with lower scientific productivity of a researcher. Accordingly, a higher level of co-authorship collaborations with women also exhibits a negative impact on the scientific productivity of a researcher. This might 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 encourage the inclusion of women in scientific collaborations and thereby, to break the cycle.

Academic rankings

When controlling for the academic status of researchers, gender differences in scientific impact was less conspicuous than in scientific productivity among researchers in tenured or tenure-track positions. The findings shed light on the disadvantaged position of female junior faculty (i.e. assistant and associate professors), 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 & Sandström (2017), which suggest that the general lower academic rank of women and their lower prevalence in leading roles have a negative impact on their performance which in turn reinforces lower academic status. 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, they comply with the system and therefore, the inclusion of a higher rate of female (main) co-authors is no longer positively associated with a higher impact for female full professors.

Along these lines, engagement in patenting activities is shown to be positively associated with scientific impact of women in top academic ranks (female full professors), and a higher rate of internal citations is most adversely associated with their research impact. These results might bear witness to the amount of extra effort that women are required to devote to their research to retain their top positions in academia (as it is more difficult for women to enter patenting due to its male-dominant nature) and how their recognition in top positions is susceptible to the disadvantages (e.g., internal citation rate) compared to men of any ranking. These results are consistent with the reduced opportunities that women have 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 highlight the need to develop gender-related policies to shatter the glass ceiling.

Funding

Similar results are found when controlling for the level of funding. Involvement in patenting is associated with the scientific impact of women with low levels of funding more strongly than their male peers, and thus could improve their chances to raise future funding. However, women with high levels of funding are less productive and recognized than men with high levels of funding, and networking and collaborative research privileges those men more than women. These factors might hamper the ability of women to raise further funding and therefore, make it more difficult for women to retain their titles as highly funded researchers. Funding is verified to be a driving force for scientific performance in Canadian nanotechnology (Tahmooresnejad et al. 2015; Tahmooresnejad & Beaudry 2015), and higher scientific performance leads to more funding (Ebadi & 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 help policymakers explore gender-responsive mechanisms to support women's involvement in patenting and to help women raise funding for research.

Work-life balance

Engagement in patenting is associated with the higher productivity of scientists struggling with work-life balance either in general or in the particular case of dual-career couples. However, since patenting is a highly male-dominant activity, without gender-related policy actions, patenting might advantage men over women, and might increase the gender productivity gap of nanotechnology scientists. Difficulties in balancing a career and marriage/partnership, specifically, is associated with lower the productivity and scientific impact of a scientist. Organizations and academic institutions 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.

Supportive and positive environment

This study confirms that a supportive and positive working environment could contribute to an increased recognition and a 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 Kanter's (1977) 'tokenism' phenomenon, highlighting the extra pressure token women (women in 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.

In an isolating and unsupportive scientific environment, first-authorship is strongly associated with the higher productivity and citation rate of a scientist. Or, in other words, scientists might be required to put extra effort and lead projects to designate themselves as productive and high impact scholars in settings where they are not treated properly by their colleagues. On the other hand, in a positive and supportive environment, collaboration with women—being measured by the share of female co-authors—does not present staggering negative effects on the productivity of a researcher and is thus more facilitated. However, this positive setting can potentially place a scientist in a denser and smaller co-authorship cluster, where author self-citations also promotes the research impact of the scientists affiliated to the cluster and thereby might result in higher rate of repetitive collaborations that increase the productivity of a researcher. These repetitions in collaborations might pose a barrier for nanotechnology scientists to receive recognition outside their immediate collaborators and decrease their overall citation impact.

Women's representation in the field

This paper also reveals that in a more gender-balanced field, the impact of the first-author production on 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 & 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, higher rate of internal citation is associated with the higher scientific productivity of a researcher in gender-balanced fields. This can be explained by the smaller and denser network of citations and authorship across more gender-balanced fields (i.e., health and clinical research) (Larivière et al. 2013b; Porter & Youtie 2009b). 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 the productivity rate of a researcher.

Gender inclusive culture

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. Furthermore, the impact of first-author production rate on productivity is the highest for nanotechnology scientists conducting research in workplaces with a gender-inclusive culture, whereas the impact of inventorship is the strongest for scholars working in a gender-exclusive culture. This finding illustrate a potential 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.

Inclusive innovation

One other important focus of this paper is on nanotechnology inclusive innovation, calling attention to the nanotechnology research in the context of developing countries. Results show that high impact scientists, who are involved in nanotechnology pro-poor research, are associated with a higher rate of first-authorship and inventorship. This acknowledges the importance of leading research and innovation in pro-poor areas, as it holds the potential to promote the economic development of both developed and developing countries. Moreover, due to the smaller and denser cluster of researchers with nanotechnology pro-poor focus (Cozzens et al. 2013), internal citations are linked to a higher rate of productivity of these scientists. Additionally, author self-citation rate is least valued in scientific productivity and impact of researchers in pro-poor application areas. This finding is compatible with the assumption that the reward system in pro-poor nanotechnology areas values development and societal impact of scientific discoveries above traditional indicators (e.g., h-index, citations, number of papers, and the like) and hence, there is less incentive for researchers to cite their own work. These findings could provide a baseline to support policy reforms that encourage more research in pro-poor areas and create more innovations that can benefit poor communities.

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 pro-poor and gendered analysis of scientific performance and impact of nanotechnology research is carried out which serves as stimulation for further research to incorporate gender equity policies into other emerging fields. The study identifies key factors that influence the performance and efficiency of Canadian nanotechnology researchers from a pro-poor and gender perspective, and offers policy recommendations to expedite development and poverty reductions, and facilitate involvement and retainment of women in nanotechnologies.

4.6.1- Research limitations

In this study, the scientific productivity of a researcher is measured as a fraction of the 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. This paper measures only first-author productivity (leading research) 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 devotion of extra effort into research, because it relates to contributions to the highest proportion of tasks performed in a paper (Larivière et al. 2016). Lastly, this study uses an exploratory approach to provide a better understanding on potential gender influences on nanotechnology's scientific reward system. Therefore, it includes the effects and trends that have weak (level of) significance and the p-value threshold for a statistically significant result is considered at 10

Chapter 5

Conclusions and Future Work

5.1- Concluding Remarks

This thesis addresses two of the priority concerns related to nanotechnology and equity: the lack of pro-poor R&D and the scant involvement of women in nanotechnology R&D. The significance of this thesis is fivefold: it (1) focuses on nanotechnology at the two priority dimensions of inequalities, rich-poor, and gender inequality, both separately and as interrelated. It (2) assesses to what extent nanotechnology research and technological efforts of one of the most affluent countries, Canada, meet the UN SDGs, presenting scientific and technological productivity and impact of pro-poor applications of nanotechnologies. It (3) analyzes women's contribution to scientific and innovative advancements of pro-poor applications of nanotechnologies and maps their scientific performance through analysis of their involvement in various collaboration networks (co-authorship, co-inventorship, and co-innovation networks). It (4) examines gender gap in wage and employment among industries that are the focus of pro-poor nano-innovation in the Canadian economy. It (5) identifies key scientific, cultural and social factors that are associated with scientific productivity and impact of nanotechnology researchers and examines whether the influence of these factors varies across genders. Finally, it (6) proposes implications to promote the implementation of both gender equality and poverty alleviation policies in emerging science and technologies and new interdisciplinary fields, and thereby improve economic development.

This research is cutting across several research areas, including but not limited to technology management, industrial innovations, labor-market outcomes, social network research, bibliometrics and statistics, and social studies of science. Therefore, the contributions of this study are conceptual, methodological and empirical, extending the research on relationships of gender, pro-poor innovation, collaboration patterns, and scientific and technological productivity and impact, and social impact of emerging technologies.

5.1.1- Conceptual Contributions

This research applies a broader definition of nano-divide that better conveys how underpinning 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) rather than the traditional North-South divide. More specifically, this study also sheds light on the divide nanotechnology R&D might precipitate between individuals of each gender (within a nation). The idea of a nano-divide is largely studied from an economic development perspective, incorporating the context of the divide between developed and developing nations, or poor and rich individuals. However, this study conceptualizes the nano-divide from a gender perspective, trying to map the divide between genders to better analyze how *individuals of each gender profit from* nanotechnology R&D differently.

Another contribution is that this study is the first attempt that focuses on two priority dimensions of Canadian nanotechnology and inequality, pro-poor innovation and gender inequality, and cross-cutting relationships between the two dimensions. The cross-dimensional analysis is also high importance because these problems interact and a solution to one may exacerbate or benefit the other, related inequity concerns and when allayed together can yield system-level benefits. For example, if the growth of interest in pro-poor nano-innovation could add to gender biases in the scientific workforce, international development efforts could be futile as they affect social development of a nation.

One of the major contributions is that this study introduces a research and development dimension, particularly to define the concept of workforce diversity in emerging science and technology markets. For disruptive technologies, which are at an incipient stage of development, the main focus of the market is on R&D activities rather than production and operations. Therefore, scientific research and inventions present important information on companies and industries where new knowledge and technology is produced and disseminated. Socioeconomic statistics from governments and international organizations provide a context for understanding the potent workforce diversity in these companies and industries.

Moreover, knowledge networks present important information on how gender diversity is practiced in collaboration teams. This study re-conceptualizes collaboration from a gender perspective, providing a more detailed study of the association between genders and collaboration formation, loyalty, and publishing and patenting activities. For this purpose, this study defines scientific collaborations based on the gender of scientists and gender diversity in their team of collaborators. This is the first study that pays close attention to scientific and technological productivity and impact of author-inventors of each gender (researchers who are involved in both patenting and publishing in nanotechnologies), whose contributions to knowledge networks are crucial as they connect the two communities of authors and inventors.

Furthermore, this research draws upon the three approaches of "gendered innovation" concept, namely 'fix the number of women', 'fix the institutions' and 'fix the knowledge'. This study introduces factors to operationalize this concept under two themes: facts and perceptions. The former considers gender differences in the level of funding, academic rankings, collaborations (including collaboration with women), scientific productivity and impact to better understand barriers hindering women's involvement and progression in science and to fix the number. Along these lines, this study examines the role of self-promotion and devotion of extra work (and efforts) in academic progression and performance of women. Moreover, this study is the first attempt that sheds light on the importance of gendered cultural and institutional factors on the scientific performance of nanotechnology researchers. These are incorporated as perceptions and are defined as the level of work-life balance (which also included the challenges facing dual career couples), positive treatment from colleagues, women's representation in the workplace, and lack of gender-inclusive culture.

5.1.2- Methodological Contributions

The major methodological contribution of this study lies in extending bibliometric methods beyond conventional analysis of articles and patents, proposing a novel approach that could be applied in a better understanding of the socio-economic impact of an emerging technology. This research suggests the use of author affiliation data and patent assignee data to identify companies that are actively involved in research and development of a novel technology within an economy. It further proposes the use of databases on company and industry information (e.g., Mergent Online, LexisNexis Academics) to identify the primary industry classification code (For example North American Industry Classification System (NAICS), Standard Industrial Classification (SIC), or International Standard Industrial Classification (ISIC)) associated to each of the selected companies, identifying the main industries of focus. Public socio-economic data at the time of (or a specific period of) the publication or patent can be further utilized to better analyze labor market outcomes. For example, public data on employment and wage across various types of work, gender, ethnicity, age, and provinces are provided by Canadian and the US government for each class of industry, which are known as Labor Force Survey (LFS) and Current Employment Statistics (CES), respectively. This method provides several avenues for the technology impact analysis and could provide an estimate for employment and age for groups of people (gender, ethnicity, economic class, province of residence, type of job, etc.). This research suggests using socio-economic data at the time of the publication or granted patent, ensuring the company was active at the time.

Another methodological contribution of this research is that this research proposes a method for the identification of author-inventors. For this purpose, first or middle initials are removed from given names. Afterwards, inventors and authors are paired by matching their (main) given names and last names. A-Is are identified as those pairs with patent(s) and article(s) similar in title(s) and abstract(s)[26], or those pairs whose main subject area(s) of publications (in Scopus database) are similar to the international patent classification (IPC) code(s) on their patents, or those pairs those pairs whose province(s) of their current and previous affiliations in the Scopus database.

The combination of the methods incorporated in this study—i.e., bibliometrics, social network analysis, regression analysis—provides a comprehensive methodological frame to conduct gender analysis in scientific workforce, requiring extensive publication and patent data processing, analysis, and detailed modeling. More specifically, This study defines province and sector (i.e. university, industry, government) of publishing or patenting activity of a researcher, gender of a researcher, fractional count of authorship and inventorship of researchers, average rate of citation and journal impact of an author, average rate of citation and patent claims of an inventor for the extracted publication and patent data. These data and methods provide a strong tool to conduct gender analysis of the scientific system and to map gender biases and differences. For example, this study incorporates a data-driven approach to reveal the possibility of the existence of phenomena of Matilda effect and Selection effect in scientific production, using authorship and

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[26] In this research, patent paper pairs are identified manually. However, various similarity measures can be applied to identify patent paper pairs (for example the method introduced in (Magerman et al. 2015)).

citation and journal impact data. This study shares the assumption that papers published in higher ranked journals are subject to higher citation impact (based on the definition of SJR). Matilda effect—systematic underestimation of women's contribution to science—is thus might be detected in gender differences in citation and journal impact. Accordingly, Selection effect—the overachievement of women in senior academic positions—could be observed in gender differences in authorship, and citation and journal impact.

Moreover, this study gives a methodological context for studying collaboration patterns of scientists. Each edge—a link that connects two authors (or inventors) when they co-author (or co-invent) together on at least one article (or patent) of the inventorship and authorship network is categorized into F-F (a link that connects two female scientists), F-M (a link that connect a male scientist to a female scientist) and M-M (a link that connects two male researchers) and pays attention to weight of each edge—a measure that shows the number of distinct papers (or patents) that the two scientists collaborated together)—as a measure of *collaboration repetition rate* or *loyalty* to better understand who are the most loyal collaborators of a researcher. These methods provide a means of mapping gendered patterns in scientific collaborations. In accordance, this study uses Gephi's Force-Atlas 2 algorithm layout (in which nodes stay closer if they are connected, and the distance is defined based on the weight of edges (Bastian et al. 2009)) for network visualization, which provides essential context to analyze the network structure and visualize location of female (vs. male) researchers within their authorship or inventorship network.

5.1.3- Empirical Contributions

The main empirical contribution is that this study informs two priority social concerns around nanotechnology research and development: the lack of focus on nano-applications that benefit developing nations (pro-poor R&D) and the scant representation of women in nanotechnology fields. Moreover, this study put a cross-cutting emphasis on mainstreaming gender-inclusive policies into pro-poor policy processes in nanotechnology, based on the assumption that equity and equality dimensions are related and development initiatives should have a positive impact on issues such as gender equality (OECD 2014b). Therefore, empirical findings are categorized into three levels of analysis: the pro-poor dimension, the gender dimension, and cross-dimensional analysis.

5.1.3.1- Pro-poor dimension

This study shows that the focus on nanotechnology's prioritized pro-poor application areas—i.e. energy, agri-food, and water—is very limited, being reflected in the share of publications and patents in these application areas. However, the growth rate of articles in the three pro-poor applications is more pronounced than that of all nanotechnology papers, which reveals the accelerating focus on scientific advancements of pro-poor technologies. Moreover, the growth rate of nanotechnology patents with water applications is slow and less than that of all nanotechnology patents, which is contrary to the case of energy and agri-food applications. This shows that technological advancements with water application are of low concentration in Canada.

However, analysis of the survey data shows that higher rate of first-author production and patenting activities are highly associated to higher prestige and visibility (measured by citation-impact) for scientists whose research could potentially improve the livelihood in developing countries. These findings confirm that leading research and innovation in pro-poor areas is not only rewarding (for nanotechnology researchers), but is of great significance due to its potent economic development incentives. This study also proposes that the reward system of scientific advancements in pro-poor areas *might value* societal impacts of the discovery more than traditional indicators such as citations, impact factor, h-index and the like.

5.1.3.2- Gender dimension

The analysis of survey data, albeit requiring further confirmation, highlighted several gendered differences and practices in the nanotechnology scientific system. This study shows that the perception of the scientific culture of nanotechnology is more masculine for women in comparison to men. Women expressed that they deal with more difficulties in balancing their scientific career and personal life, and more specifically, reported that their careers suffered (at a higher rate compared to men) in order to manage their spouse/partner's career advancements. Women addressed receiving a lower level of support and positive treatment from their colleagues and found themselves in a workplace that overlooks gender inclusive initiatives at a higher rate compared to men.

The findings of this study reveal that women are significantly less productive in nanotechnology publishing and a higher rate of co-authorship collaboration with women is associated with lower productivity of a researcher. It is of utmost importance to explore policy mecahnisms to address these disparities in nanotechnology. Otherwise, they might form a vicious circle that continues to disadvantage women. This study also shows that the gender gap in citation impact is less conspicuous than in productivity, and women are involved in the same impact research as their male peers.

This research also highlights gender disparities in scientific productivity and impact among researchers of different academic rankings and with different levels of funding. The findings show that women in junior faculty positions might be disadvantaged because their productivity and the impact of their research benefit less from first-author publishing and patenting (extra effort in scientific research), and scientific collaborations, respectively.

Collaborating with a higher share of female co-authors is associated with higher citation impact and more recognition for female junior professors compared to men of any ranking. However, as women climb the academic rank ladder, they are more likely to comply with the male-dominated system and the share of female co-authors, thus, presents no positive association with the total impact of the female full professors.

The results of this study also confirm that women in top academic positions might be required to devote extra effort into their research (i.e., become involved in patenting) to become more influential than their male colleagues. However, their recognition in top academic positions in the field could be fragile, and their recognition in top ranks are most susceptible to negative impacts (in this case: negative effects of internal citations).

Similar results are found when the level of funding is considered. Although women are required to show higher competency to raise high levels of funding, their title as a highly funded researcher might be altered because they are less productive and influential than men of the similar title.

Moreover, networking and increases in collaborations could potentially advantage highly-funded male researchers over women of the same title in terms of scientific production and impact, which could hinder the ability of women to raise further funding. These findings could explain the reasons behind women's lack of career progression in science and the persistence of glass ceiling and leaky pipeline phenomena in academia and shed light on the need to develop gender-related policies to support women's career advancements.

Another important contribution of this study is that it also focuses on gender-related cultural factors of nanotechnology research system. In this regard, this research found that patenting is associated with the higher productivity of those with difficulty in balancing personal and professional lives, both in general and for the particular case of dual-career couples. However, since this activity is highly male-dominated and might present more opportunities to men, policy reforms are required to explore mechanisms to eliminate the barriers women face in patenting. Furthermore, having difficulties in balancing work-life negatively affects the research impact of women who are not in tenured or tenure-track positions, which could work to the detriment of those female researchers, affecting their promotion or tenure-track hiring processes.

Another important contribution of this study is that it shows that highly cited women and men are not treated equally by their colleagues: highly cited women are treated poorly, while their male peers receive support and positive treatment from their colleagues. This is of great significance because this might result in isolation and exclusion of high impact female researchers from their peer group and thus leads to lower level of recognition in long-term, leaving women dealing with more difficulties in retaining their status as a highly cited researcher.

Nanotechnology is interdisciplinary and representation of women varies across nanotechnology fields. This research illuminates that in gender-balanced fields, researchers might be required to lead their publications more and work harder to be identified as highly productive researchers. This might be due to the fact that these researchers need to compensate gendered cultural differences between their workplace and their scientific community. Moreover, author self-citations is more associated with productive researchers across male-dominated fields than across gender-balanced fields, which might be related to the higher propensity of men to self-cite (King et al. 2016).

This research draws attention to the implementation of gender-inclusive policies. Because the findings reveal that lack of gender-inclusive culture could results in lower visibility, recognition and scientific impact of researchers. Most importantly, it reveals that gender-inclusive culture could provide more equitable context to reward scientists and boosts their productivity: this culture promotes the first-author production rather than patenting, which is easier for women to become involved.

5.1.3.3- Cross-dimensional analysis

This research also reflects cross-cutting relationships between the two primary inequality concerns around nanotechnology (pro-poor innovation and gender inequality), to analyze how the progress in pro-poor research and development could alter gender inequality in the R&D workforce. This study reveals that research and innovation in nanotechnology's three prioritized pro-poor application areas are highly male-dominated. Women account for 18.45% of total authorship and 11.3% of total inventorship. Moreover, companies that are involved in research and development of these pro-poor applications are active in highly male-dominated industries where women face high wage and employment gap in the workforce. Women are involved in lower impact (citation rate) papers and patents, compare to their male peers. However, when women are author-inventors, they contribute to higher impact publications and patents compared to male A-Is.

This study also provides insights into the gendered authorship practices and impact in pro-poor applications of nanotechnology. Female led-authored (first-authored) papers receive lower citation rates, although being published in higher impact-factor journals. This might suggest the presence of Matilda effect when women lead a research project, in the sense that women receive lower recognition for their scientific work as expected—i.e., expected rate of citations received by co-authoring papers with a higher number of researchers and publishing in higher ranked journals. However, when women are corresponding (or last authors), their papers receive equal (or higher) citation impact and is published in journals with equal (or slightly lower) ranks (SJR). This might be related to a selection effect, which asserts that women who reach senior positions in academia are required to be extremely competent and qualified; otherwise, they tend to leave the field.

This study provides a detailed analysis of collaboration patterns of researchers involved in pro-poor nanotechnology R&D across genders. It showed that women are as or more collaborative than their male peers in their networks of co-authorship and inventorship collaborations. It also looked into gender homophily in collaborations and found that collaborations with women are increasing over time in the authorship network. Nevertheless, single-gender collaborations are increasing in the inventorship network. This study revealed that women are involved in more gender-balanced authorship and inventorship collaboration teams, and argues that although scientists of both genders are more productive when involved in a mixed-gender team, more than 45% of male authors and 58% of male inventors collaborate exclusively with men. This is an important implication for policymakers to consider and support the aspect of collaboration with women in the development of gender-related and pro-poor policies.

5.1.4- Policy implications

Results of this PhD study are of great help to provide implications for policy design on: (1) how to encourage nanotechnology scientists to publish and patent in the pursuit of United Nations Sustainable Development Goals, (2) how to promote women's participation in nanotechnology publishing and patenting activities and how to promote collaboration with women (3) how to provide opportunities and enhance employment of women in nanotech-related sectors, and finally (4) how to change the gendered culture in academia and scientific workplaces in order to remove barriers for women as they attempt ascent to scientific eminence. These analyses also provide insights into the understanding of the role of the cross-cutting relationship between pro-poor technologies and gender equality in knowledge production, dissemination and utilization, upon which policy and business strategies to promote innovation within a more equitable economy can be developed.

Canada has been actively involved in international development initiatives, going back to the foundation of the Canadian International Development Agency (CIDA) in 1968 with the mission to manage Canada's international efforts to help people in poverty—which was lamentably merged into the Department of Foreign Affairs, Trade and Development in 2013. As a part of Canada's international development efforts, in 1970, Parliament of Canada established the International Development Research Centre (IDRC) with the mission of investment in knowledge, innovation, and solutions to improve livelihood in developing nations. Development Finance Institution was recently (in 2017) established with the main objective to support the contribution of private sector investment to development. These efforts accentuate Canada's great potential in aligning its research and development activities in support of the needs of developing countries and the Sustainable Development Goals. This study calls for the clear need to integrate pro-poor policies into the science and technology policy discourse in emerging fields in Canada.

However, this study informs policymakers on the importance of mainstreaming cross-cutting concerns. This study shows that pro-poor scientific and innovative efforts are highly male-dominated and women are disadvantaged both in their scientific community and market workforce.

Therefore, it is important that policymakers pay attention to both gender and pro-poor concerns simultaneously, because practices to increase pro-poor innovation might result in wider gender gap and adversely affect the social development. On the other hand, Canada's efforts to increase participation of women in science and technology is very limited and is confined to 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, none of which has a mere focus on gender initiatives. Moreover, NSERC's policies largely focus on participation rather than retention or progression of women in the science and engineering fields.

Canada's R&D efforts in nanotechnology is long established and prestigious, which are credited with founding the Centre for Advanced Nanotechnology at the University of Toronto in 1997, and National Research Council (NRC) institutes in Alberta, British Colombia, Quebec, and Ontario, introducing large institutions such as National Institute for Nanotechnology (NINT) and NanoQuébec (established in 2001). Despite all these efforts, initiatives to mainstream gender in nanotechnology R&D is nonexistent at national, institutional, and organizational levels. The results of this study have strong implications for policy development (or reform) targeting both gender equality and poverty alleviation in emerging interdisciplinary areas, promoting a more equitable and inclusive society.

5.2- Prospects for future research

This study incorporates the analysis of the gender dimension merely based on survey data analysis and modeling. Although regression modeling has its own merits and helps define important gendered aspects of scientific reward system in nanotechnology, it is also important to incorporate bibliometrics and social network analysis to better map gender disparities in nanotechnology in Canada (which in this research is only confined to cross-dimensional analysis).

This study focuses only on Canada. One promising research avenue is to conduct similar analyses for other countries and provide cross-country comparisons to better understand who is actively involved in the development of pro-poor innovation in nanotechnologies and how these developments differ across the globe. Another future research direction is related to the issue of inequity and diversity, including other underrepresentative groups (for example race, ethnicity, religion or economic background) to better understand how nanotechnology R&D could potentially offer solutions or exacerbate the existing inequities.

This study could also inform future studies around social sciences of other emerging technologies such as artificial intelligence and machine learning. Canada is attempting to become a leader in artificial intelligence, investing $125 million in Pan-Canadian Artificial Intelligence Strategy led by the Canadian Institute for Advanced Research (CIFAR)[27]. The investment will be devoted to three research centers—namely the Montreal Institute for Learning Algorithms (MILA), the Alberta Machine Intelligence Institute (AMII) in Edmonton, and the new Vector Institute for Artificial Intelligence, in Toronto—to engage more scientists and improve scientific excellence in this emerging field. However, studies around equity, equality and development challenges of this emerging technology are nascent but necessary. This research could potentially provide a baseline for these studies to address equity concerns of this emerging technology.

Last but not least, qualitative methods (e.g., interview and observation) provide necessary means to examine in more detail several dimensions of inequalities that may be caused by the development of nanotechnologies. These methods help better understand the findings drawn from bibliometric analysis of articles and patents, network and regression analysis, and will bring insights into why results gained through quantitative means occurred. These methods help provide answers to key questions arising from the analytical findings of this Ph.D. research: What are the key elements for scientists to get involved in publishing or patenting in the three pro-poor applications of nanotechnology – water, energy, and agri-food? Who do they define as the main beneficiaries of their research? What are the motivations behind initiating collaboration with other scientists? Are these authorship and inventorship collaborations motivated by the pursuit of new product development? What benefits do academic scientists (or inventors) obtain from their collaboration with industry (or academia)? What are the key elements for scientists to get involved in publishing or patenting? What are the strategies for coping or succeeding in male-dominant fields? How these responses vary among men and women scientists? And finally, what are the obstacles women face in their collaboration with other researchers that impede their scientific and technological productivity?

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[27] https://www.cifar.ca/assets/pan-canadian-artificial-intelligence-strategy-overview/

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