Canada’s Innovation landscape: Technological Diversity, Invention Ownership, and University Intellectual Property Policies

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

This thesis examines Canada's innovation landscape in three essays: the first identifies the patterns of innovation and technological diversification of Canada during the last three decades, the second identifies the ownership of Canadian inventions, and the third identifies the determinants of university funding in Canada.

The first essay examines the changing landscape of Canada's technological development and diversification based on the patent data filed in Canada and the United States by Canadian inventors for the period between 1980 and 2014. This is one of the first studies that compare the destinations of patents using both domestic and foreign patent databases. Using multiple databases can help explain the patenting behavior of domestic inventors and the technological landscape of a country in more detail. This study investigates the causes of any sharp increase or decrease in patenting trends in Canada and the United States. Moreover, it measures the technological diversification of various types of assignees by patent destination countries. Based on the patent data of Canadian inventors, the result of the study shows that although the number of patents increases, the diversity of technologies shrinks over time. Finally, the study focuses on innovation and technological diversification in census metropolitan areas of Canada. Canada's innovative activities concentrate in a few metropolitan areas, and diversity of technology varies across Canada.

Few recent studies (The Council of Canadian Academies, 2018; Gallini & Hollis, 2019) expressed concern that the foreign entities and foreign subsidiaries in Canada increasingly owned the Canadian invented patents. Motivated by the concern, the second essay investigates the ownership pattern of Canadian invented patents in a broader set of technology categories. Utilizing the USPTO patent data of Canadian inventors between

1976-2014, this study finds that the share of Canadian and foreign-owned patents varies by technology class, geographic origin, and types of assignees over time. Most of the shares of modern technologies, such as information technology is going to the hands of foreigners. Canadian invented patent with higher quality is also going to the hands of foreign assignees. This study also shows that the number of unassigned patents is declining over time due to the increase in Canadian patent quality in general.

In 2002, the Government of Canada released its innovation policy report, titled "Achieving Excellence," that emphasized on the commercialization potential of federally funded academic research (Government of Canada, 2002). To meet the government mandate, Canadian universities started to encourage their researchers to engage in projects with more commercialization potential (Langford et al., 2006; Bubela & Caulfield, 2010). Motivated by this observation, the third essay analyzes whether the number of patents can predict the amount of funding to universities. However, the technology commercialization effort of a university depends on which Intellectual Property (IP) ownership policy it follows. Canada does not have any unique Intellectual Ownership (IP) policy for its universities. Using the panel data of 54 Canadian universities between 2000 and 2012, this study addresses the following two questions: (i) does university intellectual property (IP) policy affect the number of patents generated by a university? And, (ii) does the number of patents affect the amount and sources of federal funding to universities? This study shows that inventor-owned IP ownership policy is the best for patent generation in Canadian universities. The results show that patents positively predict the amount and sources of funding. This study also finds that the amount of funding from the private sector is strongly affected by the number of patents.

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Dedication

To someone who loves me unconditionally.

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Chapter 1
Introduction

Innovation is the driving force of economic growth for any country (Adams, 1990; Mansfield, 1991; Romer, 1990). Innovation helps to improve productivity growth and ensure sustainable competitive advantages for businesses (Jenkins et al., 2011). Canada is the 18th most innovative country in the world in 2018 based on the Global Innovation Index (GII), although Canada remains in the 10th position in the innovation input sub-index of GII (Cornell University, INSEAD, & WIPO, 2018). The strength of Canada's input side of innovation, especially in institutions and market sophistication, makes Canada an attractive place for companies to conduct research; however, Canada is considered a less attractive country to convert the research output into commercially viable products (Council of Canadian Academies, 2018; Schwanen & Wyonch, 2018). As a result, Canadian inventors often sell their patents abroad rather than 'scaling-up' and commercialize their innovations (Gallini & Hollis, 2019). Motivated by the above observations, this thesis examines Canada's innovation landscape by utilizing approximately last three decades patents, which are granted to Canadian inventors by the US and Canadian patent offices, in three essays: the first identifies the patterns of innovation and technological diversification of Canada, the second identifies the ownership of Canadian inventions, and the third identifies the determinants of university funding in Canada.

1.1 Definition of Innovation and Patent Data

Most of the existing literature defines innovation as a process of generating new or improved knowledge that helps to increase a firm's performance (Teece, 1986; Rogers, 1998). Oslo Manual of the OECD (2018) defines innovation as "a new or improved product or process (or a combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)." The Oslo manual's definition of innovation covers a broad set of innovative activities that may be helpful for conducting an innovation survey. But this thesis focuses on patented innovations. Hence, the thesis defines innovation as an invention that can be exploited commercially (Martin, 1994; Sugheir et al., 2012).

Existing literature shows that there is no universal measure of innovation; each method has pros and cons (Pavitt, 1982; Griliches, 1990; Rogers, 1998; Mendonca et al.,2004). Various measures of innovation can group into input and output measures of innovation. Input measures of innovation include R&D expenditures, acquisition of technology, expenditure on new manufacturing set-up for new product development, intellectual property statistics, etc. Whereas, output measures of innovation include the introduction of a new product or process, firm performance based on a new product, intellectual property statistics, etc. All the measures of innovation are biased towards large firms except for patents. Interestingly some literature considers patent as an input measure of innovation (Griliches, 1990) and others as an output measure of innovation (Langford et al., 2006).

Patent data is the main data that appears in all three essays in this thesis. The patent system provides innovation incentives by rewarding R&D efforts through a monopoly right in exchange for full disclosure of the invention. To be granted a patent, the invention must be new, non-obvious, and useful. The patent process is costly and time-consuming. Hence, an applicant incurs the cost by applying for a patent when the applicant considers the invention as a valuable new knowledge that has commercial potential (Archibugi & Pianta, 1996). The grant of a patent confirms the newness of the invention and its potential usefulness. The thesis uses granted patent as a proxy of innovation, because, to be innovation, by definition, the invention has to be new and useful for its users, and the granted patents confirm the newness and usefulness of an invention that has commercialization potential. Patents help to expedite the commercialization of technologies that otherwise remain in the lab (Maine & Thomas, 2017).

Patent data have some limitations that include: (i) not all inventions are patented or patentable (Hall & Ziedonis, 2001), (ii) not all patented inventions become innovation (Cantwell & Vertova, 2004), (iii) the significance of patents differs greatly across firms, industries, and time (Silverman, 1999), (iv) incremental innovations are hardly patented (Puga & Trefler, 2010), and (v) difficult to identify which patent is valuable and which is negligible (Cantwell & Vertova, 2004). Moreover, complexities of patent data collection and changing nature of spatial and technological composition may create additional problems (Kuhn et al., 2019; Lerner & Seru, 2017). Despite all these disadvantages, patent data consider as a powerful indicator of technological output (Griliches, 1990; Audretsch, 1995; Gallini, 2017) and a fairly reliable measure of innovative activity (Acs et al., 2002). Patent data is highly relevant for this thesis since the data provide a longest-running historical record of technological activities (Cantwell & Vertova, 2014).

This thesis collects the bibliographic patent data from the Canadian Intellectual Property Office (CIPO) for the period between 1980 and 2014, and the United States Patent and Trademark Office (USPTO) for the period of 1976-2014. However, the use of the patent data varies in the three essays depending on the research questions. The bibliographic data includes such information as the application and grant dates, inventors' and assignees' name and address, the title of the patent, International Patent Classification (IPC) code, and so on. In addition to patent data, this thesis utilizes several other data sources that will explain in detail in the essays.

1.2 Innovation and Technological Diversification of Canada

The first essay analyzes Canada's technological landscape and its patterns of diversification using the patent data filed in Canada and the United States by Canadian inventors.

Inventors can patent their inventions anywhere in the world: some patents only in their home country, others in foreign countries, and still others in both home and foreign countries. Some technologies geared to domestic markets are likely to be patented only domestically, while other technologies with global reach are more likely to be patented in foreign countries, sometimes bypassing the domestic market. Given the diverse market and legal environments across countries, analyzing the innovation landscape of a country from a single patent data source may provide only a partial aspect of a country's technological capacity. As analyze in later sections, the top three technologies by Canadians are civil engineering, fine organic chemistry, and consumer goods if using the Canadian patent data. But, telecommunications, information technology, and measurement & control technologies if using the US patent data. Hence, if the research questions revolve around the landscape of a country's technological development, it is necessary to utilize both domestic and foreign data to get a comprehensive portrait.

Most of the existing literature utilizes patent data from a single source, either domestic or external, to represent the innovation activities of a country (Archibugi & Pianta, 1992; Cantwell & Vertova, 2004; Wang et al. 2015). Although few of the literature utilize multiple sources of data to represent a country's innovation activities (Paci et al., 1997; Licht and Zoz, 2000; Albuquerque, 2000; Guellec and Potterie, 2001), they did not observe whether the patents in multiple offices are same patents or not. As mentioned in page 18 of IP Canada Report 2017:

> “In 2015, Canadians filed for 19,857 patents abroad and 4,277 patents domestically. Note that the same invention may be counted more than one as Canadian will seek protection in the relevant markets for each of their patented inventions.”

This paper finds out the overlapping patents that are patented simultaneously in Canada and the US. From the patent databases of the United States Patent and Trademark Office (USPTO) and the Canadian Intellectual Property Office (CIPO), this study collects all patents by Canadian inventor from 1980 till 2014. This study first investigates the patterns of patenting in Canada and the United States by Canadian inventors during the period between 1980 and 2014, then classifies all patents into three categories: those that were granted only in the United States, those only in Canada and those in both the United States and Canada. Within each category, it further sorts out patents by applicant types (firm, university, government, and individual) and by 30 technology classes (Schmoch, 2008). This study also analyzes the innovative activities and technological diversification at the regional level by sorting the data based on the assignee’s address into thirty-three Census Metropolitan Areas (CMAs) of Canada.

This study provides several contributions to the current literature. First, this is one of a few studies which categorize patent data by destination countries: Canada-only, US-only, and Canada-US. By classifying them in different applicant and technology categories, this study can provide insights on how different types of inventors choose the destination of their patents. The second contribution of this study is to provide further methodological debates on whether a single source of data is enough to portray the true technological landscape of a country (Kim & Lee, 2015). This study highlights the differences in patenting behavior among technology and assignee categories and argues the importance of multiple sources of data. The third contribution of this study is to evaluate the technological diversifications of various types of assignees by destination countries. Technological diversification is important since it gives ‘economies of scope,’ and this study examines how Canadian technological capacity has diversified or concentrated during the past three decades, which may help shape Canadian innovation policy. Finally, this study evaluates technological diversification at the level of Census Metropolitan Areas (CMAs) to compare geographical differences in the technological capacity and pattern, which also provide policy insights on the choice of technology focus at the geographical levels.

The results of the study show that Canadian inventors patent more in the United States than in Canada. After identifying the patterns of patenting in the US and Canada by Canadian inventors during the period between 1980 and 2014, this study investigated the causes behind any sharp increase or decrease in patenting during that time. For instance, there was a surge in patenting in the United States by the Canadian inventor during the period between 1996 and 2001, which is parallel to the ‘explosion’ of the US patenting of that time (Kim & Marschke, 2004; Hall, 2005). Both Kim & Marschke (2004) and Hall (2005) identified that the growth of the US patents was largely due to the increased patenting in scientific instruments, electrical, pharmaceuticals, biotechnology, and computing technology sectors. Jaffe & Lerner (2006) argue that the rise of patenting in the US in the early 1990s was due to two reasons: (i) creation of the Court of Appeal, and (ii) change in the structure of fees and financing of the USPTO. These two reasons and expansion of patenting in new areas (biotechnology, software, and business models) stimulate an increase in patenting drastically of that time. Examining the US patent data by Canadian inventors, this study found that Canadian patenting patterns in the US followed the almost same trend during that time. Half of the USPTO granted patents to Canadians are related to the scientific instruments, electrical, pharmaceuticals, biotechnology, computing technology, and telecommunications. The study reveals different patenting trends in the US and Canada during the period between 2006 and 2009. While the surge of Canadian patenting muted during 2006 – 2009 in the United States, it continues to increase since 2000 in Canada. The surge of patenting in Canada during the period was possibly due to the reform of the Canadian patent act, improvement of management process due to the digitalization of the Canadian patent office, and hiring new patent examiners during the 1990s. The declining trend of patenting in the U.S. by Canadians in the early 2000s coincides with the decline in world economic output during that time (Nikzad, 2013). Since 2010, Canadian inventors patenting activity has rapidly increased in both home and abroad, but more sharply in the US due to telecommunications-related patents.

The results of the study also show that patenting behavior varies based on technology class and assignee type over time. For instance, Canadian inventors focus more on information technology in the United States, but on civil engineering in Canada. Another finding of this study is that Canada's technology diversification index is declining more rapidly in the United States than in Canada. These findings imply that using a single source of data may misrepresent a country's technological capacity and pattern. The analysis at the regional level of patent data reveals that Canada's innovative activity concentrates in a few large cities. Census Metropolitan Areas (CMA) of Toronto, Calgary, Montreal, Kitchener-Cambridge-Waterloo, Ottawa-Gatineau, Vancouver, and Edmonton accounts for 87.48% of all Canadian patents. Moreover, the technological composition and diversity vary significantly across the metropolitan areas of Canada. Large metropolitan areas, such as Toronto, Montreal, Vancouver, and Ottawa-Gatineau, are more diversified since innovative activities of those areas spread across many fields.

1.3 Ownership of Canadian Invention

The Council of Canadian Academies (2018) expressed concern that foreign assignees have increasingly owned the patents invented by Canadian inventors. The expert panel on the state of science and technology and industrial research and development in Canada expressed their concern in the following way:

> "The increasing flow of intellectual property out of Canada is also alarming. More patents are now invented in Canada than are owned in Canada. As a small, open economy, Canada is often an attractive place for companies to conduct R&D (or to procure its products such as patents and talented innovators). However, it is too often a less attractive place for developing and commercializing products, and growing companies with global reach. The end result is a loss of economic benefits and opportunities for Canada."

A study on Canada's patent strategy conducted by Gallini & Hollis (2019) confirmed the CCA's concern by showing that many patents that are granted to Canadian inventors by the USPTO are instantly assigned to foreign entities. According to Gallini & Hollis (2019):

> "Canadian innovation landscape is that most USPTO-granted patents attributed to at least one Canadian inventor are actually owned by foreign entities and foreign subsidiaries in Canada."

Both CCA (2018) and Gallini & Hollis (2019) use a limited number of technology classes and shorter periods of data to reach a conclusion about the ownership of Canadian invented patents. Moreover, they did not consider the quality of the patents. Although Beaudry & Schiffauerova (2011) consider the quality of the patents, their work only focuses on Canada's nanotechnology.

Motivated by the observations of CCA (2018) and Gallini & Hollis (2019), this study investigates the ownership pattern of Canadian invented patents in a broader set of technology categories. This study is important to investigate because foreign subsidiaries conducting scientific research in Canada are eligible for a scientific research and experimental development (SR&ED) tax credit program. Hence, Canadian invented patents owned by foreigners mean foreigners own fruits of Canadian tax-payers money. Using the USPTO patent data granted to Canadian inventors during the period between 1976 and 2014, this study focuses on three research questions. First, what is the temporal trend of the ownership of the patents invented by Canadians? Second, how does the ownership of technologies vary based on technology classes and assignee types? Third, how does the ownership pattern vary based on the geographic origin of the patents? Besides, this study also examines the quality of the Canadian patents that are owned by different assignees in the home or abroad.

The results of the study contribute in several ways. First, this study analyzes the ownership of Canadian patents by thirty technology categories and five types of assignees over time. This analysis can shed light on the type of technologies that are owned more by foreigners, and that have no assignees, which can help pinpoint Canada's strengths and weaknesses in various technology sectors. Second, this study considers all thirty-three census metropolitan areas of Canada to explain the geographic origin of inventions by Canadians that might be helpful for think about regional innovation policy.

This study shows that with the increasing number of inventions invented by Canadian inventors, the share of unassigned patents is declining over time. Compared to the shares in 1980, the share of patents of Canadian ownership increased by 37% and that of foreign ownership by 63% in 2014, while the share of unassigned patents decreased by 74%. This study also illustrates that while Canadian inventors are continuously creating new technologies, they fail to capitalize on the inventions by creating commercially attractive products and services, which is consistent with the argument by Trefler (1999). The quality of Canadian invented patents has been growing over time in all technology classes, which may explain the declining share of unassigned patents. However, better quality patents are increasingly owned by foreigners, especially in such technologies as information technology, telecommunications, optical, and electrical engineering. The study identifies that the highest share of foreign-owned patents is in the field of information technology, while Canadian ownership concentrates on traditional technologies such as civil, mechanical, and chemical engineering.

For the geographic clustering of patents in Canada, approximately 60% of all patents originated from the Census Metropolitan Areas (CMAs) of Toronto, Ottawa-Gatineau, Montreal, Vancouver, Kitchener-Cambridge-Waterloo, and Calgary. Among the top five CMAs based on the number of patents, Toronto has the highest share of foreign assignees, and Kitchener-Cambridge-Waterloo (KCW) has the highest share of local assignees. Approximately 80% of the KCW's patents are granted to Blackberry Limited by the USPTO. The paper also finds that the proportion of inventor-ownership varies according to the different types of assignees and the different composition of technologies. For instance, the highest share of foreign-firm owned patents are in the field of information technology, and that of foreign-university owned patents is in the field of the semiconductor. We find most unsigned patents in the field of consumer goods & equipment.

1.4 University IP Policy and Determinants of Funding

Universities have long been getting pressure to convert their research outputs into commercially suitable knowledge (Henderson et al., 1998). Today the transfer of research outcome from university to industry becomes a global trend as many governments try to reform their national innovation systems (Poyago-Theotoky et al., 2002; Rasmussen, 2008; Fini et al., 2017). In 2002, the Government of Canada released its innovation policy report, titled "Achieving Excellence," that emphasized on the commercialization potential of federally funded academic research (Government of Canada, 2002). Page 52 of that report focuses on the importance of commercialization of the publicly funded research:

> "Leverage the commercialization potential of publicly funded academic research. Support academic institutions in identifying intellectual property with commercial potential and forging partnerships with the private sector to commercialize research results. Academic institutions would be expected to manage the public investment in research as a strategic national asset by developing innovation strategies and reporting on commercialization outcomes…"

Moreover, in recent years, universities have been facing challenges to convert their research outputs into commercially appropriable knowledge due to budgetary pressures (Bolli & Somogyi, 2011). To meet the government mandate and solve financial problems, Canadian universities started to encourage their researchers to engage in projects with more commercialization potential (Langford et al., 2006; Bubela & Caulfield, 2010). Given this changed research focus in Canadian universities, an interesting research question is to analyze whether the number of patents can predict the amount of funding to universities. However, the technology commercialization effort of a university depends on which Intellectual Property (IP) ownership policy it follows. While some countries, such as the United States, the United Kingdom, Australia, and Japan, have a national policy on the university IP ownership, other countries, such as Canada does not have a uniform policy. As a result, universities in Canada are free to implement their policies (Robinson, 2006; Baere & Maine, 2017). Hence, some universities, such as the University of Waterloo and the University of Alberta, have inventor-owned IP policy, some have university-owned IP policy, such as the University of British Columbia and the University of Saskatchewan, and others have joint-owned IP policy, such as the University of Toronto and McGill University. Using the panel data of 54 Canadian universities for thirteen years between 2000 and 2012, this paper addresses the following two questions: (i) does university intellectual property (IP) policy affect the number of patents generated by a university? And, (ii) does the number of patents affect the amount and sources of federal funding to universities?

This study makes several contributions. First, this is one of the first studies which compares the impact of different kinds of IP ownership policies of Canadian universities to predict patenting behavior. The findings of this study may help policymakers decide about a uniform IP policy for Canadian universities that impacts more on technology commercialization. Second, this study investigates whether patents predict the amount of funding from different sources. University authorities might be benefited from the results of the study since it shows the usefulness of patenting for attracting funds. The results of the study show that the university's IP ownership policy has a significant impact on the number of patents generated by the university. According to the data of this study, the inventor-owned IP ownership policy is the best predictor of the number of patents generated by a university. Commercialization of university research needs incentives (Zucker & Darby, 1996); the inventor-owned IP policy provides more incentives because inventors enjoy more freedom than other IP policies. The number of patents positively predicts Tri-council funding to universities. Among the Tri-council agencies, funding from the Canadian Institutes of Health Research (CIHR) and the Natural Sciences and Engineering Research Council (NSERC) are strongly affected by the number of patents, and the funding of Canada Foundation for Innovation (CFI) and Canada Research Chair (CRC) is somewhat positively affected by the number of patents. This study also finds that private donations are increased most by the number of patents, and universities with less than four patents are negatively related to private funding. This study suggests that the number of patents is particularly important to get funds from the private sector.

This thesis is structured as follows: section 2 includes the essay on innovation and technological diversification of Canada; section 3 consists of the essay on the ownership of Canadian invention; section 4 focuses on the essay on whether university IP policy and patents determinate the funding to Canadian universities, and section 5 includes conclusion of the thesis.

Chapter 2
Innovation and Technology Diversification of Canada

2.1 Introduction

This thesis analyzes the changing environments of Canada's technological landscape and its patterns of diversification using the patent data filed in Canada and the United States by Canadian inventors. There exists an extensive list of literatures which use patent data to analyze the patterns of innovation activities at the country level (Archibugi & Pianta, 1992, Cantwell & Vertova, 2004), regional level (Acs et al., 2002; Apa et al., 2018), and firm-level (Gemba & Kodama, 2001; Kim el. al., 2016). Many of these studies, however, examine patent data from a single source, mostly from an individual country's patent database, US patent database or European patent database (Paci et al., 1997; Licht & Zoz, 2000; Albuquerque, 2000; Guellec & Potterie, 2001). Given the diverse market and legal environments across countries, analyzing the technological pattern and patenting behavior from a single source may provide only a partial aspect of a country's technological capacity. One of the objectives of this thesis is to portray a technological landscape and patenting behavior of Canadian inventors using two sources of patent data, Canada and the United States.

Inventors can patent their inventions anywhere in the world: some patents only in their home country, others in foreign countries, and still others in both home and foreign countries. The decision to apply for patents in different jurisdictions depends on many factors such as market size, legal environments, imitation risks, invention quality, competitive level, and institutional aspects (Eto & Lee, 1993; Eaton & Kortum, 1996; Paci et al., 1997; Hu, 2010; Archontakis & Varsakelis, 2017; Beneito et al., 2018). Some technologies geared to domestic markets are likely to be patented only domestically, while other technologies with global reach are more likely to be patented in foreign countries, sometimes bypassing the domestic market. If the research questions revolve around the landscape of a country's technological development and diversification, it is necessary to utilize both domestic and foreign data to get a comprehensive portrait. To the best of our knowledge, existing literature ignored this aspect when evaluating a country's innovation portfolio, and this study evaluates Canadian inventors' patenting decisions on the target country.

From the patent database of the United States Patent and Trademark Office (USPTO) and the Canadian Intellectual Property Office (CIPO), this study collects all patents by Canadian inventor from 1980 till 2014. This study first classifies all patents into three categories: those that were granted only in the United States, those only in Canada, and those in both the United States and Canada. Within each category, it further sorts out patents by applicant types (firm, university, government, and individual) and by 30 technology classes (Schmoch, 2008). With the CIPO database, this study also analyzes the innovative activities and technological diversification at the regional level by sorting the data based on the assignee's address into thirty-three Census Metropolitan Areas (CMAs) of Canada.

This study provides several contributions to the current literature. First, this is one of a few studies which categorize patent data by destination countries: Canada-only, US-only, and Canada-US. By classifying them in different applicant and technology categories, this study can provide insights on how different types of inventors choose the destination of their patents. The second contribution of this study is to provide further methodological debates on whether a single source of data is enough to portray the true technological landscape of a country (Kim & Lee, 2015). This study highlights the differences in patenting behavior among categories and argues the importance of multiple sources of data. The third contribution of this study is to evaluate the technological diversifications of various types of assignees by destination countries. Technological diversification is important since it gives ‘economies of scope,’ and this study examines how Canadian technological capacity has diversified or concentrated during the past three decades, which may help shape Canadian innovation policy. Finally, this study evaluates technological diversification at the level of Census Metropolitan Areas (CMAs) to compare geographical differences in the technological capacity and pattern, which also provide policy insights on the choice of technology focus at the geographical levels.

This study finds that Canadian inventors patent more in the United States than in Canada. A total of 53,989 patents granted in Canada and 63,613 in the United States. Among these patents, 19957 granted in both countries. This study also shows that Canadian inventors focus more on telecommunications and information technology in the United States, but on civil engineering and telecommunications in Canada. This finding implies that using a single source of data may misrepresent a country’s technological capacity and pattern. Another finding of this study is that technology diversification is declining more rapidly in the United States than in Canada. When pursuing a foreign patent, inventors should consider the cost and focus only on a few technological fields. The analysis at the regional level reveals that (i) patenting activity has been increased in the Canadian CMAs during the past few decades, (ii) only 10% of the regions of the CMAs accounts for 60% of the all Canadian patents granted by the CIPO, and (iii) the technological composition varies significantly across the CMAs. Moreover, the analysis shows that large metropolitan areas, such as Toronto, Montreal, Vancouver, and Ottawa-Gatineau, are more diversified since innovative activities of those areas spread across many fields.

This paper is structured as follows: section 2.2 presents the literature review; section 2.3 explains the data and diversification measure; section 2.4 presents and discusses the results; and section 2.5 presents conclusions.

2.2 Theoretical Background and Contributions

This paper is related to two streams of literature: One being the changing composition of the technological landscape and the other being the technological diversification. Most literature on the technological landscape of a country utilizes a single source of patent data, either from the domestic data or from foreign patent data such as US data or the European patent data. Trajtenberg (2001) analyzes Israel's technological composition and innovation landscape relative to other countries by utilizing the patent data from the USPTO. Jacobsson & Philipson (1996) analyze the strength of the Swedish technological landscape with the patent data collected by the Science Policy Research Unit of the United States. Hicks et al. (2001) examine the geographic composition of innovative activities, and the growth of university patenting with the US invented USPTO patents.

Regarding the technological landscape, a few kinds of literature explain the reason behind the recent surge in patent and the changing pattern of the technological composition of a country. To the best of our knowledge, Kortum & Lerner (1999) are one of the early studies which argue that the rise of patenting in the US in the early 1980s was due to the increase in research productivity spurred by the better management of technology. Gallini (2002) mention that the surge in patenting activity during the 1980s and 1990s due to strengthening in the US patent system in three ways: introducing new patentable subject matters, providing more power to patent holder related to infringement lawsuits, and lengthening patent life. Jaffe & Lerner (2006) argue that the rise of patenting in the US in the early 1990s was due to two reasons: (i) creation of the Court of

Appeal, and (ii) change in the structure of fees and financing of the USPTO. These two reasons and expansion of patenting in new areas (biotechnology, software, and business models) stimulate an increase in patenting drastically of that time. Kim & Marschke (2004) and Hall (2005) also explore that the increase in patenting during the period between 1983 and 2000 was due to a few technology areas such as information technology and electrical and computer-related technologies. Canadian patenting pattern in the US follows nearly the same path during the past few decades.

Only a few studies utilize multiple sources of data to examine a country's innovative activity. Comparing domestic and foreign patent data of six industrialized countries, Paci et al. (1997) observed that while domestic patenting provides a broader measure of innovative activity of a country, foreign patenting shows the technological excellence of that country. With firm-level German inventions filed in the German, European, and US patent offices, Licht & Zoz (2000) found that large firms tend to patent in multiple countries and small firms only in the domestic country. In the study of Brazil's innovative activities with the domestic and US patent database, Albuquerque (2000) show the patterns of patent activities by assignee types and technology areas are significantly different between the two datasets. Most of these studies use either the USPTO data or EPO data for cross-country analysis of the innovation activities, due to their reliability and ease of access.

The second stream of literature related to this study is the pattern of technology diversification at a country level. Technological diversification can define as the spread of innovative activities in more than one technology (Breschi & Malerba, 2003) or the expansion of technology base into wider technological fields (Laten et al., 2007; Wang et al., 2016). The majority of the existing literature focuses on technological diversification at the firm level. Some literature shows positive effects of technological diversification in terms of economies of scope, sharing of knowledge, reduction of risks, and greater rent in the market (Granstrand, 1998; Suzuki & Kodama, 2004; Miller, 2006; Kim et al., 2016). Few other pieces of literature show its negative impacts, such as increased coordination costs and uncertainty due to unfamiliar activities (Granstrand & Oskarsson, 1994; Garcia-Vega, 2006). Still, a few pieces of literature show mixed views by finding an inverted U-shaped relationship between technological diversification and innovation activities (Leten et al., 2007; Huang & Chen; 2010, Kim et al., 2016).

A few kinds of literature examine the technology diversification with patent data at the regional level (Sun, 2000; Fornahl & Brenner, 2009; Boschma et al., 2014; Lengyel et al., 2015; Wang et al., 2016, Apa et al., 2018), and the consistent result from these works of literature is that innovation activities concentrate in only a few locations. Wang et al. (2016) show a positive relationship between technological diversification and regional innovation capacity. Apa et al. (2018) find that technological diversification negatively affects the intensity of regional technological progress. Analyzing 269 European regions for the period of 1996-2012, they show that technological relatedness positively affects a region's technological progress. Analyzing the USPTO patent data related to 366 US cities during the period between 1976-2010, Boschma et al. (2014) show that the entry probability of new technologies in a city depends on relatedness with existing technologies.

Only a few studies have focused on technological diversification at the country level (Archibugi & Pianta, 1992; Cantwell & Vertova, 2004; Wang et al., 2015). These studies find a positive relationship between national technological size, in terms of a number of patents, and technological diversification. Archibugi & Pianta (1992) and Cantwell & Vertova (2004) show that large countries diversify their technological activities across many fields relative to smaller countries. However, Cantwell & Vertova (2004) argue that the nature of the relationship between national technological size and diversification adversely affected due to the internationalization of R&D by multinational enterprises. In a recent work on the relationship between national technological size and diversification, Wang et al. (2015) observed the positive relationship between technological size and diversification, however, found structural shifts of Chinese technological focus from traditional such as consumer goods to modern sectors such as electronics and computing.

2.3 Data and Diversification Measure

2.3.1 Patent Database

This study utilizes the bibliographic information of the patent database (Archibugi & Pianta, 1992; Chen & Chang, 2012; Wang et al., 2015). The patent system provides innovation incentives by rewarding R&D efforts through a monopoly right in exchange for full disclosure of the invention. To be granted a patent, the invention has to be new, non-obvious, and useful. Patent data are a powerful indicator of technological output (Griliches, 1990; Audretsch, 1995) and a fairly reliable measure of innovative activity (Acs et al., 2002). Patent data provide information on technological areas in the form of international patent classification (IPC) codes (Quintana-Garcia & Benavides-Velasco, 2008; Acosta et al., 2018; Malerba & Orsenigo, 1999). However, a few limitations of the patent data include: (i) not all inventions are patented or patentable (Hall & Ziedonis, 2001), (ii) the significance of patents differs greatly across firms, industries, and time (Silverman, 1999), and (iii) incremental innovations are hardly patented (Puga & Trefler, 2010).

This study collects bibliographic patent data from the Canadian Intellectual Property Office (CIPO) and the United States Patent and Trademark Office (USPTO). The bibliographic data includes such information as the application and grant dates, inventors' and assignees' name and address, the title of the patent, IPC code, and so on. To focus on the behavior of Canadian inventors, first, we collected the patents in which the inventor's address in Canada. Second, we screened the patents whose assignee's address in Canada and whose patent granted between 1980 and 2014. From the CIPO data, we selected a total of 53,989 patents and from the USPTO data, we select a total of 63,613 patents using the following criteria: (i) the patent grant year is between 1980 and 2014, and (ii) any of the assignees of a patent is Canadian. Hence, we eliminated the patents that do not have any assignee names. Finally, we classified each patent into the firm, university, government, and individual based on the first assignee's name (see Table 2.1).

Each patent contains one or more technology field codes, known as the International Patent Classification (IPC) code. The IPC code is a hierarchical system of classifying technology areas of a patent and is used in more than 100 countries for classifying patent documents (WIPO, 2018). The structure of IPC codes consists of 8 sections at the 1-digit level, and 131 classes at the 3-digit level. Technology literature uses several classification methods of technological areas: 1-digit IPC codes (Noruzi & Abdekhoda, 2012), 3-digit IPC codes (Leydesdorff et. al., 2014; Yan & Luo, 2017), 4-digit IPC codes (Huang & Chen, 2010; Chen et.al., 2010), FhG-ISI's 28 technology classification (Grupp & Schmoch, 1992; Engelsman & Raan, 1994), WIPO's 35 technology categories (Picci & Savorelli, 2013), and OECD's 30 technology categories (Breschi

& Malerba, 2003; Leten et. al., 2007). This study mainly uses the 30 technology categories (see Appendix A) (Schmoch, 2008), and the 3-digit and 4-digit IPC codes for comparisons.

The number of Canadian inventions filed in Canada is significantly different from that in the United States, implying that some patents are filed only in one country. To investigate the phenomenon, we classify all patents into one of three groups: Canada only patents, US only patents, and "matched" patents which filed in both countries. To find the matched patents, we first create a single dataset by combining the CIPO and the USPTO patent data with a total of 117,602 patents (53,989 CIPO data and 63,613 USPTO data). We then standardize 'invention title,' 'assignee name,' 'city name of the first assignee,' and 'first inventor's name' in the both datasets (Breschi & Catalini, 2010), which involving manual checking (Nelson, 2009) and browsing the internet (Sterzi, 2013) to confirm about the inventor and assignee names if necessary. Finally, we applied the STATA procedure 'dup' to find out the matched patents based on 'invention title,' 'assignee name,' 'city name of the first assignee,' 'first inventor's name,' and 'first inventor's country name.' This procedure leads to a total of 19,957 matched patents, 34,032 Canada only patents, and 43,656 US only patents. (See table 2-1)

Table 2-1: Distribution of Canadian Invented Patents by Assignee Type, 1980-2014

Destination	**Only Canada**		**Only US**		**Both Canada & US**	
Assignee	No. of patents	% Share	No. of patents	% Share	No. of patents	% Share
Firm	22012	64.68	38872	89.04	16854	84.45
University	415	1.22	2473	5.66	706	3.54
Government	670	1.97	1561	3.58	1004	5.03
Individual	10935	32.13	750	1.72	1393	6.98
Total	34032	100	43656	100	19957	100

2.3.2 Diversification Measure

Two kinds of diversification measures observe in the literature: continuous measure and categorical measure (Hall & John, 1994). The continuous measure of diversification includes product count measure and entropy measure of diversification. The product count measure of diversification (Gort, 1962; Rhoades, 1973) primarily based on the Standard Industrial Classification (SIC) system. The SIC system categorizes all industries into 11 divisions at the one-digit level, 83 major groups at the two-digit level, 416 industry groups at the three-digit level, and 1005 industries at the 4-digit level. The product count measure helps to measure the diversification objectively and quickly. However, it is difficult to classify firms in 2 or 3-digit levels in some industries. Moreover, the distance between SIC numbers cannot interpret as a measure of relation that is ‘numerical difference cannot be interpreted on an interval or ratio scale’ (Montgomery, 1982; Martin & Sayrak, 2003).

Rudolf Clausius first developed the entropy concept in 1865 for thermodynamics and later used in information and communication (Shannon, 1948) and economics (Theil 1967). Jacquemin & Berry (1979) proposed the entropy measure of diversification to analyze the relationship between diversification and corporate growth. Subsequent studies use the entropy measure to calculate diversification score and show how the score is related to firms' performance (Palepu, 1985; Kodama, 1986; Grant et al., 1988, Davis & Duhaime, 1992; Chatterjee & Blocher, 1992; Gemba & Kodama, 2001). Jacquemin & Berry (1979) argues that the entropy measure provides analytically clear and simple decomposition technique (Jacquemin & Berry 1979), and Hoskisson et al. (1993) showed relative effectiveness of entropy measure over Rumelt's categorical measure in terms of accounting and market.

The categorical measure of diversification was introduced by Rumelt (1974) to overcome the problems of product count measure. The categorical measure focuses on individual firms and their unique pattern of diversification. Rumelt used a classification system consisting of four kinds of business areas with ten diversification categories, which based on quantitative and subjective criteria. Assignment of a firm to a diversified category based on the percentage of the firm's total sales in a discrete business area. While some policy researchers strongly support the Rumelt's categorization process due to its strong conceptual framework, others raise a question about the method's reliability due to subjective judgments in categorizing business areas (Montgomery, 1982, Hall & John, 1994).

This study uses the entropy measure to analyze technological diversification. The entropy measure of technology diversification define as

$$Entropy = \sum_{i=1}^{n} \left(P_i * ln(1/P_i)\right), \qquad where\ P_i \neq 0$$

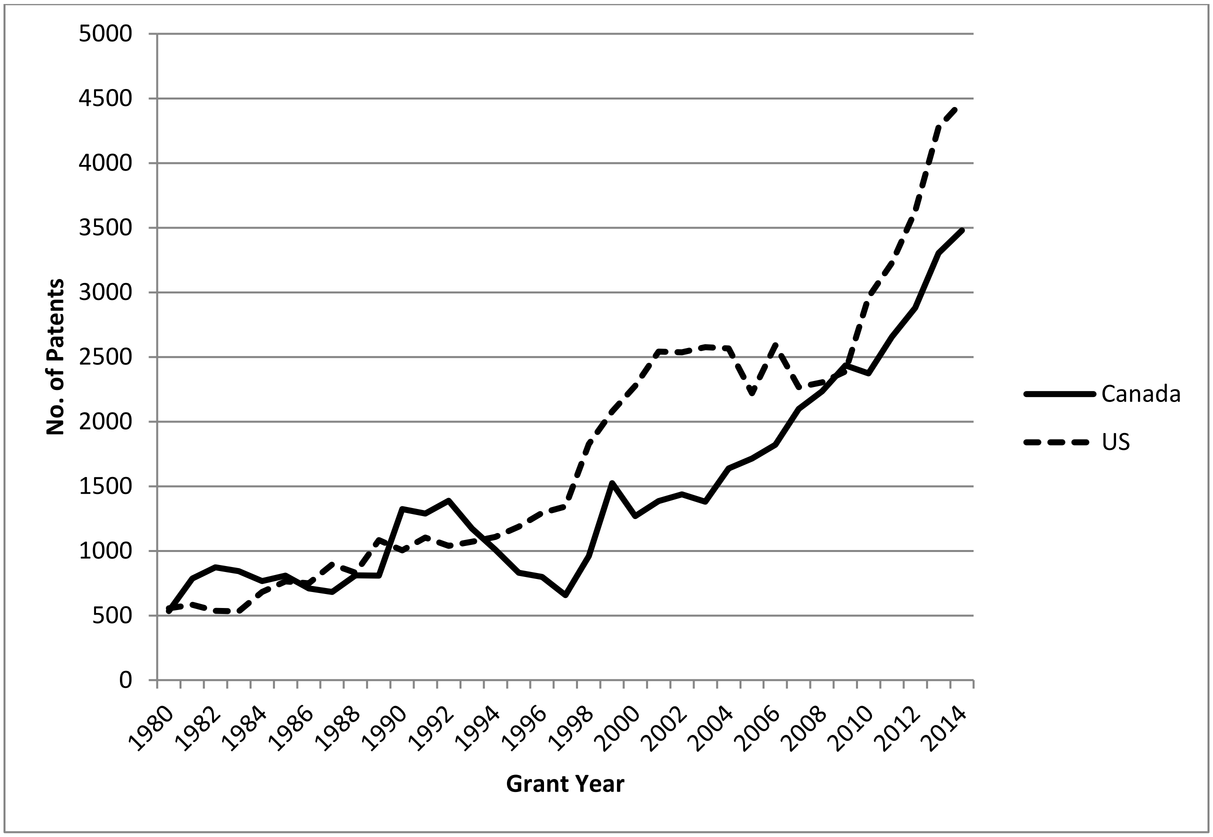
P_i is the number of patents attributed to technology area i and $ln(1/P_i)$ is the weight given to each technology area. The measure considers both the number of technology areas in which an assignee (i.e., firm, government, university, or individual) operates and the frequency of total patents each technology area represents. The value of entropy measure varies between 0 to $ln\, n$, where 0 means concentration on one technology and $ln\, n$ means the equally distributed weight among the maximum possible technologies. The above entropy equation is attractive because it considers two aspects of diversification: (i) the number of technologies in which a country or city or firm or any other entity operates; and (ii) the relative importance of each of the technology category in terms of patents. However, the problem of the above entropy measure is that firms with diversified technological portfolios might have the same diversification scores. To solve the problem, Raghunathan (1995) proposed a refined entropy measure of diversification that helps to decompose unrated and unrelated technological diversification.

2.4 Results and Implications

2.4.1 Changing Composition of Innovation Activity in Canada

The top three international destinations of Canadian patents were the United States (66% of the total foreign filing), the European Union (8%), and China (5%) in 2015 (IP Canada Report, 2017). Figure 2-1 compares the annual patent granted to Canadian inventors by the United States and Canadian patent offices. The number of granted patents increases over time, and Canadian inventors patent more in the United States than in Canada. There was a surge in patenting in the United States by the Canadian inventor during the period between 1996 and 2001, which is parallel to the ‘explosion’ of the US patenting since 1984 (Kim & Marschke, 2004; Hall, 2005). Both Kim & Marschke (2004) and Hall (2005) identified that the growth of the US patents was largely due to the increased patenting in scientific instruments, electrical, pharmaceuticals, biotechnology, and computing technology sectors. Examining the US patent data by Canadian inventors, we see that about half of the patents are related to the technology, as mentioned above, and telecommunications. A high level of economic integration between the two countries may stimulate Canadians’ patenting surge in the United States (Trajtenberg, 2000). Moreover, Canada’s high-tech sectors lag the US rate of new technology creation and commercialization (Trefler, 1999) that possibly another reason behind more patenting in the US.

Figure 2-1: Patent Granted to Canadian Inventors by the US and Canadian Patent Offices, 1980-2014



During the period between 2000 and 2014, a total of 43,176 patents (54.94 %) granted in the United States, but only 35,415 patents (45.06 %) in Canada. The increasing pattern of patenting in the United States can be explained, generally, by a large U.S. market size, and geographical & cultural proximity between the countries. The United States is the primary market for Canadian exports. In 2017, 73% of Canada's total export went to the United States with a value of $377 billion (Observatory of Economic Complexity, 2019).

Careful observation of Figure 2-1 reveals different patenting trends during the period between 2006 and 2009. While the surge in patenting muted during 2006 – 2009 in the United States, it continues to increase since 2000 in Canada, possibly due to the reform of Canadian patent act, improvement of management process due to digitalization of the Canadian patent office and hiring new patents examiners during the 1990s (see Table 2-2). The declining trend of patenting in the U.S. by Canadians in the early 2000s coincides with the decline in world economic output during that time (Nikzad, 2013). As a result of the 'great recession' in the early 2010s, Canadian exports to the US dropped significantly during that period. In 2009, the GDP growth rate of the world[1] and that of the G7 countries decreased by 10.76% and 13.58%, respectively, compared to that of 2006; and the rate of US import[2] from Canada was decreased by 37.51%. In the same period, the growth rate of the Canadian patent in the US decreased by 13.02%. This result reminds the works of Yang & Kuo (2008), who showed that a country's international patenting influenced by trade-related aspects, such as exports and foreign direct investment.

Since 2010, Canadian inventors patenting activity has rapidly increased in both home and abroad, but more sharply in the US due to telecommunications-related patents. More than 50% (17, 282) of all telecommunications patents granted during the period between 2008 and 2014 by the USPTO. During the period between 1993 and 1997, we observed the declining trend of patenting in Canada, and, then, it started increasing rapidly. Canadian patent office had gone through several reforms in the 1990s. In 1989 Canada reformed the Canadian Patent Act (CPA) so that it helps to expedite the international patent practices that arose from the 1989's Free Trade Agreement between Canada and the US. The CPA adopted several inclusions, notably the filing of International Patent Cooperation Treaty (PCT) applications in Canada, and granting a patent based on the 'first-to-file' an application in Canada or a priority country. In 1989, CIPO also adopted the International Classification System (IPC), which originated from the Strasbourg

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[1] Calculated from the data available in the World Economic Outlook of International Monetary Fund (source: https://www.imf.org/external/datamapper/NGDPD@WEO/OEMDC/ADVEC/WEOWORLD/CAN)
[2] Calculated from the data available in the United States Census Bureau (source: https://www.census.gov/foreign-trade/balance/c1220.html)

Agreement of 1971. Moreover, in 1994, the North American Free Trade Agreement (NAFTA) included provisions for strengthening patent protection in Canada.

Table 2-2: Major Changes in the Canadian Patent Systems during 1985-2000

Year	Event
1985	Canadian Government Program Review launched to review all federal programs to minimize the cost that Identified duplication between Canadian and foreign patent office examination process
1986	Federal Fund approved to automate the Canadian Patent Office
1986	The US proposed the creation of the North American Patent Office based on the model of the European patent office
1989	Free Trade Area agreement between Canada and the US
1989	The Canada Patent Act reform that provides many things, including • filing of International Patent Cooperation Treaty (PCT) application in Canada, • granting patents based on the first-to-file application in Canada or a priority country
1989	CIPO adopted the International Classification System (IPC)
1992	CIPO initiated a project to automate Canada's patent system
1994	North American Free Trade Agreement (NAFTA) included provisions for strengthening patent protection in Canada
1997	The electronic patent system launched
1999	Online patent filing launched

Note: The information of this table collected from the works of McMaster (2007) and the Annual Reports of the Canadian Patent Office during the period between 1995 and 2004.

In 1992, the CIPO initiated a project known as 'Project TechSource' to automate Canada's patent office in harmony with the trilateral automation projects of the US, Japan, and the European patent offices. The implement of the TechSource project lasts for nine years (1992-2000). To adapt to the new system, the CIPO staff needed the required training, which runs for two years and completed at the end of March 1997 (CIPO Annual Report 1996-1997). During the period between 1993 and 1996, CIPO faced a shortage of staff who have both IT and patent-related skills; moreover, PCT patent administration procedures made the overall patenting process complicated (McMaster, 2007). As a result, during the period between 1993 and 1997 patent granting process became slower; however, it started increasing since then due to the inception of automation of CIPO in June 1997.

The composition of technologies between the Canadian patenting in the US and Canada varies (see Appendices B and C). Table 2-3 shows the dominance of information technology, telecommunications, biotechnology, and pharmaceuticals related patents in the US. Those four technologies contributed to approximately 54% of the total patent increase in the US during the period between 1997 and 2014. If we look at Canada during the same period, we see the dominance of civil related patents. We observe the negative change in patenting of organic-fine-chemistry and macromolecular-chemistry-polymer in Canada; whereas, positive change in the same technologies in the US. Out of 30 technologies, only six technologies had a faster growth rate than the average in the US and ten technologies in Canada during the period between 1980-1996 and 1997-2014. The evidence presented in Table 2-3 suggests us technological composition differs in both destinations over time. Hence, relying on a single source of data to portray a country's technological landscape is misleading.

Separating the patents granted in both Canada and the US, this study shows that what kind of assignees with which technologies are patenting more only in Canada or only in the US. Table 2-1 shows that the share of patents at various destinations. Compare to that of only Canada; we observe a higher number of patents in the only US in all assignee categories except for individual categories. We find that 19957 (37%) patents that granted in Canada, also granted in the United States. Compare to patenting in only Canada, 28.28% (9624) more inventors patent only in the United States.

Table 2-3: Changing Composition of Innovative Activity of Canada

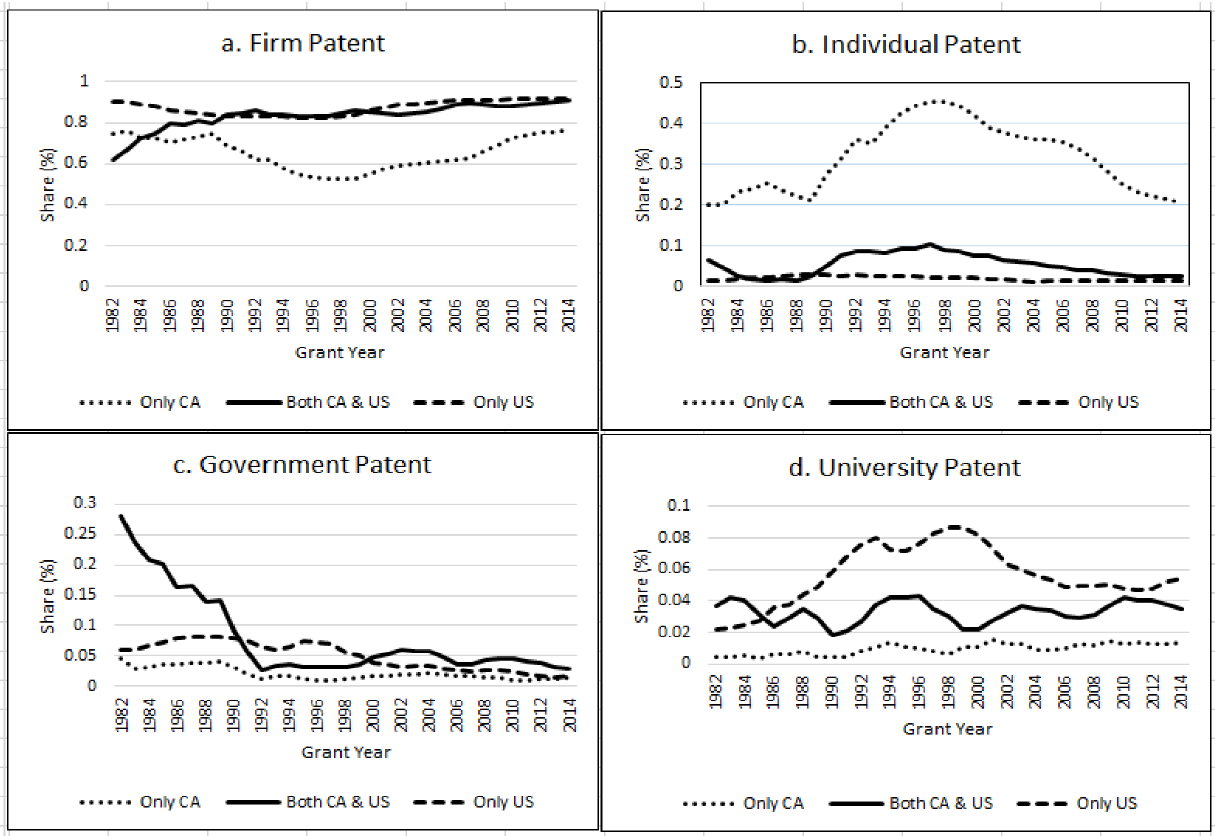
Technology Class	CANADA				United States			
	No. of Technology*		% change	Share of total change	No. of Technology*		% change	Share of total change
	1980-1996	1997-2014			1980-1996	1997-2014		
Agriculture	1110	2732	146.13	1.09	524	930	77.48	0.36
Audio-visual	1270	3882	205.67	1.76	900	4806	434.00	3.44
Biotechnology	1322	7169	442.28	3.94	1302	9054	595.39	6.83
Chemical	4776	9580	100.59	3.24	2092	3948	88.72	1.63
Civil	6977	26224	275.86	12.97	2524	5678	124.96	2.78
Consumer	4931	13324	170.21	5.65	2476	5036	103.39	2.26
Control	5492	14968	172.54	6.38	3326	10062	202.53	5.93
Electrical	4428	10980	147.97	4.41	2808	7916	181.91	4.50
Engine	1317	6843	419.59	3.72	678	3574	427.14	2.55
Environmental	911	3204	251.70	1.54	466	1082	132.19	0.54
Food	1946	5944	205.45	2.69	920	2430	164.13	1.33
Hauling	3141	8825	180.96	3.83	2546	3868	51.92	1.16
Heat	1783	4634	159.90	1.92	834	1270	52.28	0.38
IT	785	10177	1196.43	6.33	742	19308	2502.16	16.35
Machine	2417	6053	150.43	2.45	1344	2690	100.15	1.19
Material	4423	7704	74.18	2.21	1996	3704	85.57	1.50
Mechanical	2220	7669	245.45	3.67	1436	2934	104.32	1.32
Medical	1574	7991	407.69	4.32	996	4316	333.33	2.92
Metallurgy	3070	5957	94.04	1.95	2066	2476	19.85	0.36
Nuclear	201	543	170.15	0.23	168	358	113.10	0.17
Optics	1558	3915	151.28	1.59	1038	3794	265.51	2.43
Organic	10188	6291	-38.25	-2.63	1480	5194	250.95	3.27
Petroleum	5966	6139	2.90	0.12	1060	2610	146.23	1.37
Pharmaceuticals	1513	11230	642.23	6.55	1518	10058	562.58	7.52
Polymer	5695	4765	-16.33	-0.63	1230	1466	19.19	0.21
Semiconductor	557	1127	102.33	0.38	480	1556	224.17	0.95
Space	903	1051	16.39	0.10	342	414	21.05	0.06
Surface	1922	3433	78.62	1.02	1944	2744	41.15	0.70
Telecom	3601	24387	577.23	14.00	2872	28800	902.79	22.84
Transportation	2872	10554	267.48	5.18	1400	4956	254.00	3.13
Total	88869	237295	167.02	100.00	43508	157032	260.93	100.00

Note: * No. of technology is based on the International Patent Classification (IPC) Codes embedded on the patents granted by Canadian & the US patent offices to the Canadian inventors. Each of the granted patents has one or more International Patent Classification (IPC) codes. Each IPC code represents the technology class (see Appendix A) that is assigned to a patent by the patent examiners. Since each patent embedded with one or more IPC code(s), the number of technologies is greater than the number of patents.

Figure 2-2 shows the patenting trend in Canada and the US more clearly. The figure shows that the share of government and individual patents are declining both in Canada and the US over time. The share of firm patents is increasing in both countries, although increasing rapidly in the

US. The share of university patents is rising in the US, whereas declining in Canada. Share of patenting in both countries together are increasing over-time at firm-level patents; whereas, declining in the other areas.

Figure 2-2: Share of Patenting by Type of Assignee & Patent Destination, 1980-2014



Now, the obvious questions are, what kind of Canadian invented technologies are patented more in only the US, what kind only in Canada, and what kind in both countries? Table 2-4 gives us answers to these questions. If we compare the top three technologies in the US and Canada, we see completely different technologies dominate in each destination. Both tables 2-3 and 2-4 and figure 2-2 prove our hypothesis that more than one data sources provide a more accurate portrait of a country's innovative activities than rely on a single source.

Table 2-4: Canadian Invented Technologies by Patent Destination Country

Both Canada & US Patents			**Only Canada Patents**			**Only US patents**		
Technology Class*	**No. of Technology**	**Share (%)**	**Technology Class***	**No. of Technology**	**Share (%)**	**Technology Class***	**Number of Technology**	**Share (%)**
Telecom	17638	14.53	Civil	25016	12.23	Telecom	11912	16.65
Control	8316	6.85	Organic	13088	6.40	IT	8020	11.21
Civil	8185	6.74	Consumer	12796	6.25	Control	4798	6.71
Electrical	7097	5.85	Control	12144	5.94	Pharmaceuticals	4693	6.56
IT	5676	4.68	Telecom	10350	5.06	Biotechnology	4267	5.96
Consumer	5458	4.50	Petroleum	10052	4.91	Electrical	3732	5.22
Transportation	5411	4.46	Chemical	9859	4.82	Organic	2653	3.71
Pharmaceuticals	5132	4.23	Polymer	8493	4.15	Consumer	2372	3.32
Hauling	4567	3.76	Electrical	8307	4.06	Civil	2239	3.13
Chemical	4497	3.70	Material	8180	4.00	Audio-visual	2230	3.12
Others	49423	40.69	Others	86323	42.19	Others	24630	34.4
Total	121400	100	Total	204608	100	Total	71546	100

Note: * Technology class is based on the International Patent Classification (IPC) Codes embedded on the patents granted by Canadian & the US patent offices to the Canadian inventors. Each of the granted patents has one or more International Patent Classification (IPC) codes. Each IPC code represents the technology class (see Appendix A) that is assigned to a patent by the patent examiners. Since each patent embedded with one or more IPC code(s), the number of technologies is greater than the number of patents.

We find the highest number of patents that are granted in both countries together in the telecommunications sector (see Appendix D for all sectors in only Canada, only the US, and the both). We find 7,288 more telecommunications patents in the matched dataset than that of only CIPO patents and 5,726 more than that of only USPTO patents. This observation indicates the strength of telecommunication related industries in Canada and the US. Most of the telecommunication related patents originated from Blackberry Limited and Nortel Network Corporation. At the firm-level, the highest number of matched patents granted in the field of telecommunications, university-level in pharmaceuticals, government-level in control and instrumentation technology, and individual-level in civil engineering (see appendices E-H for details). For the interested readers, the top 20 firm-level and top 10 university-level Canadian assignees in Canada and the US patent offices added in the appendices (see Appendices I and J).

Table 2-5: Changing Composition of Innovative Activity at Different Destination

Technology Class*	Only US		Only Canada		Both US & Canada	
	%change between 1996 and 2014	share of total change	%Change between 1996 and 2014	share of total change	%change between 1996 and 2014	share of total change
Telecom	1752.36	24.31	560.00	11.24	461.02	16.14
IT	3340.45	17.16	842.08	6.13	1207.00	6.09
Pharmaceuticals	636.61	8.16	380.94	7.60	1393.02	6.16
Biotechnology	707.73	7.70	242.02	3.87	806.27	4.16
Control	241.61	6.02	118.14	7.02	212.07	5.86
Electrical	261.73	4.87	105.37	4.39	148.47	4.13
Audio-visual	558.95	3.72	130.56	1.60	221.76	1.71
Organic	286.59	3.59	-65.88	-10.45	434.00	3.17
Medical	374.70	2.94	293.08	5.64	554.21	3.29
Optics	409.90	2.80	113.04	1.75	176.59	1.60
Transportation	236.44	2.55	160.17	5.57	477.97	5.33
Engine	311.63	1.88	186.05	3.23	1068.06	4.13
Consumer	101.93	1.85	126.67	7.80	241.25	4.21
Civil	85.68	1.52	235.91	21.01	295.53	6.80
Material	93.93	1.48	38.12	2.08	144.82	2.34
Semiconductor	384.25	1.31	52.66	0.28	139.08	0.49
Petroleum	152.58	1.17	-22.41	-2.02	194.77	1.42
Chemical	67.58	1.10	49.54	3.08	232.40	3.43
Mechanical	86.36	0.93	167.61	4.28	324.33	3.19
Hauling	48.89	0.93	149.02	4.88	175.69	2.98
Machine	76.25	0.82	120.43	3.24	175.45	2.02
Food	106.95	0.75	104.18	2.63	481.16	2.93
Surface	46.39	0.67	55.70	1.16	98.33	0.95
Environmental	110.27	0.38	178.66	1.85	342.76	1.43
Agriculture	93.98	0.36	123.23	1.55	102.30	0.52
Metallurgy	20.83	0.31	41.97	1.41	159.92	2.43
Polymer	33.42	0.30	-38.35	-3.21	115.59	1.02
Heat	26.10	0.17	94.83	2.08	273.88	1.80
Space	83.10	0.14	21.26	0.18	-10.24	-0.06
Nuclear	71.01	0.11	71.54	0.14	283.33	0.32
Total	313.93	100.00	91.85	100	300.28	100

Note: * No. of technology is based on the International Patent Classification (IPC) Codes embedded on the patents granted by Canadian & the US patent offices to the Canadian inventors. Each of the granted patents has one or more International Patent Classification (IPC) codes. Each IPC code represents the technology class (see Appendix A) that is assigned to a patent by the patent examiners. Since each patent embedded with one or more IPC code(s), the number of technologies is greater than the number of patents.

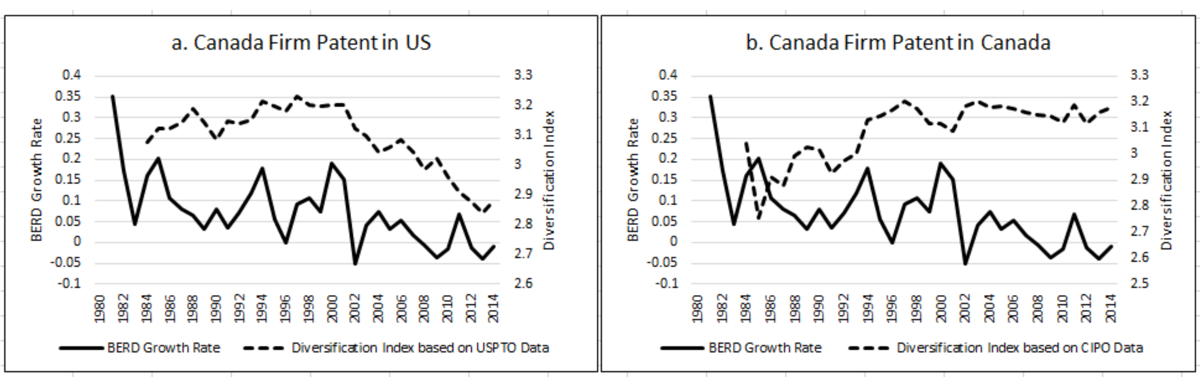
The composition of patenting in the different destinations changes over time. Table 2-5 captures that aspect by comparing the cumulative number of technologies between 1996 and 2014. Compare to the cumulative number of technologies in 1996, in 2014, the only Canada technologies increased by 91.85%, the only US by 313.93%, and both Canada & Us by 300.28%.

If we look at the top three technologies we see, compared to 1996, in 2014, 50% of the only US technologies dominated by telecommunications, information technology, and pharmaceutical-related patents. 40% of the only Canada technologies dominated by civil, telecommunications, and consumer goods related patents. And 29% of both US and Canada technologies dominated by the telecommunications, civil, and pharmaceuticals related patents.

2.4.2 Technological Diversification of Canada

Figure 2-3 illustrates the indices of technological diversification related to Canadian patents. The technology diversification indices are declining over time in Canada and the United States, though the number of patents is growing rapidly in both countries. The lower diversified indices in the US might be explained by the phenomenon that inventors become more selective when they go for patenting abroad. In Table 2-1, 32.13% of patents granted to individuals in only Canada, but the figure is 1.72% patents in the only US. This 32.13% of patents contributed to the additional diversity of the domestic patents since patents are scattered around many technology classes. Paci et al. (1997) argue that domestic patenting provides a broader portrait of a country's innovative activities, and international patenting presents an 'innovation excellence' of a country's innovation system.

Figure 2-3: Relationship between Technological Diversification and Business Enterprises R&D (BERD) Growth Rate, 1980-2014



To assess the causes behind the declining diversification indices, we use the Business Enterprises R&D (BERD) growth rate from the annual BERD data[3] Figure 2-3 shows the relationship between technology diversification and the growth rate of the business expenditure on the R&D. A patent application is a success of an invention, which is usually conducted by the R&D 1-2 years ago (Trajtenberg, 2001), and the grant may take additional 2-3 years. Due to this R&D-application-grant lag, it would be better if we compare the R&D and diversification five years apart. Both the figures 2-3a and 2-3b clearly show a co-movement of the diversification and growth data with reasonably lag for five years. For instance, if we look at the peak of Figure 2-3a around 1984 for the BERD growth rate, we see the reflection on diversification reached a peak approximately five years later.

[3] https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB#

Figure 2-4: Composition of the Diversification Indices at Assignee-level and Patent Destination Country

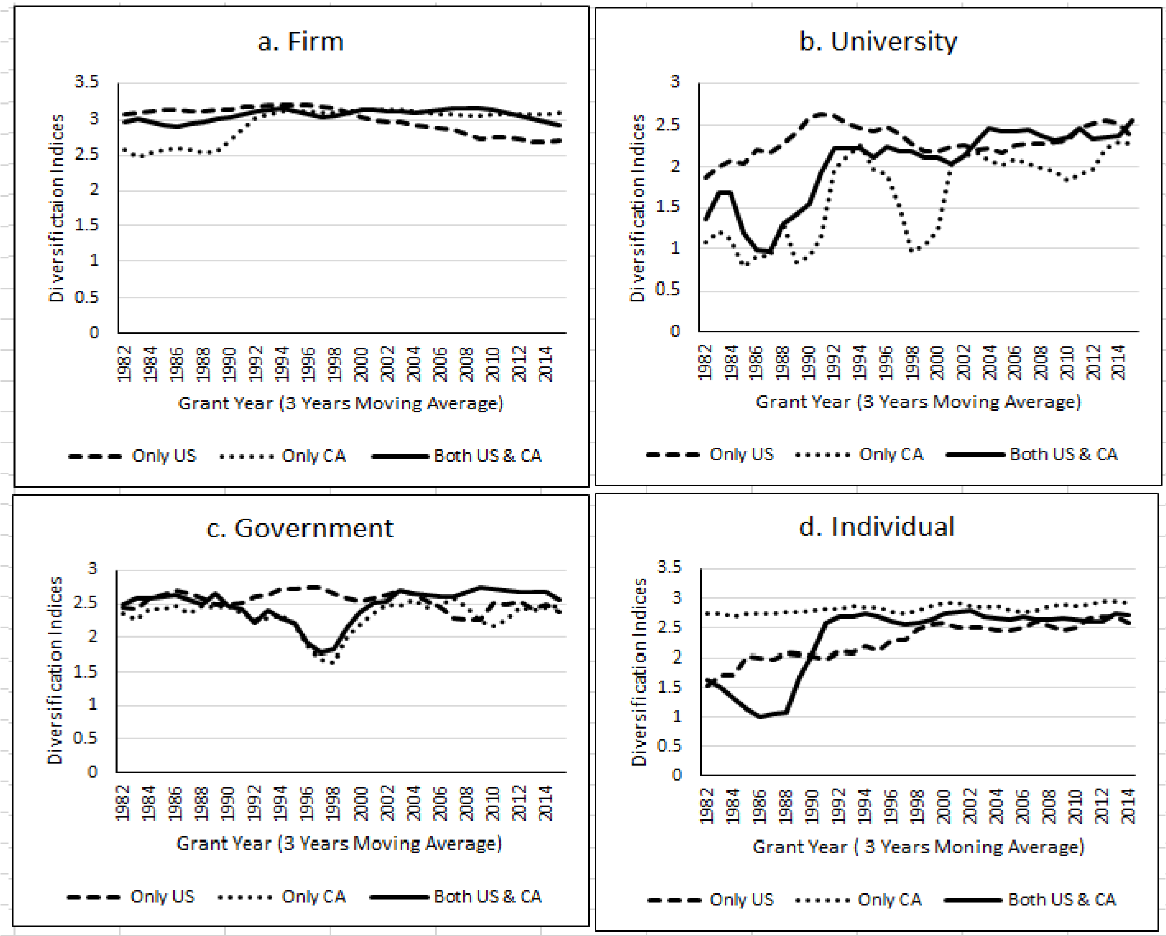


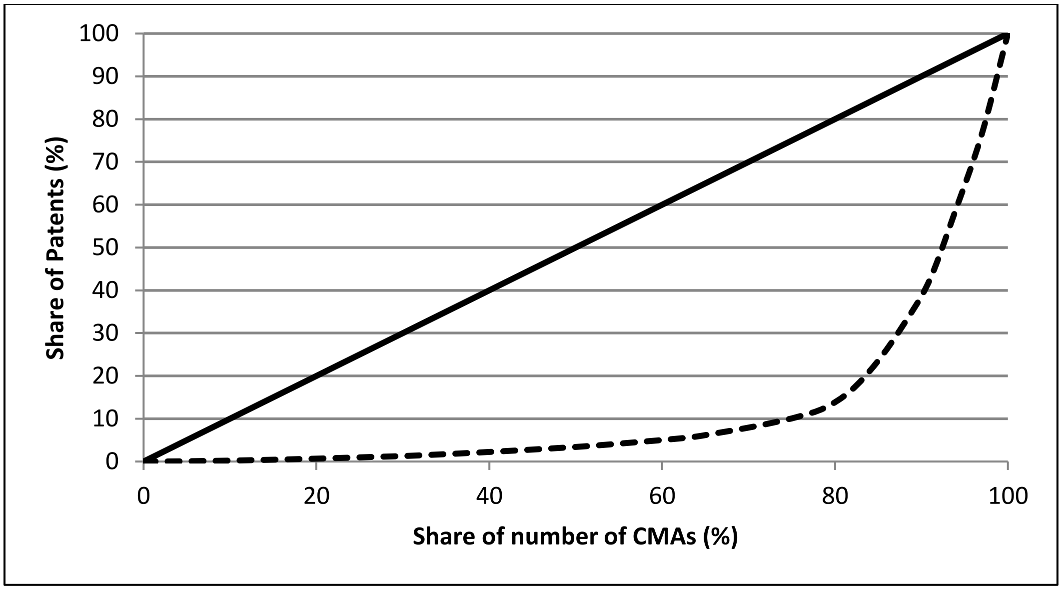
Figure 2-4 shows that diversification indices are lower in the external patenting compared to domestic patenting for Canadian firms, government entities, and individuals; however, diversification index of the patents related to Canadian universities shows the opposite direction. At the firm level, technology diversification indices declined more rapidly in the only US than that of only Canada and the both US and Canada; because only a few numbers of technologies dominated the large portion of shares.

2.4.3 Innovation and Technological Diversification in Metropolitan Area

In his book "Geography and Trade," Krugman (1991) mentioned that 'States aren't really the right geographical units.' Motivating by the works of Krugman, Audretsch (1998) used 'city' as a geographic unit of analysis. To observe Canada's technological diversification more closely, this section focuses on the technology diversification as the level of census metropolitan areas (CMA) of Canada using CIPO data.

The patenting activity has been increased in the Canadian CMAs in the last 36 years, especially since the 2000s (see Appendix K). Out of a total of 33 CMAs, only top-six CMAs generated large enough number of patents: Toronto, Calgary, Montreal, Kitchener-Cambridge-Waterloo (KCW), Ottawa, and Vancouver (see Appendix L). Figure 2-5 shows the relationship between the share of CMAs in terms of the number of CMAs and the share of patents granted to Canadian inventors during the period between 1980 and 2014. The 45-degree straight line indicates an equally distributed pattern across all CMAs. The data show that only 10% of the regions of the CMAs are responsible for 60% of all patents, and the lower 60% of the regions of the CMAs for only 5% of the patents. The highly bent line in figure 2-5 indicates the concentrated pattern of technological activities in a few areas in Canada. This observation indicates that technology creation activities highly concentrated in a few areas in Canada, which is consistent with existing literature (Feldman & Florida, 1994; Sun, 2000).

Figure 2-5: Lorenz Curve for Regional Distribution of Canadian Invented Patents based on CIPO Data



Archibugi & Pianta (1992) observed that large countries usually spread their innovative activities across many fields. We observed the same patterns when comparing the innovative activities and technological diversification in the CMAs. Table 2-6 exhibits the number of patents and technological diversification indices for all CMAs. The table shows that Toronto generated the highest number of patents, but it has the sixth-highest patent rate, which is the number of patents per capita. The most innovative metropolitan area in Canada in terms of patent rate is KCW. In the United States, New York has the highest number of patents but ranked third based on the patent rate, while San Francisco is the most innovative in terms of the patent rate (Feldman & Audretsch, 1999).

Table 2-6 shows that large metropolitan areas are more diversified than in small metropolitan areas. We also see that CMA with a higher number of patents also has a higher diversification index.

Figure 2-6: Patenting Activity in the CMAs of Canada

CMA (1)	GDP per Capita (2)	No. of Patents (3)	Patent per Capita (4)	Diversification (5)	No. of university (6)	Highest Education (7)	Research Centre (8)
Toronto	47880.00	7877	146.42	3.28	3	40.90	6
Calgary	57435.09	5918	520.32	2.83	3	38.30	2
Montréal	38691.83	5484	147.56	3.18	4	31.90	9
KCW	42641.53	3465	739.53	2.87	2	28.90	0
Ottawa-Gatineau	48616.68	2889	242.55	3.06	5	39.90	34
Vancouver	40882.26	2220	99.88	3.04	5	37.50	6
Edmonton	54185.03	1338	122.50	2.77	6	28.90	4
Winnipeg	39140.31	680	94.30	2.49	4	31.60	5
Hamilton	34849.22	481	66.80	2.39	1	28.40	5
Saskatoon	44357.67	411	165.60	2.07	1	31.40	5
Québec	39104.71	353	47.80	2.21	2	30.20	2
London	38460.83	337	70.92	2.28	1	27.70	2
Kingston	36633.58	204	128.10	1.80	1	29.40	0
Sherbrooke	29354.57	175	89.87	1.65	2	25.70	1
Regina	55012.11	170	82.80	1.94	1	30.40	2
Windsor	37578.58	161	48.76	1.83	1	26.00	0
Victoria	40573.95	133	39.05	1.64	2	33.80	6
Halifax	40696.14	123	31.77	1.53	5	35.20	2
Guelph	45388.41	115	82.74	1.54	1	34.70	2
Brantford	30396.25	110	81.43	1.41	0	16.70	0
Kelowna	32104.78	104	61.32	1.46	1	21.20	0
Barrie	27925.05	96	53.21	1.13	0	19.80	0
St.Catharines-Niagara	32393.39	92	22.97	1.49	1	20.40	0
Oshawa	32087.89	62	18.06	1.19	2	22.00	0
Trois-Rivières	32260.14	62	42.03	0.98	0	21.80	0
Abbotsford Mission	27450.73	60	36.36	1.20	0	18.70	0
Moncton	37678.52	57	43.39	0.95	4	24.70	3
Thunder Bay	36579.51	49	38.80	0.94	1	23.70	0
Greater Sudbury	43945.31	44	26.86	1.01	1	20.30	1
Peterborough	31022.29	37	30.86	0.98	1	23.50	0
Saint John	39308.82	32	25.29	0.90	1	23.00	0
St. John's	43652.23	21	11.16	1.06	1	29.40	3
Saguenay	35140.61	8	5.03	0.35	1	18.90	1

Note: (1) *33 CMAs* are based on the 2011 Census of Population of Canada conducted by Statistics Canada. (2) *GDP per capita* is based on an average of 12 years (2001-2012) GDP per CMA by the 12 years population per CMA[4]. GDP at basic prices expressed in dollar X 1,000,000. (3) The *number of patents* indicates patents granted to the Canadian inventions by the Canadian Intellectual Property Office (CIPO) for the years between 1980 and 2014. (4) In calculation patent per capita, twelve years (2001-2012) average population per CMA[5] is used. (5) The *entropy measure calculates the diversification index*. (6) The *number of universities* in each CMA in 2018. (7) The *highest education*-level is measured as the share of the labor force in 2016 accounted for the workers who have a university certificate, diploma or degree at bachelor level or above, based on the 2016 Census by Statistics Canada[6]. And (8) *Research centers* are the National Research Council operated research facilities in the CMA[7] in 2018.

[4] Statistics Canada. Table 36-10-0468-01 Gross domestic product (GDP) at basic prices, by census metropolitan area (CMA) (x 1,000,000)

[5] Statistics Canada. Table 17-10-0078-01 Annual demographic estimates by census metropolitan area, age and sex, based on the Standard Geographical Classification (SGC) 2011

[6] https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/hlt-fst/edu-sco/Table.cfm?Lang=E&T=22&Geo=00&SP=1&view=3&age=2&sex=3&SO=20D

[7] https://www.nrc-cnrc.gc.ca/eng/about/directions/index.html

A positive relationship between the number of patents and diversification indices already established in the existing literature (Cantwell & Vertova, 2004; Wang et al., 2015). Distribution of innovative activities, however, are skewed in Canada. The mean number of per capita patents of all metropolitan areas in Canada is 104.97. If we compare the patent per capita in each CMA with the mean of all the CMAs, only eight CMAs are more innovative than the average. Feldman & Audretsch (1999) conclude that 'innovative appears to be a large cities phenomenon' in the United States, and the same pattern observed in Canada. The correlations between the number of patents, diversification indices, and other measures of innovative activity added in Appendix M for the interested reader.

Although the number of patents is increasing rapidly (see Appendix K), diversification indices started decreasing for Toronto, Calgary, and Saint John since 2006; and for Ottawa-Gatineau, Windsor, Victoria, Greater Sudbury, St.John's, and Trois-Rivieres since 2011 (See Appendix N) . The possible reason for the decreasing of the diversification indices might be the impact of globalization, which stimulates inward foreign R&D investment towards specialization (Cantwell & Vertova, 2004). We observe the variation of innovation activities across Canada. Metropolitan areas of the Central and west coast are more involved in generating modern technologies, such as information technology, telecommunications, audio-visual, pharmaceuticals, and biotechnology; those of the Prairie Provinces are more involved in traditional technologies, such as civil, chemical, mechanical, and agriculture-related technologies.

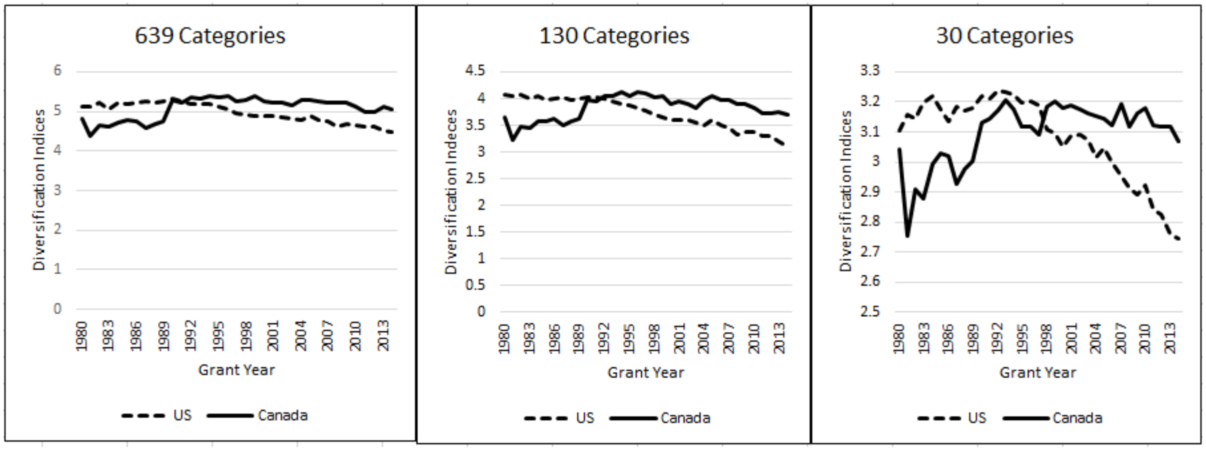
The CMAs can be grouped by four broad geographic regions of Canada to facilitate the discussion of innovative activities. In central Canada (15 CMAs in Ontario and Quebec) with more than half of the Canada population, Toronto ranked first in 15 technology categories out of

30 (see Appendix O) and is the most diversified CMA of Canada, followed by Montreal. Ottawa-Gatineau has the highest number of patents to the government assignees, and Kitchener-Cambridge-Waterloo (KCW) has the highest per-capita patent. In the Prairie Provinces (5 CMAs in Alberta, Manitoba, and Saskatchewan), Calgary is the most diversified CMA in the region with the sixth overall in Canada, followed by Edmonton, Winnipeg, and Saskatoon. Calgary ranked first in the patents on civil engineering, chemical engineering, control technologies, organic chemistry, petroleum, and polymer technologies. In the West Coast (4 CMAs), Vancouver is the fourth largest technologically diversified CMA in Canada, with the highest number of patents in the field of civil engineering-mining-architecture, electrical devices & engineering, pharmaceuticals & cosmetics. We do not observe any significant patenting activity in the CMAs of the Atlantic Provinces, though Halifax is the most diversified in the region.

2.4.4 Technological Diversification of Canada: An Extension

The study uses the classification of 30 technology categories to evaluate technological diversification. However, it can be interesting to see how the measures can change if we use the 3-digit IPC does (with 130 technology categories) and 4-digit codes (with 639 technology categories). Figure 2-7 compares the diversification indices based on the three types of technology categories. While the exact shapes are different, the figure shows that the diversification indices are declining over time, and this pattern is more pronounced in the US patent, for the three types of classification.

Figure 2-7: Comparison of Technology Classes based on Alternative Categories



If we use the 3-digit IPC code, Canada's top three technology includes 'electric commination technique,' 'medical or veterinary science; hygiene,' and 'organic chemistry' for the CIPO data (see Appendix P), and 'electronic communication technique,' 'computing, calculating, and counting' and 'medical or veterinary science; hygiene' for the USPTO data (see Appendix Q). Based on the 4-digit IPC codes, Canada's top three technology includes 'earth or rock drilling,' 'preparations for medical, dental, or toilet purposes,' and 'heterocyclic compounds' for the CIPO data (see Appendix R), and 'electric digital data processing,' 'preparations for medical, dental, or toilet purposes,' and 'transmission of digital information' for the USPTO data (see Appendix S). Technology composition varies between Canada and the US whether we use 3-digit or 4-digit IPC codes. Hence, relying on a single source of data to portray a country's innovative activity can be misleading.

2.5 Conclusions

The study presents a detailed portrait of Canada's technological landscape utilizing patent data of Canadian inventions from the Canadian and United States patent offices granted between 1980 and 2014. By showing the variation of technologies that reflected in the patents granted to

Canadian inventors by the patent offices of Canada and the United States, this study argues the importance of using multiple sources of data. Measuring the patterns of technological diversity of Canadian inventions, we show how Canadian technological capacity evolves. The results of the study show that Canada's technological diversification decreases over time, although the number of patents grants increases. The Canadian firms, universities, and governments are more interested in patenting in the US than in Canada. However, Canadian individuals are interested in Canada than the US for patenting their inventions. The number of matched patents is growing steadily and the diversification indices for those patents are declining since 2000. The number of patents in the Only US is growing more rapidly than in only Canada. We found more diversified patents in only Canada than in the only US and matched data. Our analysis also reveals that patenting activity increased in the Canadian metropolitan areas in the last 36 years; however, it increased rapidly since 2000. We found that only 10% of the regions of the CMAs account for 60% of all patents granted by the Canadian patent office to Canadian assignees. This observation indicates that technology creation activities concentrate on only a few areas in Canada.

Policymakers might be benefited from the insights of the study since it shows the technology classes in which Canada excels or lag, technology classes that are scaping the border or stay at home, and regions that are more diversified or not. This study is not above the limitations. This study focuses on the US as the foreign destination of Canadian patents. This study would provide more insights if future researchers include four things. First, collecting and analyzing patent data of Canadian inventors from the other patent offices, such as European Patent Office (EPO) and China National Intellectual Property Organization (CNIPA) since 8% of the Canadian invented patents going to the EPO and 5% to the CNIPA (IP Canada Report, 2017). Second, incorporating the ratio of outward foreign direct investment to inward foreign direct investment of Canada and then compare the ratio with the ratio of foreign patenting to domestic patenting to get further insight. Third, identify the nationality of co-inventor with the Canadian inventors. And, fourth, identify the ownership of the firms and their annual R&D expenditures during the analysis period of 1980-2014.

Chapter 3: Who Owns the Canadian Inventions?

3.1 Introduction

The Council of Canadian Academies (2018) expressed concern that foreign assignees have increasingly owned the patents invented by Canadian inventors. Canada is the 18th most innovative country in the world in 2018 based on the Global Innovation Index (GII), although Canada remains in the 10th position in the innovation input sub-index of GII (Cornell University, INSEAD, & WIPO, 2018). The strength of Canada's input side of innovation, especially in institutions and market sophistication, makes Canada an attractive place for companies to conduct research. However, Canada is considered as a less attractive country to convert the research output into commercially viable products (Council of Canadian Academies, 2018), which might have stimulated the growth of foreign ownership of inventions made by Canadian inventors. Motivated by this concern, this study examines the pattern of the ownership of patents that are invented by Canadian inventors.

Existing literature on internationalization of R&D usually classifies a country's patent portfolio into three categories (Archibugi & Michie, 1995; Archibugi & Iammarino, 2002): (i) domestic patents, also termed as resident patents– patent applications by inventors of a country "A" in the country "A," (ii) foreign patent, also known as non-resident patents- patent applications by inventors of country "B" in the country "A," and (iii) external patents- patent applications by inventors of the country "A" in the country "B." The ratio of foreign patents to domestic patents may indicate that foreign ownership of domestic inventions varies by country. For instance, large foreign firms owned 39.7 % patents in Belgium, 19.1% in the UK, 16.9% Canada; 3.1% in the US, and 1.2 % in Japan among the patents that were granted to the inventors of these countries by the USPTO during the period between 1981 and 1986 (Archibugi &

Michie, 1995). However, most of the internationalization of R&D literature did not evaluate the scenario when a patent invented by an inventor of a country, but ownership of that patent belongs to the assignee of another country. That is a patent invented by inventors of country "A," but ownership of that patent goes to the firm of country "B." This gap is partially filled by the works of Trajtenburg (2001) and Beaudry & Schiffauerova (2011), which show that the share of foreign ownership of domestic inventions is growing. The objective of this study is to investigate the ownership pattern of patents developed by Canadian inventors in a broader set of technology categories during the period between 1976 and 2014.

Using the USPTO patent data, which granted to Canadian inventors between 1976 and 2014, this study focuses on three research questions. First, what is the temporal trend of the ownership of the patents invented by Canadians? Second, how does the ownership of technologies vary based on technology classes and assignee types? Third, how does the ownership pattern vary based on the geographic origin of the patents? Besides, this study also examines the quality of the Canadian patents that are owned by different assignees in the home or abroad. The results of the study contribute in several ways. First, this study analyzes the ownership of Canadian patents by thirty technology categories and five types of assignees over time. This analysis can shed light on the type of technologies that are owned more by foreigners and that have no assignees, which can help pinpoint Canada's strengths and weaknesses in various technology sectors. Second, this study considers all thirty-three census metropolitan areas of Canada to explain the geographic origin of inventions by Canadians. Existing literature on ownership of patents either shows international comparison (Trajtenburg, 2001) with a limited number of clusters (Beaudry &

Schiffauerova, 2011). City planners can benefit from the study since the result will show the geographical cluster of technologies by patent ownership.

This study shows that with the increasing number of inventions invented by Canadian inventors, the share of unassigned patents is declining over time. Compared to the shares in 1980, the share of patents of Canadian ownership increased by 37% and that of foreign ownership by 63% in 2014, while the share of unassigned patents decreased by 74%. This study also illustrates that while Canadian inventors are continuously creating new technologies, they fail to capitalize on the inventions by creating commercially attractive products and services, which is consistent with the argument by Trefler (1999). The quality of Canadian invented patents has been growing over time in all technology classes, which may explain the declining share of unassigned patents. However, better quality patents are increasingly owned by foreigners, especially in such technologies as information technology, telecommunications, optical, and electrical engineering. The study identifies that the highest share of foreign-owned patents is in the field of information technology, while Canadian ownership concentrates on traditional technologies such as civil, mechanical, and chemical engineering.

For the geographic clustering of patents in Canada, approximately 60% of all patents originated from the Census Metropolitan Areas (CMAs) of Toronto, Ottawa-Gatineau, Montreal, Vancouver, Kitchener-Cambridge-Waterloo, and Calgary. Among the top five CMAs based on the number of patents, Toronto has the highest share of foreign assignees, and Kitchener-Cambridge-waterloo has the highest share of local assignees. The paper also finds that the proportion of inventor-ownership varies according to the different types of assignees and the different composition of technologies. For instance, the highest share of foreign-firm owned patents are in the field of information technology, and that of foreign-university owned patents is in the field of the semiconductor. We find most unassigned patents in the field of consumer goods & equipment.

This paper is structured as follows: section 3.2 presents the literature review related to ownership of patents; section 3.3 explains the data and methodology; section 3.4 discusses limitations of the study; section 3.5 discusses the results of the study; and section 3.6 presents conclusions, policy implications, and potential direction of future studies.

3.2 Theoretical Background and Contributions

Literature shows that the growing share of innovations invented by the inventors of one country and owned by the firms of another country (Trajtenburg, 2001; Guellec & Potterie, 2001; Cincera et al. 2006; Danguy, 2017). Moreover, foreign-owned patents have better quality than locally owned patents (Tong & Frame, 1994; Beaudry & Schiffauerova, 2011). When analyzing the ownership of patents, it also observed that some portion of the patents remains unassigned. The goal of this study is to analyze the ownership of the innovations invented by Canadian inventors. Hence this paper is related to three groups of literature: the internationalization of innovation at the country level, the quality of patents, and the issue of unassigned patents.

Archibugi & Michie (1995) classified three different components of the globalization of innovation: (i) international exploitation of technology, (ii) global technology collaborations, and (ii) global generations of technology. In the first component, inventors attempt to reap economic benefits by stepping into the international market, directly through the export of products or indirectly through licensing patents (Archibugi & Iammarino, 2002). In the second component of collaboration, inventors create joint ventures between local and foreign firms or collaborate with universities or national research labs, while maintaining their institutional identity and ownership (Archibugi & Michie, 1995). For the third case component, multinational enterprises are conducting R&D not only in their home countries but also in the host countries through their affiliates and disseminating R&D outputs through foreign direct investment.

In 1996, foreign affiliates of the multinational corporations accounted for 40.3% of total R&D in manufacturing in Canada, 39.5% in the UK, 24% in the Netherlands, and 12% in the US (Archibugi & Iammarino, 2002). They often employ scientists from the host countries. An affiliate of a multinational firm may seek legal rights of its inventions in the host country, in the home country, or other countries. This paper is related to the internationalization of innovation, in which the ownership of inventions moves across a country's border (Guellec & Potterie, 2001). Cross-border ownership of technology can explain by the ownership of patents invented by inventors in one country but owned by entities of another country. Internationalization of R&D activities may take several forms, such as exports, licensing, the cession of patents, foreign production, etc. (Archibugi & Michie, 1995). Among the forms, patent enjoys the highest level of internationalization due to its disembodied nature (Carlsson, 2006).

Although lots of literature focus on globalization and internationalization of R&D, very few literature studies on the foreign ownership of local inventions at the country level with patent data (Trajtenburg, 2001; Guellec & Potterie, 2001; Cincera et al. 2006; Danguy, 2017). Using patent data of OECD countries, Guellec and Potterie (2001) show that the degree of internationalization is higher for small countries, and countries are more likely to collaborate if they are geographically close together. Danguy (2017) shows the increasing trend of the share of foreign ownership by using patent data collected from the European Patent Office (EPO) for 21 industries in 29 countries between 1980 and 2005. Using the patent data from the European and the US patent offices between 1978 and 2001, Cincera et al. (2006) measure the extent to which patenting activities are internationalized by considering the patents of Belgian inventors and foreign assignees and find that 40% of the patents invented in Belgium assigned to foreign assignees.

Most literature considers the assignee's country address when measuring the share of foreign assignment of local invention. However, Cincera et al. (2006) distinguish among local firms, affiliates of foreign firms located in Belgium, and locally based firms with affiliates abroad to calculate the share more appropriately. Using the USPTO patent data from 1968 through 1997, Trajtenburg (2001) addressed the question of who owns the patent of Israel inventions with three groups (local, foreign, and unassigned). By sorting patents across six technology categories and three types of assignees, he found that the local shares were slowly increasing, the foreign shares were rapidly increasing, and the shares of unassigned patents were declining. Table 3-1 summarizes the literature related to the research questions of the study.

Table 3-1: Summary of the Literature Related to Foreign Ownership of Local Invention

Author and Year	**Data**	**Method**	**Main Objectives**	**Main Findings**
Guellec & Potterie (2001)	Patent data of 29 OECD countries Collected from the EPO and the USPTO for the periods of 1985-1987 & 1993-1995.	Develop and compare three patent-based indicators of internationalization of technology, including an indicator for measuring share of foreign ownership of the domestic invention.	Present & analyze three patent-based indicators of internationalization of technology	A growing share of innovations invented by the inventors of one country and owned by the firms of another country
Trajtenburg (2001)	USPTO patents that granted to Israel and other reference	Distribute the patents based on technology	Closely investigate the innovative activities of Israel,	A large share of patents went to the

	countries during the period between 1965 and 1996.	categories to show who owns what kinds of technology over time.	including ownership of locally developed patented inventions.	hand of foreign assignees.
Cincera et al. (2006)	Using the patent data from the EPO and the USPTO for the period of 1978-2001	Two patents-based measures are developed that investigate the patenting activity of domestic inventors, foreign inventors, domestic assignees, and foreign assignees.	Assessing the foreign control of the production of technology in case of a small open economy	A significant portion of patented inventions is owned by foreign affiliates.
Tong & Frame, 1994	Patent claim data of 7531 patents that are granted to inventors of the US, UK, Japan, France, & West Germany in 1970, 1980, and 1990.	Comparing the patent claim data based on technology categories in three time periods across the five countries.	Measure the technological performance of a country with patent claim data	foreign-owned patents are better in terms of quality than the local owned patents
Beaudry & Schiffauerova, 2011	nanotechnology patents collected from the USPTO for the period of 1978-2004	Identify where the patent invented based on the inventor's address, who owns the patent based on the assignee's address.	Investigate the ownership of patents invented by Canadian nanotechnology inventors	foreign-owned patents are better in terms of quality than the local owned patents
Archibugi & Michie (1995)	USPTO patent granted to OECD countries between 1981-1986	Develop a taxonomy to measure three aspects of globalization of technology: exploitation, collaboration, & generation of technology on a global basis.	Several objectives to investigate the globalization of technology, including identifying the share of patenting by local and foreign-owned large firms of OECD countries.	The share of foreign-owned patents is low for two large countries: US (3.1%) and Japan (1.2%); the figure is 16.9% for Canada.
Danguy (2017)	Patent filing data of 21 industries of 29 OECD countries collected from the EPO's PATSTAT database during the period of 1980-2005	Indicator developed by Guellec and Potterie (2001)	Measure the extent to which production of innovation is globalized	The increasing share of foreign ownership of local innovation

This paper is also related to patent quality. Literature used various measures of patent quality, such as patent renewal data (Schankerman & Pakes, 1986; Lanjouw et al., 1998), patent family size that is the number of countries in which the invention protected (Putnam, 1996; Harhoff et al., 2003), the number of patent citations (Trajtenberg, 1990; Hall et al., 2005), and the number of claims in the patent applications (Tong & Frame, 1994). Instead of using a single measure, Lanjouw & Schankerman (2004) developed a composite index, which consists of the number of claims, backward citation, forward citation, and family size. Although existing literature prefers the 'patent citation' as a quality measure, a recent study by Kuhn et al. (2019) provides evidence that due to change in the data generation process, patent citation leads to 'biased, worse, or invalid' results. This study uses the number of claims as a measure of patent quality. The patent claim defines the legal scope of the patent (Tong & Frame, 1994; Lanjouw & Schankerman, 2001), and the higher number of claims can indicate a higher patent value with broader technology areas (Tong & Frame, 1994; Beaudry & Schiffauerova, 2011). However, it noted that the number of claims might vary due to the technology field, ownership country, and time (Lanjouw & Schankerman, 2001).

Finally, this paper focuses on the unassigned patents because we are investigating the ownership of patents. The unassigned patents are those patents that are still owned by the original inventors. Hall et al. (2001) identified that 18.4% of patents are unassigned in the USPTO database. Most of the existing literature drops the unassigned patents from the analysis, and only a few pieces of literature consider the unassigned patents for comparing with other assignee categories (Patel and Pavitt, 1994; Popp et al., 2004; Agrawal et al., 2010). Utilizing 91 technological sub-categories to test the relationship between technological convergence and vertical disintegration, Patel and Pavitt (1994) considered unassigned patent with other types of assignees and found negative relationships in case of unassigned, individuals, and small firm patents. To identify who is affected by the variation of patent grant lag, Popp et al. (2004) classify and compare patents by assignee types, which includes the unassigned patents. Popp et al. (2004) identified 17.80% unassigned utility patents in the USPTO database during the period between 1976-1996. Agrawal el.al. (2010), drop the unassigned patents from their analysis; however, to test the robustness of the results, they use the unassigned patents.

Literature indicates that the quality of the unassigned patents is very low. Using patent renewal data to estimate the value of the US patents, Bessen (2008) found the lowest rate of renewal of unassigned and individual-assigned patents. In an effort to identify the 'worthless' patents, Moore (2005) identified that unassigned, individuals, and government patents are more likely to expired than corporate patents. Some literature treated unassigned patent as an individual assigned patent (Patel and Pavitt, 1994; Mahmood and Singh, 2003; Nemet and Johnson, 2012), while others treat them as 'others' (Alcacer et al., 2009; Bessen, 2008). And use various measures of that 'others' assignee type of patents, such as count the number of patents, the share of 'others,' the share of citations generated from the 'others' category, etc. This study will investigate what kind of patents remained more unassigned. Moreover, we will investigate whether the share of unassigned patent changes over time due to improving patent quality.

3.3 Data and Method

The uses the USPTO patent data that granted to Canadian inventors during the period between 1976 and 2014. A patent is a temporary monopoly right awarded to the inventor(s) in exchange for full disclosure of the invention, which is new, non-obvious, and useful. Patents are considered a powerful indicator of innovation output (Griliches, 1990; Audretsch, 1995), despite a few well-recognized limitations: (i) not all inventions are patented or patentable (Hall &

Ziedonis, 2001), (ii) the significance of patents differs greatly across firms, industries, and time (Silverman, 1999), and (iii) incremental innovations are hardly patented (Puga & Trefler, 2010).

Inventors can patent their inventions anywhere in the world. Some Canadian inventors patent their inventions in Canada or other countries such as the United States. According to IP Canada Report (2017), 66% of Canada's external patents, patent applications by inventors of Canada abroad, went to the US in 2015. This study uses US data because only the US database provides the inventor's address information (Beaudry & Schiffauerova, 2011).

A patent document reports information about the inventor(s) and assignee(s) of an invention. Inventors always are an individual, and there can be multiple inventors of a patent. According to the convention of the USPTO, the nationality of a patent is determined by the country of the first inventor at the time of patent application (Trajtenberg, 1999). If a patent has multiple inventors from multiple countries, the country of the first inventor determines to which country the patent belongs to. The assignee is a legal entity that owns the patent right, which can be a firm, university, government, non-profit organization, or individual. A patent may not have designated assignee, called an 'unassigned patent.'

To identify the extent to which Canada can benefit from its inventions, we classify the Canadian patents into three categories based on their assignees' address: Canadian, foreign, and unassigned. A firm may assign its patents to its subsidiary in a foreign country, which may create an issue whether the patent is considered a local or foreign (Trajtenberg, 2001; Cincera et al., 2006). To solve this uncertainty, we first identify the origin of the firm and change the address accordingly. For example, we treat "Research in Motion Corporation" with the US address as a Canadian patent, and "Xerox Canada" with the Canadian address as the US patents (see

Appendix X for the example of companies). Then, instead of the assignee's name, we focus on the assignee's address to find the foreign and Canadian ownership of patents. By examining the names of assignees, we classify the assigned patents, whether local or foreign, into five categories: firm, university, government, a non-profit organization, and individual.

To measure Canada's technological portfolio more closely, Census Metropolitan Areas (CMAs) of Canada considered by this study. According to Statistics Canada, adjacent municipalities centered on a population core form a CMA. In Canada, a CMA must have a total population of at least 100,000 of which 50,000 or more must live in the population core (STATCAN, 2017). According to the 2011 Canadian Census, Canada has 33 CMAs. To portray each Canadian census metropolitan area's innovation activities over time, this study screens the US PTO patents using the following criteria: (i) the grant year is between 1976 and 2014, (ii) first inventor' address in Canada, and (iii) first inventor's city address. We then converted the first inventor's city address into relevant CMAs based on the statistical area classification of Statistics Canada.

To find out the technological composition of Canadian invention, the four digit-level of IPC codes converted into 30 technology categories (Schmoch, 2008) (See Appendix A). Although a patent may consist of more than one IPC code, the study considers the first IPC code as the primary technology embedded in a given patent. The quality of patents is measured by the average number of patent claims for all types of assigned and unassigned patents over time (Tong & Frame, 1994; Beaudry & Schiffauerova, 2011).

3.4 Limitation of the Study

This study did not consider the issue of patent reassignment. Patent reassignment means a change in ownership of a granted patent (Marco & Miller, 2019). Patent reassignment arises from patent trading or patent transfer. For example, Apple, Blackberry, Microsoft, and Sony, as a part of Rockstar Consortium, bought a patent portfolio from bankrupt Nortel Network for $4.5bn (Arthur, 2011). The potential new assignee may reap more benefits from a transferred patent than its original assignee. Potential new assignee might be more capable of capturing value from an invention than its original assignee. Patent reassignment varies according to types of patentees and technology categories. Individuals and small firms are more active in patent transfer than large firms and government agencies (Serrano, 2004; Figueroa & Serrano, 2019). Patent reassignment data is difficult to identify since the patent office's reassignment data includes name changes of assignees, transfer of employee name to the company name, and name changes due to merger and acquisition. Moreover, the recordation of the change of ownership and the change of owner name is voluntary (USPTO, 2019). The patent office completes the reassignment procedure if the assignee and assignor want to do so (Leiponen & Delcamp, 2019).

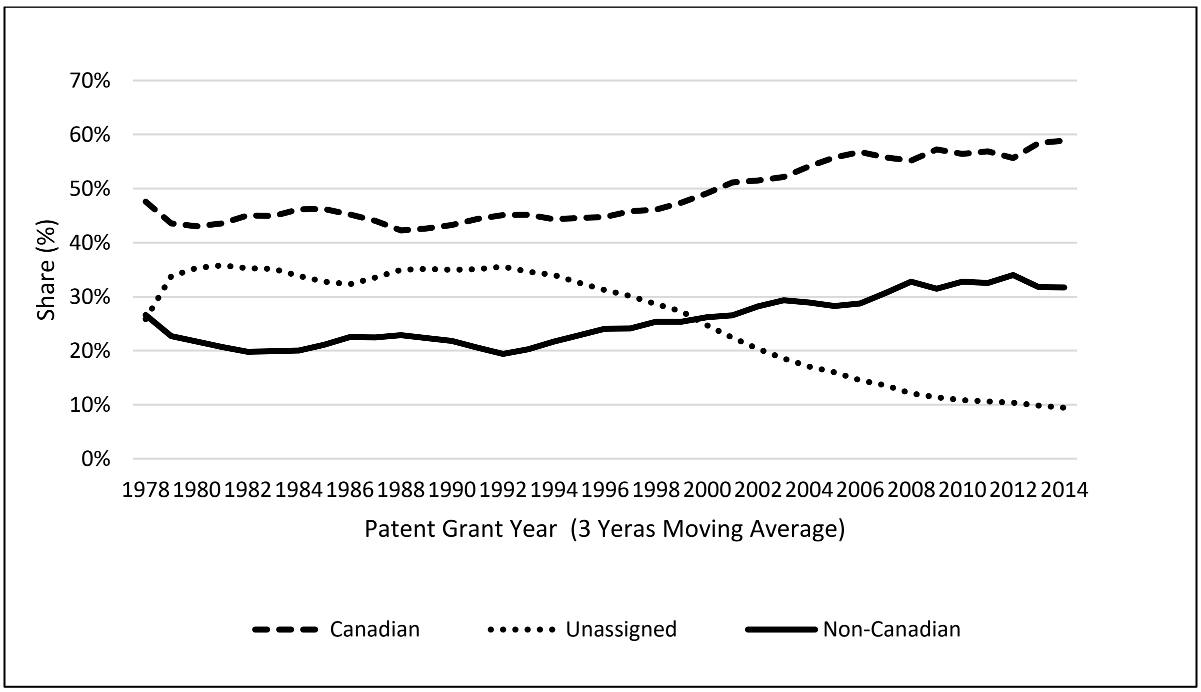
3.5 Results and Implications

3.5.1 Basic Facts about Canadian Invention Ownership

We use 103,693 patents based on the first inventor's address in Canada that is granted by the USPTO from 1976 through 2014. Among the all Canadian invented patents, 72,371 (69.79%) assigned to firms, 2,962 (2.86%) assigned to governments, 1,185 (1.14%) assigned to individuals, 238 (0.23%) assigned to non-profit organizations, 3,136 (3.02%) assigned to universities, and 23,801 (22.95%) unassigned. The ownership of Canadian invention categorized into three groups: Canadian assigned, foreign assigned, and unassigned patents.

Figure 3-1 shows the share of Canadian inventions' ownership patterns during the period of 1976-2014. In general, the share of foreign assignees is growing, and the share of unassigned patents are declining over time. Among all Canadian invented patents in 1980, 43% assigned to Canada, 19% to foreign, and 39% unassigned. In 2014, the share of Canadian assignee went up to 59% and that of the foreign assignee to 31%; whereas, the share of unassigned patents went down to the 10% (see Appendix T for the number and share of yearly ownership of Canadian inventions). These statistics indicate that both local and foreign assignees increasingly own inventions made by Canadian inventors. Foreign ownership is rapidly increasing since 1995, specifically due to information technology and telecommunications-related patents.

Figure 3-1: Share of Canadian Invention by Ownership based on the USPTO Data, 1976-2014



Another important observation is the decreasing trend of unassigned patents. The share of assigned patents is decreasing due to the increasing quality of Canadian patents. The share of unassigned patents decreases by 75.61% in 2014 compared to that of 1980; at the same time quality of Canada owned and foreign-owned patents are increased by 76.74% and 86.76% respectively (See Appendix T, which shows the decreasing share of unassigned patents with an increasing number of claims of Canadian inventions in all types of ownership categories). In general, the quality of patents in terms of the number of claims for all kinds of patents is increasing over time. Tong & Frame (1994) observed the increasing trend of patent quality when comparing the average number of patent claims for five countries; in 1970 average number of claims per patent was 7 for France, 6.6 for Japan, 7 for the UK, 8.4 for the US, and 9.3 for West Germany; whereas, in 1990 that was 11.1 for France, 10.1 for Japan, 12.1 for the UK, 13.8 for the US, and 12 for West Germany. According to our data, the average number of claims was 9.05 in 1976, and 12.53 in 1990 for Canada. Tong & Frame (1994) find that the highest number of claims per patent (13.80) in the US in 1990. At the same time, if we look at the Canadian patents that are owned by US firms, we see the number of claims per patent is 13.13. When comparing the quality of Canadian invented nanotechnology patents that are owned by Canadian and the US assignees, Beaudry & Schiffauerova (2011) find that the US-owned patents have better quality in terms of a number of claims than that of Canada owned.

Table 3-2 reports the distribution of Canadian invented patents among the different types of assignees during the period between 1976 and 2014. Among the assigned patents, 69.37% assigned to Canada, 24.80% assigned to the US, and 5.83% assigned to non-US entities. Hall et al. (2001) identified that 78.4 % of USPTO patents granted to firm-level assignees; among them, 47.2% owned by the US and 31.2% owned by foreign firms. Our result is very close to that of Hall et al. (2001) for the share of foreign ownership; in the case of Canadian invented patents, 30.68% owned by foreigners.

Table 3-2: Ownership of Canadian Invention by Assignee Types based on USPTO Patent Data 1976-2014

Assignee / Type	Canadian			Non-Canadian						Total
				US			Non-US			
	No. of Patent	Share (%)	Claim (mean)	No. of Patent	Share (%)	Claim (mean)	No. of Patent	Share (%)	Claim (mean)	
Firm	48,331	87.21	18.14	19,463	98.22	18.30	4,577	98.3	18.37	73,371
Government	2,857	5.16	17.5	73	0.37	17.82	32	0.69	18.03	2,962
Individual	1,089	1.96	17.53	77	0.39	16.25	19	0.41	16.05	1,185
Non-profit	211	0.38	16.36	20	0.1	29.15	7	0.15	9.71	238
University	2,932	5.29	17.7	183	0.92	20.44	21	0.45	22.89	3,136
Total	55,420	100		19,816	100		4,656	100		79,892

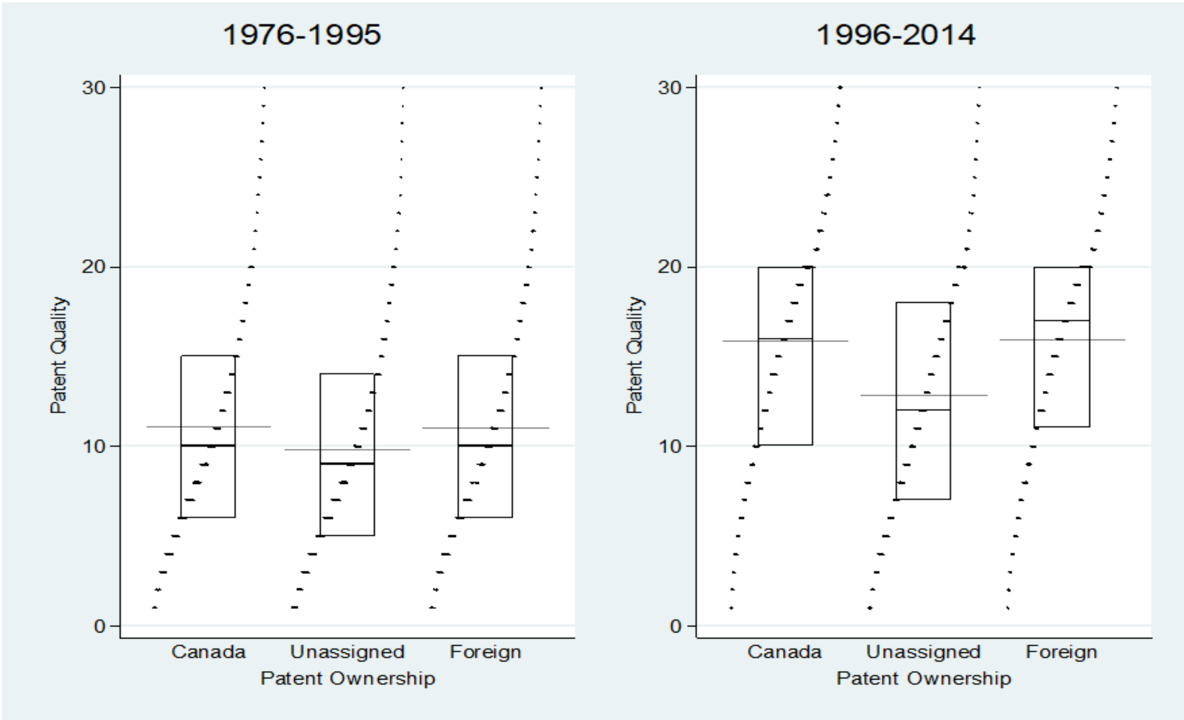
Among the Canadian assignees, more than 87 % are Firms. The top five technologies that assigned to Canadian firms include telecommunications (14.66%), information technology (13.79%), control & measurement instrument (6.3%), electrical (6.02%), and civil (4.76%). The top three Canadian assignees are Blackberry Limited, Nortel Network Limited, and Pratt & Whitney Canada Corporation. Among the Canadian assignees, only Blackberry owns approximately 10% of the patents granted in the US. Although it represents only 5.29% patent ownership by Canadian universities, those patents are mainly in the fields of pharmaceuticals, biotechnology, and measurement & control technologies.

98% of the US assignees of Canadian patents are private firms. In the US, top assignees of Canadian inventions are Xerox Corporation, International Business Machines Corporation, and Exxon Corporation. Xerox owns 10% of Canadian Inventions assigned to the US (for details about the top 10 US assignees see Appendix U). 51% of all patents assigned to the US originated from the five fields, namely information technology (19.65%), telecommunications (12.83%), optical engineering (6.58%), measurement & control (6.01%), and electrical engineering (5.76%). Among all IT patents assigned to the US, International Business Machines (IBM) Corporation owns 34%. The top five non-US but foreign assignee countries includes France

(0.87%), Sweden (0.86%), Germany (0.49%), Japan (0.47%), and Switzerland (0.43%). According to the data, Canadian inventions owned by foreign assignees of 73 countries across the world.

Now the question arises about the quality of the patents that are owned by Canadian or foreign assignees or are unassigned. As Table 3-2 shows, the quality, measured by an average number of claims, of the US-owned patents in all five assignee categories is higher than that of Canada owned. Even patents assigned to the non-US countries, patent quality, is higher than that of Canadian firm, government, and university level assignees. Though only focuses on nanotechnology patents, Beaudry & Schiffauerova (2011) found the same observation as the US firms own better quality patents than Canadian firms that are invented by Canadian inventors. Among all assignee types, unassigned patents have the lowest quality. The large portion of Canadian inventions remains unassigned. We find the highest number of unassigned patents in the field of consumer goods (16.62%), followed by civil (11.08%), transportation (8.03%), and so on. Figure 3-2 shows that over time, the quality of Canadian patents has improved. The boxes show the median and interquartile range. The added line, which extended out of the boxes, shows the position of mean values. If we closely look at the medians, means, and quartiles, we see the quality of the patents increased in the 1996-2014 period.

Figure 3-2: Quality of Canadian Patents by Ownership

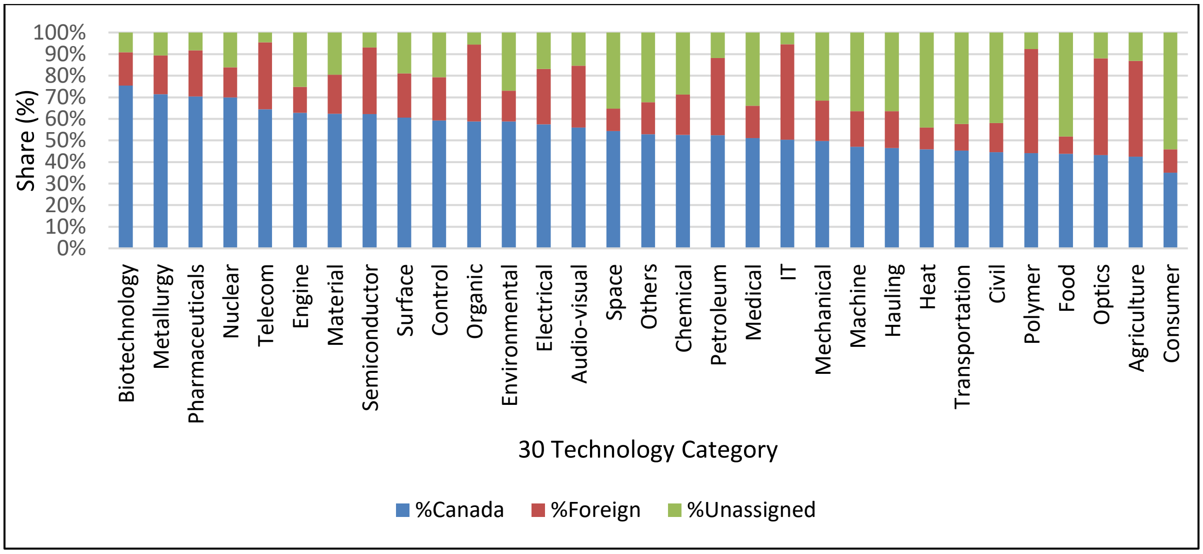


3.5.2 Technological Composition and Canadian Invention Ownership

We converted the technology embedded in each patent into 30 technology categories. We then group the technologies according to patent ownership. Canada's top three technologies, in terms of a number of patents, are telecommunications (11.08%), information technology (10.47%), and consumer goods & equipment (7.04%). However, both the telecommunications and information technology patents sharply increased since 1995 (see Appendix V for the number and share of invention ownership by technology class). Figure 3-3 depicts the share of ownership by each technology class for the period between 1976 and 2014. Among the top 10 technologies in terms of a number of patents, information technology has the highest share of foreign assignees (44%), followed by telecommunications (31%), and electrical (26%). Consumer goods & equipment has the highest share of unassigned patents (54%), followed by civil (42%), and transportation (42%) in the top 10 technologies classes. Among the top ten technology areas, pharmaceutical (70%)

has the highest share of local assignees, followed by telecommunications (64%), and measurement & control (59%).

Figure 3-3: Share of Invention Ownership by Technology Classification, 1976-2014



Blackberry Limited and Nortel Limited owned 22.25% and 17.48% of all telecommunications patents assigned to Canadian entities. Blackberry also owns the highest share of information technology patents (14.28%) in Canada. After observing Figure 3-3, we can conclude that ownership of Canadian patents is not equally distributed among all types of technology areas; rather, it varies from technology to technology. Modern technology, such as information technology, telecommunications, optical engineering, and electrical, related patents are more owned by the foreigners; whereas, traditional technology, such as civil, mechanical, and chemical-related patents are more owned by the local assignees. This pattern matches the findings of Trajtenberg (2001), who find that foreign assignees are more interested in modern technologies, such as computer and communication-related fields.

Figure 3-4: Share of Foreign Assignees of Canadian Invention by Technology, 1976-2014

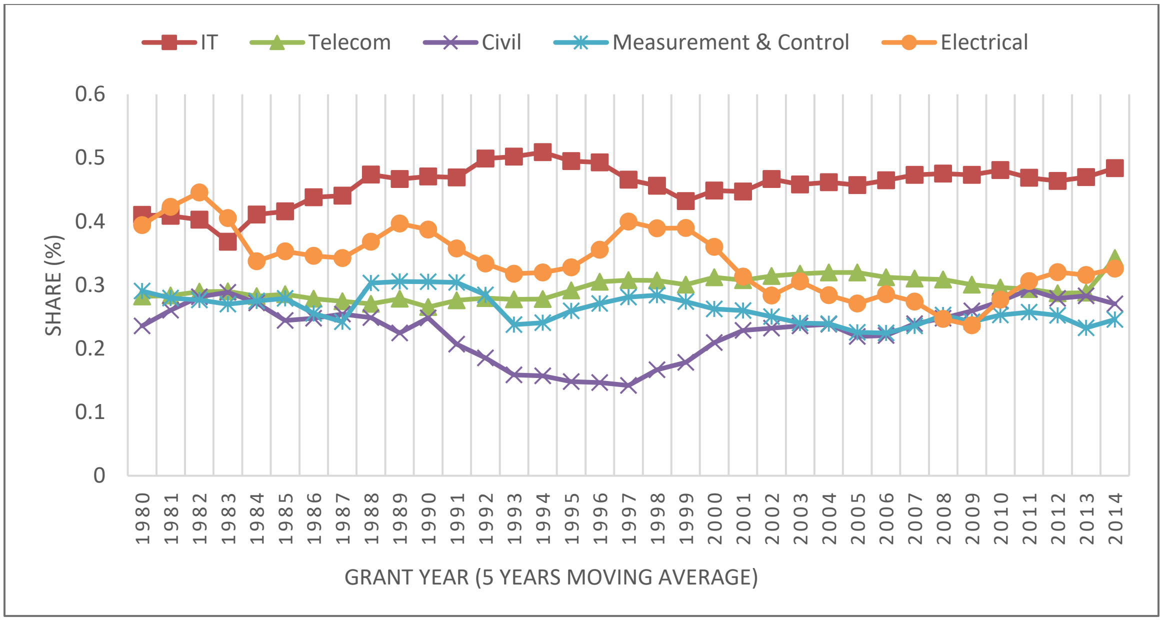


Figure 3-4 shows the share of the top five technology categories that are invented by Canadian inventors owned by foreign assignees. Except for civil, the shares of the other four technology classes are growing. Overall, foreign assignees owned 44% of the information technology patents invented by Canadians. Figure 3-4 shows the highest and persistence foreign-owned patents for the IT sector of Canada. In 1980, 40% of IT-related patents owned by foreigners that went up to 50% in 1994. During the period between 1995 and 2014, foreigners owned approximately 45%, and domestic assignees owned 55% of IT-related patents. This pattern can be explained by the presence of two giant corporations across the border, namely IBM Corporation and Blackberry Limited. IBM corporation owns 27.46% of IT patents assigned to foreigners, whereas, at the same time, Blackberry owns 26.58% of IT patents assigned to Canadians. We observe the zigzag pattern of foreign ownership of electrical-related patents. The highest 33% of the electrical patents are owned foreigners in 1996, then it started declining and reached the lowest point, with 15% of foreign-owned patents in 2001. Since then, the share started increasing. IBM owns 6.40% of Canadian invented electrical patents, whereas, in Canada, Nortel owns the highest share (12.15%). We observed a steady flow of telecommunication patents with movement around 30% of foreign-owned shares over the years except for 2014. In 2014, foreign assignees owned 50% of the telecommunication patents. Among the foreign assignees, only the Swedish company Ericsson owns 64.68% patents. The Ericsson owns approximately 13% of all foreign-owned telecommunications patents, whereas, in Canadian assignees, both the Blackberry and Nortel capture approximately 33% and 26% patents, respectively. The share of foreign-owned patents related to measurement and control technologies started increasing since 1991 and reached a maximum of 26% in 2008, although initial decreasing then increasing patterns between 1980 and 1990. We did not observe any dominant corporation in the home or abroad who control a significant portion of this technology. Rather, many companies in diversified fields own the measurement & control related patents of Canada, including Honeywell (4.22%), Xerox (2.57%), Schlumberger (2.14%), General Electric (2.07%), and French company Alcatel Lucent (2.71%). In Canada, Blackberry owns 4.28% of the measurement & control related patents. In general, civil engineering shares the lowest portion of the foreign-owned patents. The declining share of foreign ownership of the civil patents reached its lowest level with a 4% share in 1993. Then the share started increasing and reached a maximum point with 25% foreign-owned shares. Since then, its share has been declining. Among the foreign assignees, Halliburton Inc. and Schlumberger own approximately 9% and 6% patents, respectively.

Foreign owners are not equality interested in all technologies developed by Canadian inventors. They are more interested in technologies related to information technology, telecommunications, optical engineering, and electrical engineering. As we see in Table 3-3, the share of foreign ownership of the technologies, as mentioned above, has increased in the 1996-2014 period than that of the 1976-1995 period. Both the Canadian and foreign firms almost equality dominate the IT and optical engineering sectors. If we look at the traditional sectors such as civil, mechanical, and chemical engineering sectors, we observe that between the period of 1976-1995 and 1996-2014, local assignees owned most of the patents.

Table 3-3: Comparison of Local & Foreign-Owned Canadian Patents in the Top 10 Technology Classes, 1976-2014

Technology Class	**Share of Patent Ownership (%)**				**The average number of Patent Claim**			
	1976-1995		1996-2014		1976-1995		1996-2014	
	Canada	Foreign	Canada	Foreign	Canada	Foreign	Canada	Foreign
IT	52.38	43.03	43.85	44.31	12.73	12.65	19.30	19.77
Telecom	67.44	26.25	63.66	32.27	13.32	12.85	19.58	19.82
Biotechnology	78.90	14.36	74.12	15.75	13.38	11.22	18.16	20.45
Pharmaceuticals	78.48	12.90	68.15	23.76	13.54	12.08	18.75	19.95
Optics	45.37	34.68	42.52	47.70	12.49	13.59	20.12	21.30
Civil	32.57	8.010	50.14	16.26	12.42	12.04	19.40	19.79
Control	47.80	19.15	63.37	20.28	12.90	11.97	19.41	20.01
Electrical	45.43	24.76	61.36	25.87	12.50	12.09	20.55	19.47
Mechanical	34.00	11.07	56.87	22.08	12.74	14.22	18.97	18.89
Chemical	40.83	14.67	57.51	20.43	13.79	11.13	20.35	20.10

Table 3-3 presents some stylish facts. First, from 1976 to 1995, Canadians own comparatively more patents in the different technology classes except for optical and mechanical engineering. However, between 1996 and 2014, except for electrical, mechanical, and chemical, the share of ownership is comparatively higher in each of the other seven technology areas. Second, the share of ownership is rising for the Canadian assignees in the traditional fields of technology, where the share of foreign ownership in growing for modern technologies. Third, in general, the quality of the patents is rising over time whether owned by Canadian or foreign assignees. And fourth, except for electrical, mechanical, and chemical patents, the quality of the patents is better than that are owned by foreign assignees during the period of 1996-2014. Our results match with results of the Trajtenberg (2001), and Beaudry & Schiffauerova (2011), who find that compare to local owned patents, better quality patents are owned by foreign assignees.

3.5.3 Invention Ownership Structure in Canadian Metropolitan Areas

We compare the ownership of Canadian invention in 33 Census Metropolitan Areas (CMA) of Canada (see Appendix W for the number and share of invention ownership by CMA). 81% of patents are originated from the 33 CMAs, and the rest of 19% is originated from the other areas of Canada. Innovative activities are not evenly distributed across Canada. Approximately 60% of all the patents are originated from the six CMAs, including Toronto (21.94%), Ottawa-Gatineau (10.58%), Montreal (9.38%), Vancouver (8.76%), Kitchener-Cambridge-Waterloo (5.67%), and Calgary (3.36%).

Figure 3-5: Share of Invention Ownership by Top 10 Census Metropolitan Areas (CMA) of Canada, 1976-2014

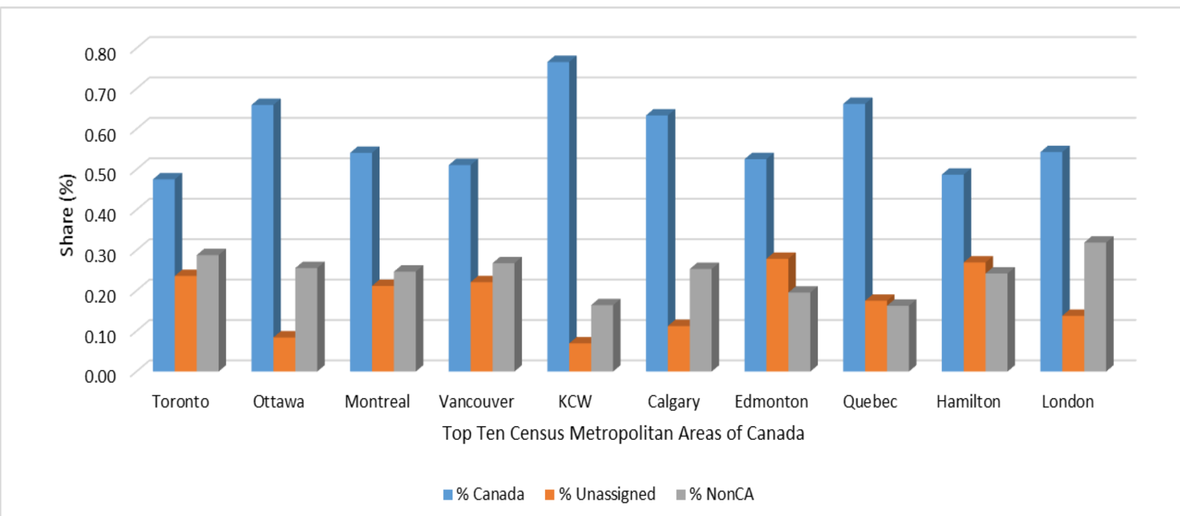
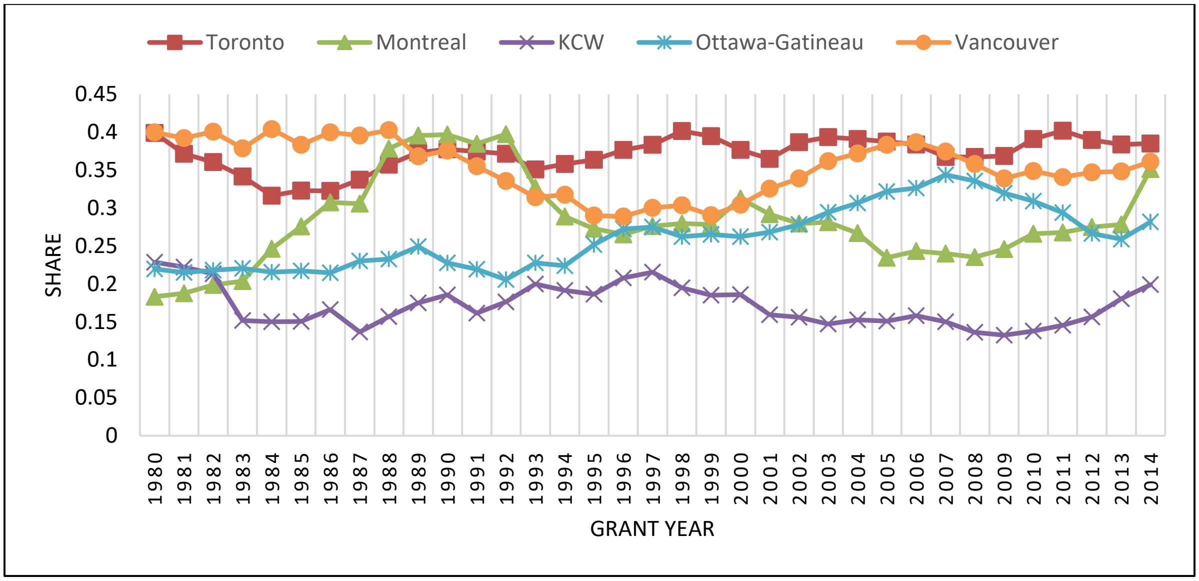


Figure 3-5 compares the share of ownership of Canadian invented patents in the top 10 CMAs of Canada. The highest share of patents that are assigned to Canadian entities is invented in CMA of Kitchener-Cambridge-Waterloo (77%). Only 7% of patents remained unassigned that are originated from the KCW. Among the assigned patents in KCW, Blackberry Limited (previously known as Research in Motion) owns 57% patents. This observation reminds us of the importance of the presence of an ‘anchor tenant’ in an area (Agrawal & Cockburn, 2003; Wolfe & Gertler, 2004). The presence of an anchor firm enhances the regional system of innovation. In KCW, Blackberry performs the role of an anchor tenant.

Among the top 10 CMAs based on the number of patents, the highest share of patents assigned to foreigners invented in London (32%), followed by Toronto (29%) and Vancouver (27%) (see Appendix E for all other CMAs). In London, a higher share of foreign assigned patents is related to petroleum (86%), agriculture (78%), and organic chemistry (71%). The US PTO granted the highest number of patents to the inventors of Toronto (22,754 patents, 21.94%). The top three patented technologies that are invented in Toronto by the Canadian inventor, but assigned to foreigners are IT, optical, and electrical engineering; among the three, optical engineering has the highest share of foreign owners (80%), followed by IT (60%), and electrical related patents (32%). Foreign assignees are also owned more than 50% shares of macromolecular chemistry & polymer (77%), and semiconductor (57%) related technologies that are originated from Toronto. The top three technologies with foreign owners in Vancouver are telecommunications (59%), IT (54%), and audio-visual (47%). Among the unassigned patents, Edmonton has the highest share (28%), followed by Hamilton (27%), and Toronto (24%).

Figure 3-6 shows the temporal pattern of the foreign assignment of Canadian invention originated from the top five CMAs of Canada. The pattern is not the same for all CMAs. If we look at the share of Toronto, we see the share of foreign assignee comparatively stable with little variation between 30% and 40% up until 1988. Since then, it varies between 35% and 40%.

Figure 3-6: Trend of Foreign Assignment of Canadian Patent from Top Five CMAs, 1976-2014



Since 2010, the share of foreign assignees has been growing steadily from Toronto. From 1984 to 1993 foreign share of Vancouver invented patents is decreased by 48.48%. Since then, they started increasing and reached a maximum of 39% in 2010. The rapid increase of foreign share during this period due to the increase of foreign shares in IT, Telecom, audio-visual, electrical, and pharmaceuticals related technologies. Throughout time, we observed the lowest share of foreign assignees in the region of Kitchener-Cambridge-Waterloo (KCW). In 1997, 21.56% of patents were owned by foreigners, whereas, in 2009, it reached the lowest level of 13%. This lowest share of foreign assignees in KCW can be explained by the presence of Blackberry, which owns most of the patents. The share of foreign-owned patents is not smoothly distributed in the case of Montreal. Initially, the share increases and reached at the maximum point with 45% in 1988, since then, in general, the share of foreign-owned patents was declining till 2001; after that, the share started increasing and reached the maximum level with 58% foreign-owned patents due to the patents of IT, telecommunications, and pharmaceuticals. Montreal invented technologies that are owned by foreigners are telecom (71%), IT (41%), organic chemistry

(44%), and pharmaceuticals (32%). The foreign share of Ottawa's patents was slowly increasing since 1992 and reached a maximum of 34% in 2007. Ottawa's top three foreign-owned technologies are IT (40%), Organic chemistry (31%), and telecommunications (28%). Ottawa's share started declining since 2007 due to a declining number of patents in electrical, civil, consumer electronic, optical, and organic chemistry-related patents. Ottawa's foreign-owned share again increased since 2011 due to IT and telecommunications-related patents.

In Table 3-4, we show a snapshot of the ownership and patent quality of the top ten CMAs of Canada. In general, both the shares of Canada and foreign-owned patents increased during the period between 1976 and 2014; this result is due to the decreasing share of the unassigned patent (see Figure 3-1). If we compare the average number of patent claims from 1976 to 1995 with that of 1996-2014, we see that the quality of the patents has increased over time. This observation matches with the Tong & Frame (1994)'s the result, who observed the increasing trend of an average number of patent claims when comparing the patent data of various countries.

Table 3-4: Comparison of Local & Foreign-Owned Canadian Patents in the Top 10 Metropolitan Areas, 1976-2014

Census Metropolitan Area	**Share of Patent Ownership (%)**				**The average number of Patent Claim**			
	1976-1995		1996-2014		1976-1995		1996-2014	
	Canada	Foreign	Canada	Foreign	Canada	Foreign	Canada	Foreign
Toronto	38.35	22.17	51.07	31.35	12.3	12.44	19.71	20.14
Montreal	42.9	18.33	58.32	27.13	12.25	12.55	19.79	19.97
Vancouver	42.08	22.1	54.42	28.55	12.82	13.17	19.32	20.14
KCW	69.74	16.01	78.31	16.53	13.41	12.51	19.13	19.53
Ottawa	66.21	20.02	65.87	27.4	13.11	12.79	19.68	19.86
Calgary	67.28	20.71	62.27	26.67	12.91	12.28	19.04	19.57
Edmonton	40.53	19.17	62.27	26.67	12.89	12.39	19.63	19.08
Quebec	53.06	12.61	70.73	17.52	12.26	14.51	19.62	19.35
Hamilton	45.3	14.42	50.1	28.2	12.14	11.21	19.8	19.46
London	49.02	15.87	55.49	35.54	13.74	12.93	20.45	17.63

The quality of the patent varies across the CMAs over time. In 1976-1995, relatively higher quality patents that are invented in KCW, Ottawa, Calgary, Edmonton, Hamilton, and London were owned by local assignees. However, higher-quality patents that are invented in Toronto, Montreal, Vancouver, and Quebec went to foreign hands. Again, in the period between 1996 and 2014, the higher quality patents that are owned by foreigners are invented in CMAs of Toronto, Montreal, Vancouver, Kitchener-Cambridge-Waterloo, Ottawa, Calgary, and Hamilton. In the same period, higher quality patents are invented in Edmonton, Quebec, and London are owned by local assignees.

3.6 R&D and Ownership of Patents: An Extension

To investigate the owners of Canadian inventions, we compare the ownership of patents with the share of R&D of the top 100 corporate R&D spenders of Canada. Every year RE$EARCH Infosource Inc. publishes a list of Canada's top 100 corporate R&D spenders since 1999. Table 3-5 combine the sixteen years of data during the period of 1999-2014 for those firms that have patents in the USPTO. Since the list consists of only the top 100 companies of each year, a company might not be on the list every year. Moreover, a company may not go for a patent for its invention. Hence, caution should be maintained to read the Table.

Table 3-5: Relationship between Share of Patent Ownership and Share of R&D, 1999-2014

Industry Classification	No. of Firms		Amount of R&D		Share of R&D (%)		No. of Patents by Owner		Share of Patent Ownership (%)	
	CA	FS	CA	FS	CA	FS	CA	FS	CA	FS
Aerospace	3	3	12171688	7881291	0.61	0.39	349	994	0.26	0.74
Agriculture & Food	0	1	0	126845	0.00	1.00	0	178	0.00	1.00
Automotive	5	1	9355212	655446	0.93	0.07	419	31	0.93	0.07
Chemicals & Materials	0	2	874847	179551	0.83	0.17	129	124	0.51	0.49
Comm/Telecom Equipment	19	7	50053659	6554094	0.88	0.12	10666	1689	0.86	0.14
Computer Equipment	2	1	441049	202045	0.69	0.31	46	100	0.32	0.68
Electrical Power & Utilities	3	0	2699016	0	1.00	0.00	11	0	1.00	0.00
Electronic Systems & Parts	12	3	3207104	3152644	0.50	0.50	402	270	0.60	0.40
Energy/ Oil & Gas	18	1	12676401	251000	0.98	0.02	866	3	1.00	0.00
Engineering Services	1	0	308092	0	1.00	0.00	2	0	1.00	0.00
Forest & Paper Products	4	0	1601180	251400	0.86	0.14	86	0	1.00	0.00
Health Services	1	0	734300	0	1.00	0.00	107	0	1.00	0.00
Machinery	1	1	1106115	328205	0.77	0.23	181	1797	0.09	0.91
Medical Devices & Instrumentation	5	0	709510	0	1.00	0.00	120	0	1.00	0.00
Mining & Metals	4	5	2684153	1311875	0.67	0.33	686	86	0.89	0.11
Other Manufacturing	6	1	594499	38176	0.94	0.06	113	229	0.33	0.67
Pharmaceuticals/ Biotechnology	38	19	11394693	12924597	0.47	0.53	666	959	0.41	0.59
Printing	1	0	81400	0	1.00	0.00	1	0	1.00	0.00
Rubber & plastic	1	0	71130	0	1.00	0.00	1	0	1.00	0.00
Software & Computer services	5	1	8523539	5819300	0.59	0.41	90	1588	0.05	0.95
Telecom Services	12	1	16559143	0	1.00	0.00	227	49	0.82	0.18
Transportation	3	0	1124161	0	1.00	0.00	64	0	1.00	0.00

Note: R&D data and Industry Classification are based on Research Info Source's yearly publication of Canada's Top 100 corporate R&D spenders (https://researchinfosource.com/). I accumulated data for the period of 1999-2014. Then, I find the patent data of those companies from the USPTO. CA means Canada & FS means Foreign Subsidiary.

Table 3-5 shows that the share of ownership varies in the different industry sectors. For instance, in the aerospace sector, 74% of patents are owned by the foreign subsidiaries of Honeywell Inc., Pratt & Whitney, and Lockheed Martin. All these US subsidiaries spent 39% of total R&D in the aerospace sector in Canada during the period between 1999-2014. 59% of patents of the pharmaceuticals and biotechnology sector are owned by foreign subsidiaries that spent 53% of the total R&D of that sector. In the machinery sector, 91% of the total patents went to the Xerox Corporation, which spent 23% of the total R&D of that sector in Canada.

3.7 Conclusions

In this study, we explore the patent ownership patterns of the technologies that are invented by Canadian inventors during the period between 1976 and 2014. This study finds that although the number of Canadian inventions is growing over time, the share of ownership of those patents is increasingly going to the hands of foreigners in some key technology sectors, such as information technology, telecommunications, electrical, and optical engineering. Traditional technology sectors, such as civil, mechanical, and chemical, are dominated by the local assignees. The United States is the main destination of the Canadian invented patents. The share of foreign ownership is steadily increasing in most technology classes since 1995. The share of ownership varies from one metropolitan area to another across Canada. In general, the quality of the foreign-owned patents is higher than that of local owned patents. Approximately 23% of patents that granted to Canadian inventors by the US PTO remained unassigned. The quality of those patents is comparatively low in all technology categories. The share of unassigned patents is significantly declining over time that indicates the growing applicability of Canadian inventions.

Policymakers might be interested in the results of the study to pinpoint Canada's strengths and weaknesses in various technology sectors in terms of patent ownership and patent quality. As an extension, this study further classifies the firm-level patents based on its industry sector, ownership, and yearly R&D spending. In the extension, this study only focuses on those firms' data that are listed in the top 100 Canadian R&D spenders during the period between 1999 of 2014. It would be better if future studies collect data for all the firms that are listed in the USPTO patents granted to Canadian inventors between 1976 and 2014. To identify the ownership, this study classifies the firms in two groups: (i) a firm considered as a Canadian firm whether it is located in Canada or its subsidiary in abroad, and (ii) a firm considered as foreign if it is a foreign subsidiary located in Canada or in abroad. Future researchers can classify the patents into four groups, namely Canadian firms located in Canada, a Canadian subsidiary located abroad, a foreign subsidiary located in Canada, and a foreign subsidiary located abroad.

Chapter 4: University IP Policy and Determinants of Funding

4.1 Introduction

Research and development (R&D) increase the stock of knowledge, which in turn leads to the creation of new products (OECD, 2015). The creation of new knowledge and innovation is crucial as it is an important source of economic growth (Adams, 1990; Mansfield, 1991; Romer, 1990). One of the main sources of knowledge is the invention created by the university, and in most countries, the government actively supports university research to advance scientific knowledge (Rosenbloom et al., 2015).

Canada's federal government spends billions of dollars every year through its various agencies to stimulate innovation across the universities in Canada. Traditionally, the role of universities was to conduct basic research in wide scope research areas funded by the government, and firms take the outcomes of basic research to perform applied research to develop solutions to problems triggered by a society. Today the transfer of research and its outcome from university to industry becomes a global trend as many governments try to reform their national innovation systems (Poyago-Theotoky et al., 2002; Rasmussen, 2008). In 2002, the Government of Canada released its innovation strategy that emphasized on the commercialization potential of federally funded academic research (Government of Canada, 2002). Moreover, in recent years, universities have been facing challenges to convert their research outputs into commercially appropriable knowledge due to budgetary pressures (Bolli & Somogyi, 2011). To meet the government mandate and solve financial problems, Canadian universities started to encourage their researchers to engage in projects with more commercialization potential. Given this changed research focus in Canadian universities, an interesting research question is to analyze whether the number of patents can predict the amount of funding to universities.

Existing literature measures the impact of funding on research output in terms of the number of patents (Payne & Siow, 2003; Beaudry & Allaoui, 2012), the number of publications (McAllister & Narin, 1983; Adams & Griliches, 1998; Lewison & Dawson, 1998; Benavente et al., 2012), and the number of citations of publications (Boyack & Borner, 2003; Jacob & Lefgren, 2011; Rosenbloom et al., 2015). By focusing on the opposite effects, this study investigates whether the number of patents determines the types and amounts of federal funding. Using the panel data of 54 Canadian universities for thirteen years between 2000 and 2012, this paper addresses the following two questions: (i) does university intellectual property (IP) policy affect the number of patents generated by a university? And, (ii) does the number of patents affect the amount and sources of federal funding to universities?

This study makes several contributions. First, this is one of the first studies which compares different kinds of IP ownership policies of Canadian universities to predict patenting behavior. The findings of this study will help policymakers decide about a uniform IP policy for Canadian universities that generates more patents. Second, this study investigates whether patents predict the amount of funding from different sources. The results of the study showed that the university's IP ownership policy has a significant impact on the number of patents generated by the university. Any IP ownership policy has a positive impact on the number of patents generated by the university, compared to no policy at all. The inventor-owned IP policy is the best predictor of the number of patents. The joint-owned IP ownership policy, which is a combination of inventor-owned and university-owned IP ownership policies, is better than university-owned IP policy in terms of generating patents. The number of patents positively predicts Tri-council funding to universities. Among the Tri-council agencies, funding from the CIHR and the NSERC are strongly affected by the number of patents, and the funding of CFI and CRC is somewhat positively affected by the number of patents. This study also finds that private donations are increased most by the number of patents, and universities with less than four patents are negatively related to private funding. Our estimates find that universities with more than four patents would get $55 million from the Tri-council, $10 million from the CFI, and $52 million from the private donations. This study suggests that the number of patents is particularly important to get funds from the private sector.

This paper is structured as follows: section 4.2 summarizes the different kinds of IP ownership policies that are in practice in Canadian universities; section 4.3 discusses the various kinds of Canadian government funding programs, section 4.4 focuses on the theoretical background of the study and hypotheses development, section 4.5 explains the data and research methodology, section 4.6 presents and discusses the results, section 4.7 provides robustness of the results of the study, and section 4.8 presents conclusion.

4.2 University IP Ownership Policy: A summary

Universities have long been getting pressure to convert their research outputs into commercially suitable knowledge (Henderson et al., 1998). Several kinds of literature show a positive impact of university research on economic growth (Adams, 1990; Mansfield, 1991; Zucker et al., 1998; Cohen et al., 2002; Toole, 2012), and university inventions can become practical innovations through the process of commercialization (Greenhalgh & Rogers, 2010). During the past few decades, many universities implemented various measures to encourage the commercialization of inventions developed by their faculty members and researchers. One of the measures is the ownership of the intellectual property rights developed by the university. While some countries, such as the United States, the United Kingdom, Australia, and Japan, have a national policy on the university IP ownership, other countries, such as Canada does not have a uniform policy. As a result, Canadian universities are free to implement their policies (Robinson, 2006; Baere & Maine, 2017).

The US Bayh-Dole Act was implemented in 1980 to encourage the commercialization of university research. This act mandates that patents developed by university researchers are owned by the university, a protocol commonly known as ‘university-owned IP ownership policy.’ Most European countries, with a few exceptions (Italy and Sweden), have also adopted the university-owned IP policy (Geuna & Rossi, 2011). In Canada, the federal government does not regulate the technology transfer of university research outputs (Atkinson & Grosjean, 2002; Robinson, 2006; Baere & Maine, 2017), and thus some universities adopted in ‘inventor-owned’ policy in which university researchers can own patent rights on the inventions conducted with university resources and other universities adopted the university-owned IP ownership policy (Robinson, 2006; Trosow et al., 2012). For example, the University of Waterloo and the University of Alberta follow the inventor-owned policy, while the University of British Columbia and the University of Saskatchewan follow the university-owned policy. A few universities, such as the University of Toronto and McGill University, have a joint-owned IP policy, which is the combination of inventor-owned policy and university-owned policy (see Appendix Y for the IP ownership policy of other universities).

The Bayh-Dole Act is the basis of the university-owned IP ownership policy in the United States, and several studies examine the impact of the Bayh-Dole Act. Henderson et al. (1998) show the positive effect of the Bayh-Dole Act on the number of university patents, industry funding, and university ‘technology-transfer’ offices, and its negative impact on the ‘quality’ of university patent. On the other hand, Sampat et al. (2003) and Mowery et al. (2001) show that the Act had little effect on the content of academic research and did not motivate the inventors. A few other studies criticize the university-owned IP ownership model and suggest alternatives. Kenney & Patton (2009) argue that the university-owned IP ownership policy failed to provide effective incentives for inventors, universities, and potential licensees and propose the inventor-owned IP ownership policy. In another study, Kenney & Patton (2011) show that the inventor ownership model has a positive impact on entrepreneurship generated by the universities; however, they compared only six universities in which one university is the follower of the inventor ownership model.

Under the inventor-owned IP ownership model, inventors can patent their inventions even if the inventions are developed through public funding. The advantages of this model include (i) it helps create more spin-offs (Kenny & Patten, 2011; Astebro et al., 2012), (ii) it reduces the barriers between inventor and market to stimulate commercialization of technologies (Grimaldi et al., 2011), and (iii) it increases efficiency by transmitting R&D funding to university startup companies (Ramli & Zainol, 2014). Its disadvantages are that (i) it is costly for individual researchers to patent the inventions, (ii) licensing and commercialization activities are limited due to individual researchers’ lack of relevant knowledge (Greenbaum & Scott, 2010), and (iii) inventors may face challenges of getting outside investment to develop further their initial invention for commercialization (Wood, 2011).

This study collected the IP ownership policies of 54 Canadian universities and classified them into four broad classes: no IP policy, university-owned policy, inventor-owned policy, and joint-owned IP policy in which the ownership is jointly assigned to the inventor and university.

4.3 Canadian Government Funding Programs

Research funding plays a pivotal role in the development of research (Lok, 2010), and the government is a major source of funding for university research. Canada's government expenditure on research is among one of the highest in the world (Rasmussen, 2008). This section briefly describes six major funding programs of the Government of Canada, which are closely related to research conducted by Canadian universities. Table 4-1 reports the yearly funding to Canadian universities by the various agencies of the Canadian government.

Table 4-1: Yearly Federal Funding for R&D in Canadian Universities

(Values in millions of dollars)

Year	SSHRC	HC	NSERC	CHIR	CFI	CRC
2000	84.8	38.5	421.1	294.9	120.0	0.0
2001	96.9	40.3	451.1	327.3	198.6	19.4
2002	97.4	33.9	452.6	418.3	190.0	52.5
2003	112.9	42.9	461.6	501.5	346.8	101.3
2004	142.2	29.0	518.2	552.8	381.1	153.9
2005	164.0	29.3	560.9	605.2	296.4	175.2
2006	179.5	35.8	564.0	684.7	364.8	208.9
2007	179.7	40.9	617.8	674.7	310.3	239.8
2008	192.4	55.2	661.3	716.2	352.3	213.7
2009	207.5	33.7	670.7	785.3	272.9	216.9
2010	220.9	50.0	748.9	814.1	320.6	236.9
2011	217.1	25.4	689.7	810.1	412.3	236.2
2012	209.7	24.6	682.8	822.4	356.7	255.3
Total	2104.8	479.5	7500.6	8007.5	3922.6	2110.1

Source: Compiled by the researcher using data from the Statistics Canada's Financial Information of Universities and Colleges Survey (FIUS)

Natural Sciences and Engineering Research Council (NSERC), which was created on May 1, 1978, supports university students in their advanced studies, promotes and supports discovery research, and fosters innovation by encouraging Canadian companies to participate and invest in postsecondary research projects. NSERC provides supports for every stage of research, from initial discovery to final innovation. NSERC invested $1.2 billion in 2016-2017. NSERC invests in more than 41,000 talented students and professors in universities and colleges across Canada. NSERC is the largest source of funding for natural sciences and engineering research in Canada.

Canada Research Chairs (CRC) Program, created in 2000, invests approximately $265 million per year to attract and retain some of the world's most accomplished and promising minds. The chair holders aim to achieve research excellence in engineering and the natural sciences, health sciences, humanities, and social sciences. The government of Canada set up 2000 research chairs among seventy-six participating Canadian universities. There are two types of Canada Research Chairs, namely, Tier 1 and Tier 2. Tier 1 chair, which is given for seven years and renewable once, for outstanding researchers who have the potential to be world leaders in their fields. An institution gets 200,000 per year for seven years for each Tier 1 chair. Tier 2 chair, which is given for five years and renewable once, is for emerging exceptional researchers who have the potential to lead their fields. An institution receives 100,000 per year for five years for each Tier 2 chair.

Canadian Institutes of Health Research (CIHR), established in 2000, is a federal funding agency composed of 13 Institutes. CIHR collaborates with partners and researchers to support discoveries and innovations that improve health and strengthen the health care system in Canada. CIHR plays a leading role in supporting the creation of new knowledge and converting knowledge into the development of improved health services and products. CIHR integrates 13 unique interdisciplinary institutes, which help to collaborate with partners and researchers to support the discoveries and innovations that improve health and strengthen the health care system in Canada. CIHR invests approximately $1 billion every year; the finding is divided into two main areas of research: investigator-driven and priority-driven. Approximately three-quarters of the $1 billion budget is used to support investigator-driven research. Usually, investigator-driven funding is provided through the Foundation Grant program, the Project grant program, and the Tri-council career and training programs, such as Canada Research Chairs, Banting Postdoctoral Fellowships, and Vanier Canada Graduate Scholarships. Investigator-driven research is also known as “curiosity-driven” or “open” research. Investigator-driven funding is allocated to projects created by individual researchers and their teams. Priority-driven funding is allocated to the projects that investigate specific health issues identified by the Canadian government.

Canada Foundation for Innovation (CFI), created in 1997 by the Government of Canada, is an independent not-for-profit organization that invests in research infrastructure in Canada’s universities, colleges, research hospitals, and non-profit research institutions to help build and sustain a research landscape in Canada. Since 1997 CFI invested $18.3 billion in the development of research infrastructures that gives researchers the tools they need to think big and innovate. CFI funding is awarded to institutions, and all funding proposals must support an institution’s strategic research plan. CFI funds up to 40 percent of a project’s research infrastructure costs. The funding is then leveraged to attract the remaining investment from partners in the public, private, and non-profit sectors.

Social Sciences and Humanities Research Council (SSHRC) was created by an Act of Parliament in 1977. SSHRC promotes and supports university-based research and research training in the humanities and social sciences. SSHRC helps to develop talent, generate insights and forge connections across campuses and communities. The goal of SSHRC is to support research that will stimulate innovative thinking about issues that affect the quality of life. SSHRC's grants and scholarship budget for 2017-18 was $388.2 million.

Health Canada (HC), created in 1993, is a federal department of the Government of Canada. Health Canada supports research to discover better solutions to deal with health-related concerns. Health Canada offers several grant and contribution programs for researchers whose works can enhance the health of all Canadians. Health Canada's visiting fellowship program supports scientists to work at government laboratories, which help scientists to work with experienced Health Canada scientists and researchers.

4.4 Theoretical Background and Hypotheses Development

This paper is related to two streams of literature: one being the university IP ownership policy and other being the determinants of federal funding to the universities.

University IP ownership related literature focuses on the impact of alternative IP ownership structures on technology commercialization of universities. Hoye (2006) analyses the relationship between IP policies and university technology transfer using the IP of 37 Canadian universities and finds no statistically significant relationship. Using 527 university spin-off data collected from the Technology Transfer Offices (TTO) during 1957-2009, Kenny & Patton (2011) found that the 'inventor-owned IP ownership' model is more efficient for generating a spin-off. Using survey data of six European countries, Crespi et al. (2010) show that the value of 'university-owned' patents is statistically similar to the value of 'university-invented' patents. With a sample of 858 university and Public Research Organization patents from a PatVel II survey conducted between 2010 and 2011 across 20 European countries, Giuri et al. (2013) analyzed the impact of 'university-owned' vs. 'university-invented' patents on the three commercialization channels: patent licensing, patent sale, and spin-off formation. They found that 'university-owned' policy positively impacts on the licensing of patents. However, existing literature did not study the impact of IP ownership policy on the patent generation of a university. As we mentioned in section 4.2, the inventor-owned IP model allows the inventor to own the patent of their inventions even if the inventions are developed through public funding. Moreover, inventor-owned IP model helps to create more spin-offs (Kenny & Patten, 2011' Astebro et al., 2012), reduces the barriers between inventor and market to stimulate commercialization of technologies (Grimaldi et al., 2011), and increases efficiency by transmitting R&D funding to university startup companies (Ramli & Zainol, 2014). Whereas, the university-owned IP ownership policy failed to provide effective incentives for inventors (Kenny & Patton, 2009). Hence our first hypothesis is:

> **H1:** Inventor-owned IP ownership policy is better than any other kind of policy for generating patents.

Most of the existing literature concentrates on the relationship between federal funding and its outcome. The federal funding is used as a predictor of research outcomes, such as the number of publications, quality of publications, the number of patents, and university-industry alliance formation. The literature shows that the federal funding positively impacts on the number of publication (McAllister & Narin, 1983; Adams & Griliches, 1998; Bolli & Somogyi, 2011; Whalley & Hicks, 2014), quality of the publications (Lewison & Dawson, 1998; Boyack & Borner, 2003; Benavente et al., 2012; Rosenbloom et al., 2015), and the number of patents (Payne & Siow, 2003). The literature that focuses on university-industry alliance formation finds that faculty members with greater federal funds have a greater propensity to become affiliated with industry (Bozeman & Gaughan, 2007; Blume-Kohout et al., 2015) and greater possibility to get non-federal funding (Blume-Kohout & Kumar, 2009). Moreover, federal funding increases the possibility of the university's collaboration with industry and technology transfer when it complements with funding from research contracts (Muscio et al., 2013). This study examines the opposite causal relationship and shows the impact of patenting on the various sources of federal funding to universities.

Table 4-2: Summary of the Literature Related to Funding of Universities

Author and Year	**Data**	**Type of analysis**	**Dependent variable**	**Main Findings (relationship with funding)**
Neumann (1978)	A stratified sample of 80 university departments	Pearson correlations	Funding in different fields	Articles predict funding
Coughlin & Erekson (1986)	52 research universities (1980-1981)	Cross-sectional OLS	State aid per student	Institutional quality, demand for higher education, legislative concern for equity & institutional effort, and success in intercollegiate are the significant determinants.
Caro et al. (2003)	A panel of 43 departments & institutes for the between 1991-2000	Iterated Feasible Generalized Least Squares (FLGS)	R&D funded by different sources	Patent attracts private funds, not public grants
Payne (2003)	Panel data of 220 Universities of the US (1973-1999)	Fixed Effect Panel Regression	Research finding to University	Politics play a role in distributing research funding to universities
Knott & Payne (2004)	Panel data of Carnegie (1994) class comprehensive and Ph.D. granting public universities of 48 states for the period of 1978-1998	Fixed Effect Panel Regression	Several variables, including the State appropriation of flagship universities	Medical schools, faculty size, and undergrad enrollment are positive predictors.
Figueiredo & Silverman (2006)	2382 Carnegie Foundation	Two-stage OLS	Academic earmark received by institutions	Universities that are represented by a House or Senate

	recognized institutions in 2000			appropriation committee member earn higher earmarks
Weerts & Ronca (2008)	Panel data of 1053 institutions of 50 States (1985-2004)	Random Effect panel regression	The first difference of the natural log of annual state appropriations	A number of Rational, political, and cultural determinants explain state support.
Cheslock & Gianneschi (2008)	Panel data of all public four-year institutions that offer an undergraduate degree have 2000 Carnegie classification of research/doctoral, masters, or baccalaureate of 47 states for 1994-2004	Pooled and Fixed effect regressions	Total fund per student	Previous years state appropriation is the main predictor, including other control variables, such as Barron's selectivity ranking, research/doctoral Carnegie class, etc.
Beaudry & Allaoui (2012)	Panel data of 5724 observations of 907 Quebec academics (1996-2005)	Cross-section Two-stage Residual Inclusion regression	The average amount of grant funding	Publications, research chair, and grant received by colleagues predict the grant funding

We can classify the literature that considers 'federal funding to universities' as a dependent variable into two groups. The first group focuses on the determinants of government funding for higher education at the state level and considers the impact of several institutional, political, and cultural factors as the determinants of funding (Coughlin & Erekson, 1986; Payne, 2003; Knott & Payne, 2004; Figueiredo & Silverman, 2006; Weerts & Ronca, 2008). The second group focuses on the determinants of government funding at the university level. The literature on the second group investigates whether number of publications, quality of publications, number of patents, university reputation, previous funding, previous research chairs, researcher's age, alma mater affiliation, lobbying, and other related variables predict federal funding (Neumann, 1978; Caro et al., 2003; Payne, 2003; Beaudry & Allaoui, 2012). Since universities have been facing challenges to convert their research outputs into commercially appropriable knowledge due to government and budgetary pressures in recent years (Government of Canada, 2002; Bolli & Somogyi, 2011), universities started to encourage their researchers to engage in projects with more commercialization potential (Langford et al., 2006; Bubela & Caulfield, 2010). And patents stimulate the commercial potential of university research (Caro et al.,2003). Given this situation, we develop our second hypothesis as follows:

H2: The number of patents positively affects the amount and type of funding.

4.4.1 Data

We use multiple data sources to measure the impact of patents on federal funding in Canadian universities: United States Patent and Trademark Office (USPTO), Statistics Canada's Financial Information of Universities and Colleges Survey (FIUS) data, Maclean's university guide, and Association of University Technology Managers (AUTM) data. The USPTO grants patents to inventors, firms, universities, and governments for their inventions. The FIUS is an annual publication that is jointly prepared by Statistics Canada and the Canadian Association of University Business Officers (CAUBO), a non-profit professional organization representing the chief administrative and financial officers at over 100 universities and affiliated colleges in Canada. FIUS is a valuable source of information for financial data of Canadian universities and colleges. Maclean's university guide provides data about the quality of Canadian universities. Maclean's data are generally accepted as the most comprehensive and reliable source of data for Canadian universities (Vaughan & Thelwall, 2005). AUTM provides a variety of data on licensing activity and income, startups, funding, staff size, legal fees, patent applications filed, royalties earned, and more. Moreover, we collected IP ownership policies of different Canadian universities from their websites (see Appendix Z). We assumed that IP policies have stayed static over the years.

Our analysis is based on a panel data of 54 Canadian universities from 2000 to 2012. We collect bibliographic patent data from the website of the USPTO (https://www.google.com/googlebooks/uspto-patents.html). From the databases, we only extracted those patents in which the assignee's name field consists of any Canadian university's name, and the patent grant year is between 2000 and 2012.

The dependent variables are the amount of yearly funding from various sources, whose data are collected from FIUS (http://odesi2.scholarsportal.info/webview/). Since both the HC and CIHR support health-related research, we combined 'HC' and 'CIHR' variables to create a new variable named 'HEALTH.' The wage and salary data of each university are from FIUS. The reputation of a university, operating budget of a university, and the number of faculty numbers with PhDs are collected from the Maclean's university guide (source: http://www.macleans.ca/education-hub/), which provides data about the quality of Canadian universities. We collected the number of start-ups formed by the university from AUTM data. Table 4-3 represents the summary statistics of dependent and explanatory variables.

4.4.2 Research Approach

The goal of this study is to investigate whether patents predict funding in Canadian universities. Hence, our dependent variable is funding, and the main independent variable is the number of patents. The control variables include the university's reputation, university size in terms of the operating budget, the number of start-ups formed from a university, wages of employees, and the number of faculty members with PhDs. Some variables have large outliers, leading to heteroscedasticity (Kennedy, 1979). To solve the problem of heteroscedasticity, we use the fixed effect panel Generalized Least Square (GLS) instead of OLS to estimate the sources of funding of Canadian universities. The estimation model is expressed in reduced form as follows:

$$Funding_{it} = f(Patents_{it}, Reputation_{it}, Operating\_budget_{it}, Startup\_formed_{it}, e\_Wage, PhDs_{it},) \quad [1]$$

The above-stated model faces the problem of endogeneity because the probability of getting patents depends on some other factors, including university IP ownership policy, the reputation of the university, operating budget of the university, and the number of start-ups formed. To correct the endogeneity problem, we use the two-stage regressions. In the first stage, we estimate the endogenous variables $patents$ with the conditional fixed-effects Poisson regression on several exogenous variables. The dependent variable 'patents' has many zeroes, and the classical Ordinary Least Square (OLS) regression is not appropriate (Hausman et al. 1984; Cameron & Trivedi, 1986). In the Poisson model, the conditional probability density function for patent i in year t is given by $Pr(Y_{it} = y_{it}|X_{it}) = \frac{e^{-\lambda_{it}}\lambda_{it}^{y_{it}}}{y_{it}!}$. This exponential form of the Poisson model ensures non-negativity. The main independent variable 'IP ownership policy' has four types: (i) no IP policy, (ii) inventor-owned IP policy, (iii) university-owned IP policy, and (iv) joint-ownership IP policy. The predicted residual values of the first stage regression are computed and use as explanatory variables in the second stage model.

As the number of patents depends on the university IP ownership policy, we use a dummy variable for IP policy in the first stage regression. To measure the 'quality' of a university, Maclean's uses six broad areas: the student body, classes, faculty, finances, library, and reputation. Maclean's uses several variables under the six broad areas. To address the endogeneity problem of the ‘patents’ variable, we use the Maclean’s’ ‘reputational survey,’ ‘operating budget’ as the control variables. Since the number of patents is related to the number of start-ups formed, we also use AUTM’s ‘startup formed’ variable as another control variable. After defining the controls, we have the following first stage regressions expressed in reduced form as:

$$Patents_{it} = f(Uni\_ipr\_policy_{it}, Reputational\_survey_{it}, Operating\_budget_{it}, Startup\_formed_{it}) \quad [2]$$

When we estimate the impact of patents on the funding sources at the second stage, we include five control variables: the reputation of the university, operating budget of the university, number of start-ups formed, wages of employees, and number of PhDs. We expect that the control variables have a significant impact on the funding sources of any university. The second stage reduced form regression can be expressed as:

$$Funding_{it} = f(\widehat{patents}_{it},\ reputational\_survey_{it}, operating\_budget_{it}, startups\_formed_{it}, e\_wages_{it}, Phds_{it}) \quad [3]$$

We use the STATA procedure $xtpoisson$ for the first-stage regressions. For the second stage regression, we use $xtgls$. Since our data are not normally distributed, the standard errors are bootstrapped.

Table 4-3: Description of Variables Used in the Regressions

Variable	Description	Source	Obs	Mean	Std. Dev.	Min	Max
f_sshrc	SSHRC funding	FIUS	669	3,273	4,484	0	26,571
f_health	Health funding	FIUS	669	12,103	26,477	0	172,671
f_nserc	NSERC funding	FIUS	669	11,552	14,500	0	77,430
f_cfi	CFI funding	FIUS	669	5,939	10,952	0	97,286
f_crc	CRC funding	FIUS	669	3,251	5,672	0	42,448
f_gov	Other government funding	FIUS	669	120,387	218,828	0	1,173,489
f_priv	Private funding	FIUS	669	21,211	57,641	0	459,955
e_wage	Wage & salary expenditure	FIUS	669	232,165	264,864	0	1,858,021
patents_us	Number USPTO patents	USPTO	618	2.45	4.53	0	27.00
Ipr	University IP policy	Websites	669	2.14	1.11	0	3.00
Reputational Survey	University reputation rank	Macleans	617	8.91	5.35	1	22.00
Operating Budget	University operating budget rank	Macleans	617	8.91	5.35	1	22.00
Stupsformed	Startups formed	AUTM	669	0.92	2.22	0	23.00
Phds	Faculty rank with PhDs	Macleans	669	6.88	5.86	0	21.00

Notes: IPR is coded as 0=" none," 1=" university-owned," 2=" joint-owned," 3="inventor-owned." FIUS has nine income/expense categories as follows: C1 general operating, C2 special purpose and trust, C3 entities consolidated, C4 entities not consolidated, C5 subtotal, C6 ancillary enterprises, C7 capital, C8 endowment, C9 total fund. We use "total fund" for our data for each type of funding. Government funding is defined as other federal, provincial, municipal, other provinces, and foreign. Private funding is defined as individuals, business enterprises and not-for-profit organizations. Wage is defined as academic ranks, other instruction, and research, other salaries and wages, benefits and travel.

4.5 Results

The results of the first-stage regressions are presented in Table 4-4. We find that our key variable of interest 'IP ownership policy' positively affects the patenting behavior of universities at the 1% level of significance when we controlled the variables, including the reputation of the university, operating budget of the university, and a number of start-ups formed by the university. Table 4-5 shows that moving from no policy to university-owned policy significantly impacts on the number of patents. Going from university-owned policy to joint-owned policy, and joint-owned policy to inventor-owned IP ownership policy increases the number of patents.

Inventor-owned IP ownership policy, as expected, has the strongest influence on university patents.

Table 4-4: First-Stage Results: Determinants of Patents

Conditional fixed-effects Poisson regression	
	patents_us
University ipr policy	1.491^{***}
	(0.0689)
Reputationalsurvey	0.0513^{*}
	(0.0285)
Operatingbudget	0.0141^{**}
	(0.00665)
Stupsformed	0.0309^{**}
	(0.0121)
Number of Obs	456
Log likelihood	-569.9
chi2	351107.7
Number of groups	37
Smallest group size	3
Average group size	12.32
Maximum group size	13

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The result of the first-stage suggests that the number of patents varies according to IP ownership policy. This estimate suggests the necessity of IP ownership policy in Canadian Universities. Although any kind of policy helps generate patents, the inventor-owned IP ownership policy is the best predictor since this policy provides maximum freedom to the inventor.

Table 4-5: Effect of university IPR policy on the number of US patents

IPR type	**Effect on US patents (number)**	**Prob>|z|**
None	0.57	0.027
University-owned	2.06	0.000
Joint-ownership	3.55	0.000
Inventor-owned	5.04	0.000

Now we focus on the determinants of the funding in Canadian universities at the second-stage results. Table 4-6 shows the positive impacts of patents on Tri-council funding. The number of patents strongly influences funding from Health (Health Canada & CIHR) and NSERC. If we look at the marginal effect in Table 4-9, we see that with zero patent, all tri-council components have negative values except for the SSHRC funding. With zero patent, the marginal effect of the SSHRC is $9.5 million. This result is not surprising since the SSHRC funding mostly targeted to social sciences and humanities research, where research output does not lead to a patent. Occasionally, SSHRC funding also contributed to developing patents. For example, USPTO granted three patents to Daniel Levitin of McGill University that are developed by using SSHRC funding (http://www.sshrc-crsh.gc.ca/funding-financement/policies-politiques/knowledge_mobilisation-mobilisation_des_connaissances-eng.aspx). Table 4-9 shows that the SSHRC funding is inversely related to a number of patents; when the number of patents in a growing, amount of funding is declining.

Table 4-6: Impact of Patents on Tri-council Funding

Fixed effect panel GLS – tri-council funding (Health Canada and CIHR are one DV)				
	(1)	(2)	(3)	(4)
	f_agencies	f_sshrc	f_health	f_nserc
h_patent (predicted value)	17334.0***	-1460.2***	9130.6***	3891.6***
	(3008.8)	(206.8)	(1549.7)	(323.2)
Reputationalsurvey	-1346.0***	163.1***	-713.5***	-353.1**
	(372.5)	(36.27)	(220.7)	(166.4)
Operatingbudget	21.08	27.55	102.5	-66.60
	(186.0)	(23.81)	(106.5)	(73.69)
Stupsformed	-1371.1**	-100.5*	-721.0*	-291.7*
	(568.5)	(57.48)	(379.3)	(161.0)
e_wage	0.184***	0.0149***	0.0753***	0.0322***
	(0.0244)	(0.00152)	(0.0126)	(0.00299)
Phds	359.6	1.214	231.2*	-31.61
	(219.2)	(16.71)	(131.1)	(49.54)
_cons	-67074.9***	4136.3***	-38433.0***	-7144.6***
	(17125.4)	(915.1)	(8146.1)	(2739.4)
Number of obs	617	617	617	617
Log Likelihood	-6552.4	-5248.9	-6211.1	-5794.8
F-statistic for test of u_i=0	36.35	11.01	48.25	31.32
corr(u_i, Xb)	-0.0487	-0.301	-0.148	0.186
Number of groups	54	54	54	54
Smallest group size	1	1	1	1
Average group size	11.43	11.43	11.43	11.43
Maximum group size	13	13	13	13
R2 within	0.745	0.581	0.597	0.518
R2 overall	0.683	0.644	0.476	0.607
R2 between	0.681	0.688	0.468	0.626
N_clust	54	54	54	54
Root mean squared error	10425.5	1260.5	5995.9	3053.9
Bootstrapped standard errors				

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4-6 suggests that 'Health' funding is strongly predicted by patents. To get funding from the 'Health,' a university should have at least three patents. A university with five patents may expect $21.6 million in funding from Health Canada and CIHR (see Table 4-9). NSERC funding is affected by a number of patents. With five patents, a university gets $16.1 million from the

NSERC funding. However, with zero patents, we see negative values for both the health and NSERC funding. This result suggests the necessity of patents for getting funds from Health Canada, CIHR, and NSERC.

Table 4-7: Impact of Patents on CFI and CRC

Fixed effect panel GLS – CFI and Canada Research Chairs		
	(1)	(2)
	f_cfi	f_crc
h_patent (predicted value)	4381.2***	1390.8***
	(1175.8)	(420.2)
reputationalsurvey	-340.5***	-102.1**
	(118.5)	(51.29)
operatingbudget	-75.41	33.01
	(95.58)	(38.98)
Stupsformed	68.52	-326.4**
	(235.0)	(130.6)
e_wage	0.0322***	0.0297***
	(0.00911)	(0.00326)
Phds	143.3**	15.46
	(72.63)	(31.88)
_cons	-16878.9**	-8754.7***
	(7390.9)	(2927.2)
Number of obs	617	617
Log Likelihood	-6179.1	-5505.7
F-statistic for test of u_i=0	3.588	10.54
corr(u_i, Xb)	-0.378	-0.741
Number of groups	54	54
Smallest group size	1	1
Average group size	11.43	11.43
Maximum group size	13	13
R2 within	0.235	0.697
R2 overall	0.452	0.761
R2 between	0.553	0.837
N_clust	54	54
Root mean squared error	5692.9	1911.2
Bootstrapped standard errors		

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4-7 shows that CFI and CRC funding are positively associated with the number of patents. CFI is negatively related to a number of patents for less than three patents. With three patents average funding from the CFI to a university is $1.7 million; this figure is $10.5 million when the number of patents is five. We see the positive effect of a number of patents on CRC when the number of a patent is at least two. Our estimate shows that $4.8 million funding is expected with five patents from the CRC.

Table 4-8: Impacts of Patents on Private and Government Funding

Fixed effect panel GLS – private and government funding		
	(1)	(2)
	f_priv	f_gov
h_patent (predicted value)	31499.5***	158232.8***
	(3704.3)	(18286.9)
reputationalsurvey	-1815.8***	-9355.1***
	(616.0)	(2811.8)
operatingbudget	-18.33	-1300.6
	(698.8)	(1332.7)
Stupsformed	2755.4	-13216.1***
	(2593.8)	(4151.8)
e_wage	0.247***	0.799***
	(0.0293)	(0.147)
Phds	34.25	-1243.7
	(275.7)	(1111.7)
_cons	-153565.9***	-596188.0***
	(23750.5)	(108203.3)
Number of obs	617	617
Log Likelihood	-7254.2	-7866.8
F-statistic for test of u_i=0	6.603	11.39
corr(u_i, Xb)	-0.772	-0.696
Number of groups	54	54
Smallest group size	1	1
Average group size	11.43	11.43
Maximum group size	13	13
R2 within	0.382	0.450
R2 overall	0.384	0.307
R2 between	0.487	0.313
N_clust	54	54
Root mean squared error	32516.0	87757.6
Bootstrapped standard errors		

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4-8 shows that patents significantly affect the private and other government funding. Table 4-9 shows that both government and private funding positively increase if a university has more than three patents. The marginal effect of other government funding shows that four patents predict 119.1 million funding; whereas, five patents predict 277.3 million funding. These figures are very high since other government funding includes other federal, provincial, municipal, other provinces, and foreign funding. The marginal effect of a number of patents on private funding shows that funding is negatively related to up to three patents. It becomes positive if a number of patents are four. Moving from four patents to five patents, private funding increase from $20.7 million to $52.2 million. Hence, the patent is very important for attracting private funding, which includes funding from individuals, business enterprises, and not-for-profit organizations.

Table 4-9: Marginal effect of patents on average funding amounts per university

Number* of patents	Effect on program funding ($'000)							
	All Tri-Council	SSHRC	Health	NSERC	CFI	CRC	Other Government	Private
0	-31,487	9,464	-24,039	-3,360	-11,395	-2,157	-513830	-105,285
1	-14,153	8,004	-14,909	531	-7,014	-766	-355597	-73,785
2	3,181	6,543	-5,778	4,423	-2,633	625	-197365	-42,286
3	20,515	5,083	3,353	8,314	1,748	2,016	-39132	-10,786
4	37,849	3,623	12,483	12,206	6,130	3,407	119101	20,713
5	55,183	2,163	21,614	16,098	10,511	4,798	277334	52,213

*Number of patents at the institutional (university) level

4.6 Robustness Check

To check the robustness of the previous result that inventor-owned IP policy generates more patents than the university-owned or joint-owned IP ownership policies, we selected the University of Waterloo and the University of Alberta; because they have inventor-owned IP policy. We tried to find out the spin-offs that are originated from the universities. Rasmussen (2011) defined spinoff as a ‘new venture initiated in a university setting and based on technology developed in a university.' We assume that a spin-off may create from patented technology, or a spin-off may produce patented technology. Faculty of Engineering of the University of Waterloo published a list of 718 spinoffs that have engineering students, faculties, staff, and alumni as founders (see Appendix CC for the complete list of Waterloo University's spinoffs and start-ups). Moreover, I collected a list of Waterloo professors with patents from the Waterloo Commercialization Office (WatCo) of the University of Waterloo. In its website related to research and innovation, the University of Alberta published a list of spinoffs that consists of 100 firms ((see Appendix DD for the complete list of Alberta University's spinoffs and start-ups).

After collecting names of the spinoffs and professors, first, we searched the websites of the spinoffs to find out information about the founder's name and year of founding. This process is not straight forward since many of the companies do not have any websites or information about the founder's name and year of founding. Hence, we searched the websites of CrunchBase, a platform for tracking start-ups, and LinkedIn, a platform of professional networking, to find the information. Then, we searched the USPTO's patent full-text and image database on each of the founder names (individually) and the spinoff name as an assignee during a period ranging from 3 years before spinoff formation to 7 years afterward. Since patent ownership may change due to the sale or acquisition of a spinoff, some of the names are not available in the USPTO's full-text database. To find out the current owner of the spin-offs, we searched the USPTO's "Patent Assignment Dataset," which provides the history of patent-ownership transfers from one party to another. We confirmed that the patent is related to the spinoff and that at least one inventor is affiliated to the University. Moreover; If we find the founder as a professor of the university, we keep all year's patent grant data of that professor instead of 3 years before spinoff formation to 7 years afterward. For the analysis, I keep the patents that are granted between 2000 and 2012 (see

Appendix AA and Appendix BB for the lists of spinoffs and professors with patents for the University of Waterloo and the University of Alberta, respectively, for the period between 2000 and 2012.

Table 4-10: Actual Number of Patents under Inventor-owned IP Ownership Policy: the University of Waterloo and University of Alberta, 2000-2012

	University of Waterloo (UW)			University of Alberta (UofA)			The proportion of Inventor-owned patent to all patents	
Patent Grant Year (A)	Inventor Owned (B)	University Owned (C)	Total Patent (D)	Inventor Owned (E)	University Owned (F)	Total Patent (G)	UW (H)	UofA (I)
2000	9	3	12	2	11	13	0.75	0.15
2001	8	7	15	2	15	17	0.53	0.12
2002	6	3	9	9	10	19	0.67	0.47
2003	21	2	23	10	13	23	0.91	0.43
2004	13	0	13	7	10	17	1.00	0.41
2005	14	1	15	10	9	19	0.93	0.53
2006	21	0	21	12	11	23	1.00	0.52
2007	26	2	28	11	6	17	0.93	0.65
2008	28	0	28	4	8	12	1.00	0.33
2009	33	2	35	11	9	20	0.94	0.55
2010	47	1	48	14	6	20	0.98	0.70
2011	41	1	42	14	18	32	0.98	0.44
2012	57	2	59	10	16	26	0.97	0.38
Total	324	24	348	116	142	258	0.93	0.45
average (/yr)	24.9	1.8	26.8	8.9	10.9	19.8		

Column B and Column E of Table 4.10 show the number of patents that are granted to the inventor, who is affiliated with the University of Waterloo and the University of Alberta as a professor, student, or researcher. Column C and Column F exhibit the number of patents in which the assignee's name is the university’s name in the USPTO database. Table 4.10 clearly shows that if a university follows an inventor-owned IP policy, many patents are not assigned to the university. Hence, if we want to get a picture of a university’s innovation output based on patent data, we must combine the number of patents that are assigned to the university and the patents that are assigned to the professors, students, and researchers of the university. Column D and Column G show that both the University of Waterloo and the University of Alberta generated more patents than reported in the USPTO data when the assignees' name contains with university's name.

4.7 Conclusions

Using panel data of fifty-four Canadian universities for the period between 2000 and 2012, this paper investigates the determinants of funding to Canadian universities. To identify the predictors of funding, this study adopts a two-stage regression. In the first stage, it investigates the relationship between university IP policy and a number of patents. The estimates of the first-stage regression suggest that inventor-owned IP policy is the best for a patent generation. Joint-owned IP ownership policy, which is a combination of both the inventor-owned and university-owned IP policies, is better than the university-owned IP policy, which is better than no IP policy. A number of patents are positively predicting the Tri-council funding to universities of Canada, specifically funding from the CIHR and the Natural Sciences, and NSERC are strongly affected by the number of patents. Funding from the Canada Foundation for Innovation (CFI) and Canada Research Chairs (CRC) is positively affected by the number of patents. The estimates also find that private donations increased most by the number of patents. A university with less than four patents is negatively related to private funding. Our estimates suggest that patents are particularly important for getting funds from the private sector.

The findings of this study will help policymakers to think about a uniform IP policy for Canadian universities that generate more patents. One of the major limitations of this study is to rely on patent data collected based on the assignee's name is the university's name. This is not a problem if a university follows a university-owned IP policy. However, in the inventor-owned IP policy, some patents may be assigned to someone else instead of the university. Hence, the university that adopted an investor-owned IP policy might have more patents than we included in our study. Future researchers may take care of this problem by carefully investigating the patents that are assigned to individuals, who might be researchers of any universities. In the robustness check part, we incorporated all patents, whether owned by university or inventor, of the University of Waterloo and the University of Alberta, who are followers of inventor-owned IP policy. Future researchers may extend our methodology to collect patents for all universities which follow inventor-owned IP Policy. This study uses several control variables to estimate the impact of patents on the funding. It would be better if future researchers include a number of publications as an additional control variable.

Chapter 5
Conclusions

The goals of this thesis are threefold. First, provide a detailed portrait of Canada's technological landscape. Second, identify the owners of Canadian inventions. And third, investigate the determinants of funding to Canadian universities.

The first essay focuses on two aspects: providing a comprehensive portrait of Canada's technological landscape and measuring diversity of technology over time. Moreover, this study shows the necessity of using multiple sources of data for drawing a conclusion of a country's technological landscape. Using patent data of Canadian inventors in Canadian and United States patent offices during the period between 1980 and 2014, this study shows that Canadian inventors patent more in the United States than in Canada; however, patenting behavior varies based on technology class and assignee type over time. For instance, Canadian inventors focus more on information technology in the United States, but on civil engineering in Canada. Another finding of this study is that Canada's technology diversification is declining more rapidly in the United States than in Canada. These findings imply that using a single source of data may misrepresent a country's technological capacity and pattern. The analysis at the regional level reveals that Canada's innovative activity is concentrated in a few large cities; Census Metropolitan Areas (CMA) of Toronto, Calgary, Montreal, Kitchener-Cambridge-Waterloo, Ottawa-Gatineau, Vancouver, and Edmonton accounts for 87.48% of all Canadian patents. Moreover, the technological composition and diversity vary significantly across the metropolitan areas of Canada.

Policymakers might be benefited from the insights of the study since it shows the technology classes in which Canada excels or lag, technology classes that are scaping the border or stay at home, regions that are more diversified or not, etc. This study is not above the limitations. This study focuses on the US as the foreign destination of Canadian patents. This study would provide more insights if future researchers include four things. First, collecting and analyzing patent data of Canadian inventors from the other patent offices, such as European Patent Office (EPO) and China National Intellectual Property Organization (CNIPA) since 8% of the Canadian invented patents going to the EPO and 5% to the CNIPA (IP Canada Report, 2017). Second, incorporating the ratio of outward foreign direct investment to inward foreign direct investment of Canada, and, then compare the ratio with the ratio of foreign patenting to domestic patenting to get further insight. Third, identify the nationality of co-inventor with the Canadian inventors. And, fourth, identify the ownership of the firms and their annual R&D expenditures during the analysis period of 1980-2014.

The second essay focuses on the ownership of patents invented by Canadians. Using the USPTO data on patents that are granted to Canadian inventors during the period of 1976-2014, this study investigates the temporal pattern of ownership of the patents based on technology classes, assignee types, and geographic origin of the patents. Moreover, it focuses on the quality of the Canadian invented patents that are owned by various types of assignees in the home or abroad. It also focuses on the unassigned patents. The results of the study show that the shares of both the local ownership and the foreign ownership of Canadian invention are growing as with the increasing number of inventions invented by Canadian; whereas, the share of unassigned patents are declining over time. This study shows that the quality of Canadian invented patents has been growing over time in all technology classes. The increasing quality of the patents might be the reason for the declining share of unassigned patents. However, better quality patents are increasingly going to the hands of foreigners, especially in the modern technology sectors, such as information technology, telecommunications, optical, and electrical engineering. The study identified that the highest share of foreign assigned patents is in the field of information technology, while the local ownership is concentrated in traditional technology fields such as civil, mechanical, and chemical engineering. This study finds that the share of ownership of Canadian invented patents varies based on where the technology is invented. Approximately 60% of all patents are originated from the Census Metropolitan Areas (CMAs) of Toronto, Ottawa-Gatineau, Montreal, Vancouver, Kitchener-Cambridge-Waterloo, and Calgary. Among the top five CMAs based on the number of patents, Toronto has the highest share of foreign assignees, and Kitchener-Cambridge-waterloo (KCW) has the highest share of local assignees. However, 77% of the KCW's patents are assigned to the Blackberry Limited (previous known as Research In Motion Limited). The paper finds the highest share of foreign firm owned patents in the field of information technology.

Policymakers might be interested in the results of the study to pinpoint Canada's strengths and weaknesses in various technology sectors in terms of patent ownership and patent quality. As an extension, this study further classifies the firm-level patents on the basis of its industry sector, ownership, and yearly R&D spending. In the extension, this study only focuses on those firms' data that are listed in the top 100 Canadian R&D spenders during the period between 1999 of 2014. It would be better if future studies collect data for all the firms that are listed in the USPTO patents granted to Canadian inventors between 1976 and 2014. To identify the ownership, this study classifies the firms in two groups: (i) a firm considered as a Canadian firm whether it is located in Canada or its subsidiary in abroad, and (ii) a firm considered as foreign if it is a foreign subsidiary located in Canada or in abroad. Future researchers can classify the patents into four groups, namely Canadian firms located in Canada, a Canadian subsidiary located abroad, a foreign subsidiary located in Canada, and a foreign subsidiary located abroad.

The third essay investigates whether university IP policy and patents determine the types and amounts of funding. Using panel data of 54 Canadian universities for thirteen years between 2000 and 2012, the results of the estimates show that the university's type of IP ownership policy has a significant impact on the number of patents. According to our estimate, inventor-owned IP policy is the best for generating patents. A number of patents are positively predicting the funding from the Canadian Institutes of Health Research (CIHR), the Natural Sciences and Engineering Research Council of Canada (NSERC), Canada Foundation for Innovation (CFI), and Canada Research Chairs (CRC). This study also finds that private donations increased most by the number of patents.

The findings of this study will help policymakers to think about a uniform IP policy for Canadian universities that generate more patents. One of the major limitations of this study is to rely on patent data collected based on the assignee's name is the university's name. This method is not a problem if a university follows a university-owned IP policy. However, in the inventor-owned IP policy, some patents may be assigned to someone else instead of the university. Hence, the university that adopted an inventor-owned IP policy might have more patents than we included in our study. In the robustness check part of the essay three, we incorporated all patents, whether owned by university or inventor, of the University of Waterloo and the University of Alberta, who are followers of inventor-owned IP policy. Future researchers may extend our methodology to collect patents for all universities which follow inventor-owned IP Policy. This study uses several control variables to estimate the impact of patents on the funding. It would be better if future researchers include a number of publications as an additional control variable.

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Appendix A: 30 Technology Categories based on IPC code

No.	Area	IPC Code
1	Electrical machinery and apparatus, electrical energy	F21; G05F; H01B,C,F,G,H,J,K,M,R,T; H02; H05B,C,F,K
2	Audio-visual technology	G09F,G; G11B; H03F,G,J; H04N-003,-005,-009,-013,-015,-017,R,S
3	Telecommunications	G08C; H01P,Q; H03B,C,D,H,K,L,M; H04B,H,J,K,L,M,N-001,-007,-011,Q
4	Information technology	G06; G11C; G10L
5	Semiconductors	H01L; B81
6	Optics	G02; G03B,C,D,F,G,H; H01S
7	Analysis, measurements, control technology	G01B,C,D,F,G,H,J,K,L,M,N,P,R,S,V,W; G04; G05B,D; G07; G08B,G; G09B,C,D; G12
8	Medical technology	A61B,C,D,F,G,H,J,L,M,N
9	Nuclear engineering	G01T; G21; H05G, H
10	Organic fine chemistry	C07C,D,F,H,J,K
11	Macromolecular chemistry, polymers	C08B,F,G,H,K,L; C09D,J
12	Pharmaceuticals, cosmetics	A61K, A61P
13	Biotechnology	C07G; C12M,N,P,Q,R,S
14	Agriculture, food chemistry	A01H; A21D; A23B,C,D,F,G,J,K,L; C12C,F,G,H,J; C13D,F,J,K
15	Chemical and petrol industry, basic materials chemistry	A01N; C05; C07B; C08C; C09B,C,F,G,H,K; C10B,C,F,G,H,J,K,L,M,N; C11B,C,D
16	Surface technology, coating	B05C,D; B32; C23; C25; C30
17	Material, metallurgy	C01; C03C; C04; C21; C22; B22; B82
18	Chemical engineering	B01B,D (without -046 to -053),F,J,L; B02C; B03; B04; B05B; B06; B07; B08; F25J; F26
19	Material processing, textiles, paper	A41H; A43D; A46D; B28; B29; B31; C03B; C08J; C14; D01; D02; D03; D04B,C,G,H; D05; D06B,C,G,H,J,L,M,P,Q; D21
20	Handling, printing	B25J; B41; B65B,C,D,F,G,H; B66; B67
21	Agricultural and food processing, machinery and apparatus	A01B,C,D,F,G,J,K,L,N; A21B,C; A22; A23N,P; B02B; C12L; C13C,G,H
22	Environmental technology	A62D; B01D-046 to -053; B09; C02; F01N; F23G,J
23	Machine tools	B21; B23; B24; B26D,F; B27; B30
24	Engines, pumps, turbines	F01B,C,D,K,L,M,P; F02; F03; F04; F23R
25	Thermal processes and apparatus	F22; F23B,C,D,H,K,L,M,N,Q;F24; F25B,C; F27; F28
26	Mechanical elements	F15; F16; F17; G05G
27	Transport	B60; B61; B62; B63B,C,H,J; B64B,C,D,F
28	Space technology, weapons	B63G; B64G; C06; F41; F42
29	Consumer goods and equipment	A24; A41B,C,D,F,G; A42; A43B, C; A44; A45; A46B; A47; A62B,C; A63; B25B,C,D,F,G,H; B26B; B42; B43; B44; B68; D04D; D06F,N; D07; F25D; G10B,C,D,F,G,H,K
30	Civil engineering, building, mining	E01; E02;E03; E04; E05; E06; E21

Appendix B: Ranking of Technology Categories, CIPO data, 1980-2014

Rank	**Overall CIPO Patents**		**Firm Patents**		**University Patents**		**Government Patents**		**Individual Patents**	
	Technology	%Share	Technology	%Share	Technology	%Share	Technology	%Share	Technology	%Share
1	Civil	10.18	Telecom	10.53	Pharmaceuticals	19.55	Control	15.62	Civil	15.39
2	Telecom	8.58	Civil	9.64	Biotechnology	17.26	Biotechnology	9.29	Consumer	14.77
3	Control	6.27	Control	6.1	Control	9.36	Electrical	9	Hauling	5.64
4	Consumer	5.6	Organic	6.09	Medical	7.87	Telecom	5.95	Food	5.48
5	Organic	5.05	Electrical	4.91	Organic	7.43	Chemical	5.63	Control	4.83
6	Electrical	4.72	Chemical	4.35	Chemical	5.85	Optics	4.65	Mechanical	4.72
7	Chemical	4.4	Petroleum	4.34	Agriculture	3.29	Metallurgy	4.21	Chemical	4.17
8	Transportation	4.12	IT	4.05	Telecom	2.91	Material	3.75	Medical	4.1
9	Pharmaceuticals	3.91	Material	3.85	Environmental	2.65	Pharmaceuticals	3.73	Machine	3.92
10	Material	3.72	Pharmaceuticals	3.85	Polymer	2.41	Organic	3.63	Heat	3.54
11	Petroleum	3.71	Polymer	3.82	Petroleum	2.37	Polymer	3.32	Electrical	3.51
12	Hauling	3.67	Consumer	3.78	Optics	2.31	Petroleum	3.26	Material	3.48
13	IT	3.36	Hauling	3.42	Metallurgy	2.25	Surface	2.72	Engine	2.53
14	Polymer	3.21	Transportation	3.38	Electrical	2.09	Space	2.66	Pharmaceuticals	1.98
15	Mechanical	3.03	Metallurgy	3.12	IT	1.71	Agriculture	2.43	Environmental	1.55
16	Medical	2.93	Mechanical	2.82	Surface	1.41	Consumer	2.17	Telecom	1.48
17	Metallurgy	2.77	Engine	2.63	Material	1.35	IT	1.78	Audio-visual	1.4
18	Biotechnology	2.6	Medical	2.56	Civil	1.15	Medical	1.68	Petroleum	1.28
19	Machine	2.6	Machine	2.42	Nuclear	1.01	Civil	1.54	Surface	1.15
20	Engine	2.5	Biotechnology	2.24	Food	0.95	Transportation	1.54	Optics	1.08
21	Food	2.42	Food	1.81	Audio-visual	0.92	Environmental	1.42	Metallurgy	1.05
22	Heat	1.97	Surface	1.72	Heat	0.79	Audio-visual	1.41	Agriculture	0.94
23	Optics	1.68	Heat	1.68	Hauling	0.63	Machine	1.29	IT	0.92
24	Surface	1.64	Optics	1.67	Consumer	0.57	Semiconductor	1.19	Biotechnology	0.85
25	Audio-visual	1.58	Audio-visual	1.65	Mechanical	0.4	Hauling	1.17	Polymer	0.67
26	Environmental	1.26	Environmental	1.14	Semiconductor	0.4	Heat	1.15	Organic	0.55
27	Agriculture	1.18	Agriculture	1.11	Engine	0.35	Food	1.12	Space	0.42
28	Space	0.6	Space	0.57	Transportation	0.35	Nuclear	1.01	Semiconductor	0.21
29	Semiconductor	0.52	Semiconductor	0.56	Machine	0.32	Engine	0.93	Nuclear	0.1
30	Nuclear	0.23	Nuclear	0.2	Space	0.1	Mechanical	0.75	Transportation	8.29

Appendix C: Ranking of technology categories, USPTO data, 1980-2014

	Overall USPTO Patents		Firm Patents		University Patents		Government Patents		Individual Patents	
Rank	Technology	%Share	Technology	%Share	Technology	%Share	Technology	%Share	Technology	%Share
1	Telecom	15.91	Telecom	17.58	Biotechnology	22.15	Control	13.65	Consumer	13.51
2	IT	10.09	IT	11.09	Pharmaceuticals	18.94	Biotechnology	13.1	Civil	8.83
3	Control	6.66	Control	6.14	Organic	10.61	Electrical	8.21	Control	6.25
4	Pharmaceuticals	5.78	Electrical	5.42	Control	8.78	Telecom	6.37	Medical	6.01
5	Electrical	5.32	Pharmaceuticals	4.90	Medical	4.84	Pharmaceuticals	5.00	Hauling	5.65
6	Biotechnology	5.12	Civil	4.32	Petroleum	3.75	Organic	4.93	Transportation	5.05
7	Civil	4.10	Consumer	3.91	Chemical	3.26	Chemical	4.47	Pharmaceuticals	4.98
8	Consumer	3.72	Biotechnology	3.53	Optics	3.04	Petroleum	4.28	IT	4.86
9	Organic	3.32	Hauling	3.46	IT	2.76	Optics	3.98	Telecom	4.56
10	Hauling	3.18	Transportation	3.45	Telecom	2.59	Metallurgy	3.64	Chemical	4.38
11	Transportation	3.17	Audio-visual	3.07	Electrical	2.37	Surface	3.58	Mechanical	3.30
12	Chemical	3.00	Material	3.00	Metallurgy	2.15	Polymer	3.34	Electrical	3.18
13	Audio-visual	2.87	Chemical	2.87	Surface	1.93	IT	2.96	Engine	3.12
14	Material	2.84	Organic	2.74	Polymer	1.88	Material	2.79	Food	2.58
15	Medical	2.66	Medical	2.49	Agriculture	1.76	Civil	2.73	Optics	2.52
16	Optics	2.39	Mechanical	2.35	Audio-visual	1.03	Agriculture	2.43	Biotechnology	2.40
17	Surface	2.30	Engine	2.31	Food	1.03	Medical	1.82	Audio-visual	2.34
18	Metallurgy	2.24	Surface	2.27	Semiconductor	1.02	Space	1.78	Heat	2.34
19	Mechanical	2.16	Optics	2.26	Environmental	0.88	Audio-visual	1.76	Machine	2.22
20	Engine	2.12	Metallurgy	2.19	Material	0.83	Semiconductor	1.59	Material	2.22
21	Machine	2.00	Machine	2.17	Civil	0.77	Transportation	1.10	Surface	1.86
22	Petroleum	1.83	Food	1.74	Consumer	0.55	Consumer	1.06	Organic	1.80
23	Food	1.68	Petroleum	1.58	Hauling	0.52	Food	0.99	Space	1.32
24	Polymer	1.33	Polymer	1.20	Mechanical	0.49	Environmental	0.95	Petroleum	1.20
25	Heat	1.06	Heat	1.11	Nuclear	0.47	Machine	0.95	Metallurgy	0.90
26	Semiconductor	1.02	Semiconductor	1.01	Heat	0.42	Hauling	0.78	Environmental	0.84
27	Environmental	0.77	Environmental	0.75	Engine	0.38	Engine	0.47	Polymer	0.60
28	Agriculture	0.72	Agriculture	0.56	Machine	0.38	Mechanical	0.47	Semiconductor	0.48
29	Space	0.37	Space	0.30	Transportation	0.33	Heat	0.44	Agriculture	0.36
30	Nuclear	0.26	Nuclear	0.24	Space	0.09	Nuclear	0.36	Nuclear	0.30

Appendix D: Comparison of technology categories by Patent Destination

Rank	Only CIPO Patents		Only USPTO Patents		Matched Patents	
	Technology	%Share	Technology	%Share	Technology	%Share
1	Civil	12.23	Telecom	16.65	Telecom	14.53
2	Organic	6.4	IT	11.21	Control	6.85
3	Consumer	6.25	Control	6.71	Civil	6.74
4	Control	5.94	Pharmaceuticals	6.56	Electrical	5.85
5	Telecom	5.06	Biotechnology	5.96	IT	4.68
6	Petroleum	4.91	Electrical	5.22	Consumer	4.5
7	Chemical	4.82	Organic	3.71	Transportation	4.46
8	Polymer	4.15	Consumer	3.32	Pharmaceuticals	4.23
9	Electrical	4.06	Civil	3.13	Hauling	3.76
10	Material	4	Audio-visual	3.12	Chemical	3.7
11	Transportation	3.92	Transportation	2.88	Material	3.25
12	Pharmaceuticals	3.71	Hauling	2.86	Metallurgy	3.14
13	Hauling	3.62	Material	2.83	Mechanical	3.08
14	Medical	3.05	Medical	2.78	Biotechnology	3.08
15	Mechanical	3	Chemical	2.65	Engine	3.04
16	Machine	2.65	Optics	2.52	Medical	2.74
17	IT	2.58	Surface	2.15	Organic	2.71
18	Metallurgy	2.55	Metallurgy	1.95	Food	2.51
19	Food	2.37	Engine	1.89	Machine	2.51
20	Biotechnology	2.32	Mechanical	1.86	Audio-visual	2.05
21	Engine	2.19	Machine	1.79	Optics	1.97
22	Heat	2.06	Petroleum	1.65	Heat	1.82
23	Surface	1.62	Food	1.34	Petroleum	1.68
24	Optics	1.5	Polymer	1.26	Surface	1.67
25	Agriculture	1.35	Semiconductor	1.23	Polymer	1.61
26	Audio-visual	1.3	Heat	0.88	Environmental	1.31
27	Environmental	1.23	Agriculture	0.69	Agriculture	0.89
28	Space	0.59	Environmental	0.64	Semiconductor	0.69
29	Semiconductor	0.41	Space	0.29	Space	0.62
30	Nuclear	0.17	Nuclear	0.26	Nuclear	0.32

Appendix E: Comparison technology categories at Firm-level

Rank	Only CIPO Patents		Only USPTO Patents		Matched Patents	
	Technology	%Share	Technology	%Share	Technology	%Share
1	Civil	11.46	Telecom	18.48	Telecom	16.09
2	Organic	8.60	IT	12.33	Civil	7.13
3	Telecom	6.54	Control	6.25	Electrical	6.14
4	Petroleum	6.34	Pharmaceuticals	5.55	Control	6.03
5	Control	6.16	Electrical	5.30	IT	5.16
6	Polymer	5.44	Biotechnology	4.15	Transportation	4.73
7	Chemical	5.05	Consumer	3.46	Consumer	4.55
8	Material	4.21	Audio-visual	3.35	Hauling	4.00
9	Electrical	4.02	Civil	3.32	Pharmaceuticals	3.63
10	Pharmaceuticals	4.00	Transportation	3.15	Chemical	3.39
11	IT	3.26	Hauling	3.14	Engine	3.38
12	Consumer	3.23	Organic	3.05	Material	3.35
13	Metallurgy	3.10	Material	3.03	Mechanical	3.28
14	Hauling	3.00	Medical	2.63	Metallurgy	3.15
15	Medical	2.64	Chemical	2.57	Machine	2.66
16	Mechanical	2.50	Optics	2.44	Food	2.55
17	Transportation	2.41	Surface	2.13	Organic	2.51
18	Biotechnology	2.38	Engine	2.06	Medical	2.45
19	Machine	2.25	Mechanical	2.03	Audio-visual	2.16
20	Engine	2.10	Machine	1.94	Biotechnology	2.05
21	Surface	1.77	Metallurgy	1.88	Heat	1.88
22	Optics	1.64	Petroleum	1.43	Optics	1.70
23	Heat	1.53	Food	1.38	Surface	1.65
24	Agriculture	1.44	Semiconductor	1.22	Petroleum	1.56
25	Audio-visual	1.29	Polymer	1.14	Polymer	1.56
26	Food	1.28	Heat	0.93	Environmental	1.19
27	Environmental	1.11	Environmental	0.64	Semiconductor	0.67
28	Space	0.60	Agriculture	0.55	Agriculture	0.65
29	Semiconductor	0.49	Nuclear	0.24	Space	0.52
30	Nuclear	0.16	Space	0.23	Nuclear	0.24

Appendix F: Comparison technology categories at University-level

Rank	Only CIPO Patents		Only USPTO Patents		Matched Patents	
	Technology	%Share	Technology	%Share	Technology	%Share
1	Pharmaceuticals	21.87	Biotechnology	23.29	Pharmaceuticals	18.32
2	Biotechnology	16.68	Pharmaceuticals	19.67	Biotechnology	17.58
3	Control	10.17	Organic	11.30	Control	8.93
4	Medical	7.86	Control	9.03	Medical	7.87
5	Organic	6.86	Medical	4.30	Organic	7.74
6	Chemical	6.76	Petroleum	3.40	Chemical	5.37
7	Agriculture	3.84	Optics	3.04	Telecom	3.85
8	Polymer	2.92	IT	2.80	Environmental	3.03
9	Optics	2.60	Chemical	2.73	Agriculture	3.00
10	Metallurgy	2.42	Telecom	2.55	Electrical	2.56
11	Petroleum	2.38	Electrical	2.25	Petroleum	2.37
12	Surface	1.96	Metallurgy	2.01	Metallurgy	2.16
13	Environmental	1.92	Surface	1.97	Optics	2.16
14	IT	1.35	Polymer	1.85	Polymer	2.14
15	Electrical	1.21	Agriculture	1.55	IT	1.90
16	Telecom	1.14	Semiconductor	1.25	Material	1.54
17	Audio-visual	1.07	Audio-visual	1.07	Civil	1.31
18	Material	1.00	Food	0.92	Food	1.18
19	Civil	0.85	Material	0.76	Surface	1.12
20	Nuclear	0.85	Environmental	0.58	Nuclear	1.10
21	Consumer	0.78	Civil	0.48	Heat	0.91
22	Engine	0.57	Consumer	0.48	Audio-visual	0.83
23	Heat	0.57	Mechanical	0.48	Hauling	0.70
24	Mechanical	0.57	Hauling	0.44	Semiconductor	0.49
25	Food	0.53	Nuclear	0.44	Consumer	0.46
26	Hauling	0.50	Engine	0.36	Machine	0.38
27	Transportation	0.28	Heat	0.36	Transportation	0.38
28	Machine	0.21	Transportation	0.34	Mechanical	0.30
29	Semiconductor	0.21	Machine	0.24	Engine	0.23
30	Space	0.07	Space	0.08	Space	0.11

Appendix G: Comparison technology categories at Government-level

Rank	Only CIPO Patents		Only USPTO Patents		Matched Patents	
	Technology	%Share	Technology	%Share	Technology	%Share
1	Control	13.63	Biotechnology	16.84	Control	16.94
2	Electrical	13.36	Control	12.64	Biotechnology	8.60
3	Biotechnology	10.37	Electrical	9.68	Telecom	7.22
4	Pharmaceuticals	4.86	Pharmaceuticals	6.21	Chemical	6.20
5	Chemical	4.77	Organic	5.60	Electrical	6.11
6	Material	4.40	Telecom	5.46	Optics	5.57
7	Organic	4.38	Metallurgy	4.05	Metallurgy	4.70
8	Polymer	4.26	Petroleum	3.83	Material	3.32
9	Telecom	4.03	Chemical	3.65	Organic	3.14
10	Metallurgy	3.47	Surface	3.40	Petroleum	3.12
11	Petroleum	3.47	Polymer	3.25	Pharmaceuticals	2.99
12	Optics	3.26	Optics	3.22	Surface	2.96
13	Space	2.64	IT	2.93	Space	2.68
14	Surface	2.36	Material	2.57	Polymer	2.65
15	Agriculture	2.18	Agriculture	2.28	Agriculture	2.59
16	Consumer	1.94	Medical	2.02	Consumer	2.32
17	Machine	1.78	Civil	1.77	IT	2.12
18	Environmental	1.76	Audio-visual	1.66	Transportation	1.73
19	Medical	1.71	Semiconductor	1.52	Medical	1.65
20	Civil	1.57	Space	1.34	Food	1.64
21	Heat	1.46	Machine	1.05	Civil	1.52
22	Audio-visual	1.32	Transportation	0.90	Audio-visual	1.47
23	IT	1.25	Environmental	0.87	Semiconductor	1.40
24	Transportation	1.25	Consumer	0.72	Hauling	1.36
25	Hauling	0.88	Food	0.69	Environmental	1.20
26	Nuclear	0.88	Hauling	0.51	Nuclear	1.09
27	Semiconductor	0.88	Mechanical	0.40	Engine	1.06
28	Mechanical	0.81	Nuclear	0.40	Machine	0.97
29	Engine	0.74	Heat	0.33	Heat	0.96
30	Food	0.32	Engine	0.25	Mechanical	0.71

Appendix H: Comparison technology categories at Individual-level

Rank	Only CIPO Patents		Only USPTO Patents		Matched Patents	
	Technology	%Share	Technology	%Share	Technology	%Share
1	Consumer	14.46	Civil	15.81	Civil	11.17
2	Civil	7.86	Consumer	15.20	Consumer	10.36
3	Control	6.88	Transportation	8.47	Control	8.43
4	IT	6.52	Hauling	5.69	Transportation	6.51
5	Medical	6.16	Food	5.60	Chemical	5.16
6	Pharmaceuticals	5.18	Mechanical	4.70	Hauling	5.16
7	Telecom	5.09	Control	4.47	Mechanical	4.91
8	Chemical	4.38	Chemical	4.08	Medical	4.89
9	Transportation	4.20	Medical	4.03	Food	4.20
10	Hauling	4.11	Machine	3.95	Machine	3.66
11	Optics	3.30	Heat	3.63	Pharmaceuticals	3.41
12	Engine	3.04	Electrical	3.56	Telecom	3.27
13	Electrical	2.95	Material	3.53	Electrical	2.97
14	Audio-visual	2.77	Engine	2.63	Material	2.91
15	Biotechnology	2.77	Pharmaceuticals	1.84	Optics	2.72
16	Food	2.50	Environmental	1.49	Heat	2.64
17	Machine	2.50	Audio-visual	1.35	Environmental	2.16
18	Mechanical	2.14	Telecom	1.30	Biotechnology	2.00
19	Heat	1.96	Petroleum	1.25	Audio-visual	1.93
20	Material	1.88	Surface	1.16	Metallurgy	1.93
21	Organic	1.70	Metallurgy	0.97	Petroleum	1.62
22	Space	1.70	Optics	0.92	Engine	1.52
23	Petroleum	1.16	IT	0.91	Agriculture	1.35
24	Surface	1.07	Agriculture	0.89	Organic	1.14
25	Polymer	0.80	Biotechnology	0.74	Surface	1.08
26	Environmental	0.71	Polymer	0.67	IT	1.06
27	Semiconductor	0.71	Organic	0.49	Polymer	0.69
28	Metallurgy	0.63	Space	0.41	Space	0.58
29	Agriculture	0.45	Semiconductor	0.18	Semiconductor	0.50
30	Nuclear	0.45	Nuclear	0.10	Nuclear	0.10

Appendix I: Top 20 Firm-level Patent Assignees

Overall USPTO			Overall CIPO		
Firm	No. of Patents	%Share	Firm	No. of Patents	%Share
Nortel Networks Limited	6006	10.63	Blackberry Limited	2910	7.49
Blackberry Limited	5598	9.91	Shell Canada Limited	1985	5.11
Pratt & Whitney Canada Corp	796	1.41	Schlumberger Canada Limited	1796	4.62
ATI Technologies Inc.	687	1.22	Northern Telecom Limited	1729	4.45
Mosaid Technologies Incorporated	649	1.15	Ciba-Geigy Investments Ltd.	1196	3.08
Husky Injection Molding Systems Ltd.	560	0.99	Pratt & Whitney Canada Corp.	584	1.50
Alcan International Limited	493	0.87	Xerox Corporation	377	0.97
Mitel Corporation	418	0.74	Mitel Corporation	364	0.94
Siemens Canada Limited	373	0.66	IBM Canada Limited	315	0.81
Bombardier Inc.	356	0.63	Hoffmann-La Roche Limited	285	0.73
Merck Frosst Canada Co.	279	0.49	Alcan International Limited	273	0.70
Mold Masters Limited	267	0.47	Husky Injection Holding Systems Ltd.	253	0.65
Magna International Inc.	243	0.43	Inco Limited	253	0.65
Ballard Power System Inc.	221	0.39	Ford Motor Company Of Canada Limited	240	0.62
Alcatal Canada Inc.	216	0.38	Du Pont Canada Inc.	136	0.35
Certicom Corp	210	0.37	Cnh Canada Ltd.	127	0.33
Wi-Lan Inc.	191	0.34	Telefonaktiebolaget Lm Ericsson	118	0.30
Du Pont Canada Inc.	164	0.29	Mold-Masters Limited	108	0.28
Inco Limited	148	0.26	Certicom Corp.	107	0.28
ViXS Systems Inc.	140	0.25	Polysar Limited	101	0.26
Others	38467	68.10	Others	25609	65.89
Total	56482	100.00	Total	38866	100.00

Appendix J: Top 10 University-level patent Assignees

Overall USPTO			**Overall CIPO**		
University	**No. of Patents**	**% Share**	**University**	**No. of Patents**	**% Share**
University of British Columbia	507	15.95	University of British Columbia	145	12.93
McGill University	325	10.22	Queen's University	112	9.99
Queen's University	282	8.87	Universite Laval	85	7.58
University of Alberta	239	7.52	University of Alberta	64	5.71
Universite Laval	179	5.63	University of Saskatchewan	52	4.64
University of Saskatchewan	143	4.50	University of Manitoba	39	3.48
University of Toronto	139	4.37	University of Ottawa	38	3.39
Universite de Montreal	112	3.52	McGill University	38	3.39
University of Waterloo	97	3.05	Universite de Montreal	35	3.12
Simon Fraser University	93	2.93	McMaster University	35	3.12
Others	1063	33.44	Others	478	42.64
Total	3179	100	Total	1121	100

Appendix K: Average Number of Patent Grants by CIPO, 1980-2014

CMA	1980-1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010	2011-2014
Toronto	101.33	103.00	133.20	139.20	178.60	272.40	375.60
Calgary	75.33	82.00	103.40	110.20	148.40	244.40	408.40
Montreal	85.83	84.00	118.00	120.20	164.00	233.20	236.60
Kitchener-Cambridge-Waterloo	51.83	67.40	104.80	24.20	73.00	88.40	286.40
Vancouver	34.50	39.00	42.80	43.20	67.00	83.00	121.40
Ottawa-Gatineau	30.50	36.80	40.80	38.20	57.00	93.80	132.00
Edmonton	22.67	26.20	28.80	31.20	45.80	56.60	52.40
Winnipeg	9.17	10.40	14.20	13.80	24.80	27.40	34.00
Hamilton	11.50	6.40	9.20	8.80	14.40	16.60	25.40
Saskatoon	8.67	9.20	9.80	4.40	14.00	15.80	20.80
London	6.50	6.20	5.60	7.40	11.60	11.80	22.40
Quebec	5.17	4.60	5.00	6.60	11.20	16.40	21.20
Regina	3.17	5.80	5.40	5.60	6.40	6.80	12.40
Kingston	2.50	4.20	5.00	5.60	3.60	7.00	12.00
Windsor	5.00	4.20	3.00	3.40	7.80	7.20	8.40
Sherbrooke	2.33	2.60	3.60	3.20	4.20	7.80	10.00
Victoria	3.50	4.20	2.80	2.80	7.00	4.60	5.60
Halifax	2.17	2.60	2.60	2.80	4.40	3.00	7.20
St. Catharines-Niagara	2.50	2.40	2.80	3.00	2.80	3.80	7.40
Guelph	1.17	2.60	2.20	1.40	2.60	4.00	8.80
Brantford	1.83	0.80	2.20	3.00	3.40	4.60	6.00
Kelowna	2.67	2.80	2.00	2.40	4.60	3.00	4.00
Barrie	1.67	1.40	2.20	1.20	4.20	2.40	5.60
Trois-Rivieres	0.83	1.40	0.60	1.00	4.00	3.20	2.40
Abbotsford Mission	1.00	1.20	0.80	2.00	2.20	2.20	2.80
Oshawa	1.00	1.00	0.60	2.00	1.60	3.20	2.60
St. John's	1.50	1.20	0.40	1.40	1.20	2.60	3.60
Moncton	0.83	1.40	1.60	2.00	1.60	2.40	1.60
Thunder bay	0.67	2.00	1.60	0.40	2.60	1.40	1.40
Greater Sudbury	1.00	0.60	1.20	1.20	0.80	1.60	2.20
Peterborough	0.17	1.00	1.00	0.80	1.20	1.80	1.80
Saint Jhon	0.00	0.80	1.20	0.80	1.80	1.20	1.00
Saguenay	0.00	0.00	0.40	0.00	0.20	1.00	0.20

Appendix L: Ranking of CMA by Share of Technology Based on CIPO Data, 1980-2014

Rank	CMA	Share of IPC Grant by CIPO
1	Toronto	23.61
2	Calgary	17.74
3	Montreal	16.43
4	Kitchener-Cambridge-Waterloo	10.38
5	Ottawa-Gatineau	8.66
6	Vancouver	6.65
7	Edmonton	4.01
8	Winnipeg	2.04
9	Hamilton	1.44
10	Saskatoon	1.23
11	Quebec	1.06
12	London	1.01
13	Kingston	0.61
14	Sherbrooke	0.52
15	Regina	0.51
16	Windsor	0.48
17	Victoria	0.40
18	Halifax	0.37
19	Guelph	0.34
20	Brantford	0.33
21	Kelowna	0.31
22	Barrie	0.29
23	St. Catharines-Niagara	0.28
24	Oshawa	0.19
25	Trois-Rivieres	0.19
26	Abbotsford Mission	0.18
27	Moncton	0.17
28	Thunder bay	0.15
29	Greater Sudbury	0.13
30	Peterborough	0.11
31	Saint Jhon	0.10
32	St. John's	0.06
33	Saguenay	0.02

Appendix M: Pearson Correlation Coefficient of Commonly Used Measures of Innovation

	Technology Diversification	No. of Patents	GDP per Capita	Patent per Capita	No. of University	Highest Level of Education	No. of National Research Centre
Technology Diversification	1.0000						
No. of Patents	0.7490	1.0000					
GDP per Capita	0.5385	0.4889	1.0000				
Patent per Capita	0.5692	0.5989	0.4359	1.0000			
No. of University	0.6023	0.4483	0.4944	0.2259	1.0000		
Highest Level of Education	0.7539	0.6213	0.7045	0.3888	0.6390	1.0000	
No. of National Research Centre	0.5056	0.3561	0.3607	0.1670	0.5270	0.5591	1.0000

Appendix N: Technology Diversification Score of CMAs Based on CIPO Data, 1980-2014

CMA	1980-1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010	2011-2014
Toronto	3.28	3.27	3.29	3.29	3.30	3.28	3.27
Montreal	3.14	3.11	3.09	3.20	3.26	3.23	3.26
Ottawa-Gatineau	2.83	2.96	3.07	3.05	3.16	3.18	3.18
Vancouver	2.99	2.98	3.00	3.00	3.12	3.05	3.17
Kitchener-Cambridge-Waterloo	2.64	2.92	3.01	2.62	2.92	2.98	3.03
Edmonton	2.60	2.65	2.72	2.75	2.87	2.84	2.99
Calgary	2.76	2.79	2.87	2.86	2.89	2.85	2.81
Hamilton	2.34	2.02	2.35	2.18	2.46	2.57	2.79
Winnipeg	2.24	2.37	2.36	2.51	2.56	2.63	2.77
London	1.98	2.14	1.96	2.18	2.42	2.56	2.71
Quebec	1.89	1.92	1.75	2.14	2.42	2.63	2.69
Saskatoon	1.90	2.03	2.08	1.32	2.33	2.36	2.49
Kingston	1.26	1.64	1.67	1.80	1.65	2.20	2.41
Regina	1.33	1.93	1.88	1.97	2.10	1.98	2.37
Windsor	1.79	1.63	1.54	1.34	1.85	2.33	2.31
Sherbrooke	1.28	1.28	1.55	1.37	1.72	2.08	2.28
Halifax	1.12	1.26	1.30	1.22	1.91	1.64	2.25
Guelph	0.53	1.29	1.75	1.47	1.69	1.85	2.19
St. Catharines-Niagara	1.14	0.97	1.47	1.45	1.54	1.72	2.17
Victoria	1.48	1.37	1.37	1.23	1.87	2.16	2.01
Barrie	0.88	0.69	1.22	1.25	1.05	0.95	1.89
Brantford	1.29	1.13	1.00	1.72	1.33	1.62	1.80
Oshawa	0.80	0.78	1.21	1.31	0.89	1.57	1.77
Kelowna	1.39	1.71	1.29	1.30	1.79	1.26	1.50
Abbotsford Mission	0.91	1.06	0.73	1.41	1.35	1.48	1.49
Moncton	0.52	0.98	0.70	1.04	1.18	0.90	1.32
Greater Sudbury	0.60	0.69	0.55	1.39	1.04	1.52	1.31
Thunder bay	1.11	0.98	0.99	0.35	1.13	0.84	1.18
St. John's	1.24	0.62	0.69	1.13	1.13	1.47	1.17
Trois-Rivieres	0.53	0.61	0.98	0.95	1.29	1.35	1.15
Peterborough	1.04	1.04	0.99	1.07	0.91	0.73	1.08
Saint John	0.00	0.87	1.33	0.83	1.30	1.13	0.81
Saguenay	0.00	0.00	0.28	0.00	1.01	1.17	0.00

Appendix O: Ranking of Top 3 CMAs by Technology Category

Technology	Rank 1	Share %	Rank 2	Share %	Rank 3	Share %
Agriculture	Toronto	28.19	Ottawa-Gatineau	10.05	Saskatoon	7.88
Audio	Toronto	24.1	Montreal	23.36	KCW	21.13
Biotechnology	Toronto	26.41	Ottawa-Gatineau	17.3	Montreal	17.2
Chemical	Calgary	38.85	Toronto	14.34	Vancouver	9.83
Civil	Calgary	49.47	Toronto	15.32	Edmonton	9.53
Consumer	Toronto	30.97	Montreal	18.29	Vancouver	8.62
Control	Calgary	27.1	Toronto	20.38	Ottawa-Gatineau	14.4
Electrical	Montreal	29.85	Toronto	22.34	KCW	11.27
Engine	Montreal	40	Toronto	18.06	Vancouver	15.15
Environmental	Toronto	20.41	Vancouver	13.58	Calgary	13.12
Food	Saskatoon	29.3	Winnipeg	22.14	Toronto	9.42
Hauling	Toronto	34.92	Montreal	16.23	Vancouver	6.83
Heat	Toronto	36.52	Montreal	15.22	Vancouver	11.79
IT	KCW	47.24	Toronto	20.1	Ottawa-Gatineau	13.46
Machine	Toronto	34.58	Montreal	17.41	Vancouver	13.09
Material	Toronto	52.04	Montreal	18.2	Ottawa-Gatineau	7.46
Mechanical	Toronto	32.58	Calgary	14.24	Montreal	12.35
Medical	Toronto	32.07	Montreal	17.17	Vancouver	9.79
Metallurgy	Toronto	36.11	Montreal	20.97	Calgary	12.48
Nuclear	Ottawa-Gatineau	25.42	Toronto	20.07	Montreal	13.71
Optics	Ottawa-Gatineau	31.43	Montreal	24.52	Toronto	18.53
Organic	Calgary	30.18	Toronto	26.69	Montreal	24.8
Petroleum	Calgary	61.74	Toronto	13.77	Ottawa-Gatineau	5.92
Pharmaceuticals	Toronto	29.4	Montreal	26.87	Vancouver	11.28
Polymer	Calgary	48.74	Toronto	20.17	Montreal	11.68
Semiconductor	Montreal	37.18	Ottawa-Gatineau	29.49	Toronto	13.3
Space	Ottawa-Gatineau	35.27	Toronto	21.99	Calgary	16.99
Surface	Toronto	36.18	Montreal	25.66	Ottawa-Gatineau	7.54
Telecommunications	KCW	43.59	Montreal	21.24	Ottawa-Gatineau	16.91
Transportation	Toronto	37.61	Montreal	14.89	Vancouver	8.99

Appendix P: Technology based on 3-Digit IPC Overall CIPO data

Rank	3-Digit IPC	% Share	Technology
1	H04	8.04	Electric communication technique
2	A61	7.23	Medical or veterinary science, Hygiene
3	C07	6.45	Organic chemistry
4	G01	5.21	Measuring and testing
5	E21	4.67	Earth or rock drilling and mining
6	A01	3.29	Agriculture; Forestry; Animal Husbandry; Hunting; Trapping; Fishing
7	H01	3.21	Basic electric elements
8	C08	3.21	Organic macromolecular compounds
9	G06	3.02	Computing; Calculating; Counting
10	B01	2.94	Physical or chemical processes or apparatus in general

Appendix Q: Technology based on 3-Digit IPC Overall USPTO data

Rank	3-Digit IPC	% Share	Technology
1	H04	14.99	Electric communication technique
2	G06	9.12	Computing; Calculating; Counting
3	A61	8.43	Medical or veterinary science, Hygiene
4	G01	5.42	Measuring and testing
5	H01	4.83	Basic electric elements
6	C07	4.45	Organic chemistry
7	C12	4.06	Biochemistry; Beer; Spirits; Wine; Vinegar; Microbiology; Enzymology; Mutation or Genetic Engineering
8	A01	2.56	Agriculture; Forestry; Animal Husbandry; Hunting; Trapping; Fishing
9	B65	2.39	Conveying; Packing; Storing; Handling Thin or Filamentary materials
10	F16	1.92	Engineering elements or units; General measures for producing and maintaining effective functioning of machines or installations; Thermal insulation in general

Appendix R: Technology based on 4-Digit IPC Overall CIPO Data

Rank	4-digit IPC	% Share	Technology
1	E21B	4.48	Earth or rock drilling
2	A61K	3.61	Preparations for medical, dental, or toilet purposes
3	C07D	2.95	Heterocyclic compounds
4	H04L	2.39	Transmission of digital information
5	G06F	2.37	Electric digital data processing
6	H04W	2.1	Wireless communication networks
7	G01N	2.01	Investigating or analyzing materials by determining their chemical or physical properties
8	C07C	1.84	Acyclic or carbocyclic compounds
9	B29C	1.69	Shaping or joining of plastics
10	B01D	1.44	Separation

Appendix S: Technology Based on 4-Digit IPC Overall USPTO Data

Rank	4-digit IPC	% Share	Technology
1	G06F	7.22	Electric digital data processing
2	A61K	5.62	Preparations for medical, dental, or toilet purposes
3	H04L	3.96	Transmission of digital information
4	H04M	2.74	Telephonic communication
5	H04B	2.5	Transmission
6	C12N	2.4	Microorganisms or Enzymes
7	G01N	2.14	Investigating or analyzing materials by determining their chemical or physical properties
8	B29C	1.55	Shaping or joining of plastics
9	C07D	1.53	Heterocyclic compounds
10	H04W	1.51	Wireless communication networks

Appendix T: Yearly Distribution of Patent Ownership & Patent Quality

Grant Year	Ownership of Canadian Invention						Average No. of Claims		
	Canada	Foreign	Unassigned	Canada (%)	Foreign Share (%)	Unassigned Share (%)	Canada	Foreign	Unassigned
1976	609	300	153	0.57	0.28	0.14	9.22	9.35	8.58
1977	531	209	416	0.46	0.18	0.36	10.28	9.91	8.66
1978	486	216	448	0.42	0.19	0.39	10.92	10.74	8.34
1979	332	134	314	0.43	0.17	0.40	11.20	9.71	8.53
1980	435	162	409	0.43	0.16	0.41	11.04	10.35	8.43
1981	446	179	439	0.42	0.17	0.41	11.59	9.92	8.74
1982	434	145	366	0.46	0.15	0.39	11.08	12.68	9.79
1983	417	145	380	0.44	0.15	0.40	11.11	11.02	10.11
1984	533	187	405	0.47	0.17	0.36	11.46	10.23	10.62
1985	567	216	438	0.46	0.18	0.36	11.88	12.50	10.48
1986	498	234	478	0.41	0.19	0.40	12.66	11.63	10.77
1987	629	246	602	0.43	0.17	0.41	12.13	13.27	10.64
1988	567	273	557	0.41	0.20	0.40	12.56	12.11	10.70
1989	779	350	732	0.42	0.19	0.39	14.02	13.17	11.37
1990	778	275	712	0.44	0.16	0.40	13.33	13.07	11.18
1991	864	311	779	0.44	0.16	0.40	14.86	13.90	11.23
1992	857	298	773	0.44	0.15	0.40	14.63	14.76	11.59
1993	868	320	701	0.46	0.17	0.37	14.57	14.45	11.57
1994	842	362	745	0.43	0.19	0.38	14.71	15.12	11.79
1995	918	372	739	0.45	0.18	0.36	14.86	14.79	11.74
1996	1,006	445	705	0.47	0.21	0.33	15.85	16.21	12.32
1997	1,061	457	804	0.46	0.20	0.35	15.62	15.99	13.02
1998	1,393	646	914	0.47	0.22	0.31	16.32	16.11	12.46
1999	1,628	676	914	0.51	0.21	0.28	17.52	18.20	13.36
2000	1,727	784	914	0.50	0.23	0.27	18.73	18.33	13.54
2001	1,991	886	859	0.53	0.24	0.23	19.19	19.80	13.87
2002	1,911	913	765	0.53	0.25	0.21	19.55	20.72	14.13
2003	1,964	932	723	0.54	0.26	0.20	20.72	21.02	15.93
2004	2,129	827	655	0.59	0.23	0.18	21.48	20.35	14.41
2005	1,802	747	527	0.59	0.24	0.17	22.49	22.66	16.28
2006	2,141	978	549	0.58	0.27	0.15	20.99	21.99	16.98
2007	1,882	947	515	0.56	0.28	0.15	20.84	21.36	16.31
2008	1,960	969	431	0.58	0.29	0.13	20.23	19.71	15.39
2009	2,443	890	481	0.64	0.23	0.13	19.64	19.98	15.97
2010	2,660	1,476	645	0.56	0.31	0.13	19.84	20.58	15.98
2011	3,021	1,423	593	0.60	0.28	0.12	19.97	19.76	15.82
2012	3,655	1,571	683	0.62	0.27	0.12	19.43	20.02	15.06
2013	4,281	1,710	782	0.63	0.25	0.12	19.24	19.32	16.09
2014	4,375	2,261	756	0.59	0.31	0.10	19.50	19.33	15.75

Appendix U: The Top 10 US Assignees of Canadian Inventions, 1976-2014

US Assignees	**No. of Patents**	**Share (%)**
Xerox Corporation	1985	10.02
International Business Machines Corporation	1567	7.91
Exxon Corporation	416	2.10
Altera Corporation	342	1.73
Interdigital Technology Corporation	319	1.61
Apple Inc.	269	1.36
Honeywell Inc.	233	1.18
Pioneer Hi Bred International Inc.	200	1.01
NCR Corporation	193	0.97
Ciena Corporation	183	0.92
Others	14,109	71.20
Total	19,816	100.00

Appendix V: Share of Canadian Invention Ownership by Technology Class, 1976-2014

Technology Classification			**Ownership of Canadian Invention**			**Share of Ownership**		
Technology	**Total**	**Share**	**Canada**	**Unassigned**	**Foreign**	**Canada**	**Unassigned**	**Foreign**
Telecom	11487	11.08	7409	523	3555	0.64	0.05	0.31
IT	10852	10.47	5471	582	4799	0.50	0.05	0.44
Consumer	7305	7.04	2564	3956	785	0.35	0.54	0.11
Control	7004	6.75	4152	1452	1400	0.59	0.21	0.20
Civil	6300	6.08	2804	2638	858	0.45	0.42	0.14
Electrical	5694	5.49	3276	960	1458	0.58	0.17	0.26
Hauling	4636	4.47	2156	1691	789	0.47	0.36	0.17
Transportation	4517	4.36	2045	1912	560	0.45	0.42	0.12
Pharmaceuticals	3574	3.45	2515	293	766	0.70	0.08	0.21
Chemical	3498	3.37	1839	1004	655	0.53	0.29	0.19
Medical	3223	3.11	1648	1093	482	0.51	0.34	0.15
Optics	3159	3.05	1363	379	1417	0.43	0.12	0.45
Mechanical	2886	2.78	1437	910	539	0.50	0.32	0.19
Audio-visual	2882	2.78	1612	442	828	0.56	0.15	0.29
Material	2756	2.66	1719	537	500	0.62	0.19	0.18
Machine	2661	2.57	1253	968	440	0.47	0.36	0.17
Food	2532	2.44	1110	1221	201	0.44	0.48	0.08
Engine	2272	2.19	1427	572	273	0.63	0.25	0.12
Surface	2134	2.06	1293	403	438	0.61	0.19	0.21
Biotechnology	2106	2.03	1588	194	324	0.75	0.09	0.15
Organic	1840	1.77	1083	104	653	0.59	0.06	0.35
Metallurgy	1790	1.73	1279	190	321	0.71	0.11	0.18
Petroleum	1666	1.61	873	198	595	0.52	0.12	0.36
Heat	1487	1.43	683	655	149	0.46	0.44	0.10
Polymer	1410	1.36	622	109	679	0.44	0.08	0.48
Agriculture	1008	0.97	428	132	448	0.42	0.13	0.44
Semiconductor	875	0.84	544	60	271	0.62	0.07	0.31
Environmental	806	0.78	474	217	115	0.59	0.27	0.14
Space	501	0.48	272	177	52	0.54	0.35	0.10
Nuclear	243	0.23	170	39	34	0.70	0.16	0.14
Others	589	0.57	311	190	88	0.53	0.32	0.15
Total	**103693**		**55420**	**23801**	**24472**	**0.53**	**0.23**	**0.24**

Appendix W: Share of Canadian Invention Ownership by CMA, 1976-2014

Canadian Invention			Ownership of Canadian Invention			Share of Ownership		
CMA	**Total**	**Percent**	**Canada**	**Unassigned**	**Foreign**	**Canada**	**Unassigned**	**Foreign**
Toronto	22754	21.94	10,819	5,380	6,555	0.48	0.24	0.29
Ottawa-Gatineau	10970	10.58	7,236	925	2,809	0.66	0.08	0.26
Montreal	9731	9.38	5,265	2,060	2,406	0.54	0.21	0.25
Vancouver	9079	8.76	4,638	2,007	2,434	0.51	0.22	0.27
KCW	5879	5.67	4,503	410	966	0.77	0.07	0.16
Calgary	3480	3.36	2,205	392	883	0.63	0.11	0.25
Edmonton	3419	3.30	1,797	954	668	0.53	0.28	0.20
Quebec	2114	2.04	1,400	370	344	0.66	0.18	0.16
Hamilton	2085	2.01	1,016	563	506	0.49	0.27	0.24
London	1943	1.87	1,055	268	620	0.54	0.14	0.32
Windsor	1848	1.78	805	378	665	0.44	0.20	0.36
Winnipeg	1634	1.58	790	626	218	0.48	0.38	0.13
Kingston	1272	1.23	826	170	276	0.65	0.13	0.22
Saskatoon	1081	1.04	769	203	109	0.71	0.19	0.10
Victoria	904	0.87	409	328	167	0.45	0.36	0.18
St. Catharines-Niagara Falls	719	0.69	282	218	219	0.39	0.30	0.30
Guelph	600	0.58	298	90	212	0.50	0.15	0.35
Kelowna	548	0.53	226	216	106	0.41	0.39	0.19
Sherbrooke	534	0.51	400	78	56	0.75	0.15	0.10
Barrie	482	0.46	190	119	173	0.39	0.25	0.36
Saint John	416	0.40	166	82	168	0.40	0.20	0.40
Halifax	358	0.35	218	77	63	0.61	0.22	0.18
Oshawa	341	0.33	151	86	104	0.44	0.25	0.30
Peterborough	313	0.30	226	41	46	0.72	0.13	0.15
Brantford	281	0.27	159	54	68	0.57	0.19	0.24
Abbotsford Mission	263	0.25	103	118	42	0.39	0.45	0.16
Regina	254	0.24	119	124	11	0.47	0.49	0.04
Greater Sudbury	224	0.22	102	97	25	0.46	0.43	0.11
St. John's	168	0.16	105	54	9	0.63	0.32	0.05
Moncton	123	0.12	71	40	12	0.58	0.33	0.10
Thunder Bay	100	0.10	19	70	11	0.19	0.70	0.11
Saguenay	85	0.08	59	19	7	0.69	0.22	0.08
Trois-Rivieres	33	0.03	14	11	8	0.42	0.33	0.24
Others	19655	18.96	8,977	7,173	3,505	0.46	0.36	0.18
Total	**103,690**	**100**	**55,418**	**23,801**	**24,471**	**0.53**	**0.23**	**0.24**

Appendix X: Example of the Canadian & Foreign Companies

Foreign Subsidiary with Canadian Address Treated as Foreign Assignee	**Canadian Company with Foreign Address Treated as Canadian Assignee**
Alcatal Canada Inc.	AnorMed Inc.
Amgen Canada Inc.	Apotex Inc
Aptalis Pharma Canada Inc.	ATI Technologies Inc.
AstraZeneca AB	Atomic Energy of Canada Limited
Aventis Pasteur Limited	Ballard Power System Inc.
Bae Systems Canada Inc.	Bell Canada
Bayer AG	Biochem Pharma
Boehringer Ingelheim (Canada) Ltd	BlackBerry Limited
Cisco Systems Canada Co.	Bombardier Inc.
Du Pont Canada Inc.	BRP US Inc.
Eli Lilly & Company	CAE Electronics Ltd.
Ericsson	Cardiome Pharma Corp
General Electric Canada Inc	Domtar Inc
General Motors LLC	Genesis Microchip Inc.
GlaxoSmithKline Biologicals S.A.	Husky Injection Molding Systems Ltd.
Hoffmann-La Roche Inc.	Isotechnika Inc.
Honeywell Inc.	JDS Fitel Inc
Huawei Technologies Co., Ltd.	MacDonald Dettwiler & Associates Inc
International Buisness Machines Corpora	Magna International Inc.
Lockheed Martin Corporation	Medicure International Inc.
Merck & Co. Inc.	Mosaid Technologies Incorporated
Miranda Technologies Inc.	Noranda Inc.
Monsanto Canada Inc.	Nortel Networks Limited
Motorola	Northland Energy Corporation
Novartis AG	Novadaq Technologies Inc.
Novelis Inc.	Oncolytics Biotech Inc.
Pfizer Inc.	Open Text Corporation
PMC - Sierra Inc.	Petro-Canada Exploration Inc.
Pratt & Whitney Aircraft of Canada Limited	Precision Drilling Corporation
Sanofi Pasteur Limited	ProMetic BioSciences Inc.
Schering Corporation	QLT Inc.
SmithKline Beecham Corporation	Royal Group Technologies Limited
Teledyne Dalsa B.V.	Visible Genetics Inc
Wyeth	Western Oil Sands Ltd.
Xerox Inc.	Zarlink Semiconductor Inc.

Appendix Y: Canadian University IP Ownership Policy, Patents, Start-ups, and Sources of Funding

Institution name	USPTO Granted patents, 2000-2012 (number)	IPR Policy† (code)	(mean funding, $'000 per year)							
			Startups 2000-2012 (number)	NSERC	Health	SSHRC	CFI	CRC	Other government	Private
Acadia University	0	I	0	1,156	0	363	181	496	0	0
Bishop's University	0	I	1	165	0	85	47	127	0	221
Brandon University	0	U	0	287	42	418	165	220	0	16
Brock University	5	I	0	2,595	164	1,334	784	517	7,057	2,406
Cape Breton University	1	I	0	147	29	196	136	273	0	470
Carleton University	3	I	0	12,227	1,049	4,077	6,805	2,217	115,846	0
Concordia University	5	I	3	8,926	339	3,840	2,603	1,564	21,076	2,915
Dalhousie University	21	I	2	14,769	16,579	2,851	5,051	3,975	74,153	0
Lakehead University	0	I	5	2,334	596	854	681	594	22,669	1,937
Laurentian University	0	I	1	2,524	693	293	454	710	0	3,348
Malaspina University College	0	N	0	0	0	0	0	0	0	0
McGill University	209	J	32	39,580	87,209	9,062	25,377	13,182	147,967	106,866
McMaster University	48	J	6	21,651	31,653	4,567	12,713	6,579	136,456	50,244
Memorial University	0	U	3	9,389	4,090	2,315	3,812	1,993	0	0
Mount Allison University	0	J	5	998	0	177	196	382	0	0
Mount Royal University	0	N	0	0	0	0	0	0	0	0
Mount Saint Vincent University	0	N	0	157	184	560	143	238	0	0
Nipissing University	0	I	0	178	0	94	58	42	0	0
Nova Scotia Agricultural College	0	N	0	0	0	0	0	0	0	0
NSCAD University	0	N	0	0	0	0	0	0	0	0
Ontario Tech University	3	N	1	1,917	19	163	346	454	0	0
Queen's University	124	I	18	25,646	13,663	5,997	11,703	4,434	228,737	42,214
Royal Roads University	0	N	0	0	0	0	0	0	0	0
Ryerson University	2	U	1	3,776	185	1,376	693	727	36,244	11,524
Saint Mary's University	0	U	0	1,456	0	1,028	547	498	0	348
Simon Fraser University	52	I	33	17,347	965	6,021	5,114	3,495	161,836	30,069
St. Francis Xavier University	1	I	3	1,758	10	683	568	574	0	0
St. Thomas University	0	I	0	0	0	165	23	137	0	89
Trent University	1	I	1	2,790	203	755	1,105	776	30,114	2,147
Universite de Moncton	1	N	0	820	2,075	511	228	484	0	3,983
Universite de Montreal	99	I	32	24,195	64,228	11,645	23,186	13,480	189,089	9,445

Institution name	USPTO Granted patents, 2000-2012 (number)	IPR Policy† (code)	(mean funding, $'000 per year)							
			Startups 2000-2012 (number)	NSERC	Health	SSHRC	CFI	CRC	Other government	Private
Universite de Sherbrooke	24	I	13	13,234	8,093	1,891	4,394	3,528	208,698	31,397
Universite du Quebec	6	N	0	7,234	0	8,101	1,250	3,927	0	0
Universite Laval	96	U	22	36,992	28,726	7,730	15,136	9,770	251,003	7,022
University of Alberta	142	I	46	40,911	37,332	9,500	20,174	10,986	720,629	69,264
University of British Columbia	220	U	69	45,853	67,165	14,082	25,812	14,370	689,171	131,351
University of Calgary	4	I	15	24,723	27,876	7,514	9,983	4,703	483,079	34,236
University of Guelph	32	I	5	18,901	2,281	2,020	6,834	3,208	0	10,761
University of Lethbridge	1	U	0	2,840	410	478	975	588	27,878	4,362
University of Manitoba	56	J	10	16,032	20,054	3,691	5,761	4,383	32,965	42,795
University of New Brunswick	25	I	14	8,598	884	1,934	1,582	1,767	117,968	23,172
University of Northern British Columbia	1	I	1	1,303	1,594	476	356	488	3,766	1,987
University of Ottawa	2	U	34	17,074	35,929	7,587	13,848	5,745	297,834	86,474
University of Prince Edward Island	2	I	0	1,201	676	452	756	525	3,715	1,538
University of Regina	10	I	0	3,307	755	957	1,003	787	94,629	0
University of Saskatchewan	74	U	15	24,610	10,298	2,200	13,141	2,927	352,167	9,630
University of Toronto	127	J	119	58,588	129,646	19,584	48,752	24,167	797,341	235,222
University of Victoria	30	I	21	14,958	4,115	5,343	9,716	3,094	208,718	6,432
University of Waterloo	24	I	51	31,509	3,649	2,904	7,554	5,452	237,391	5,233
University of Western Ontario	55	I	29	18,851	17,365	6,328	12,371	6,272	294,559	112,815
University of Windsor	1	I	0	6,534	240	1,064	1,106	1,441	14,934	1,201
University of Winnipeg	1	J	0	915	0	595	309	412	0	0
Wilfrid Laurier University	0	I	0	1,659	168	1,704	1,115	529	8,392	7,183
York University	4	U	2	8,483	1,625	9,200	2,112	3,325	179,241	1,226

†" N"=none, "U"=university-owned, "J"=joint-ownership, "I"=inventor-owned

Note: patent data are taken directly from USPTO, IPR policy data were collected directly from university web pages (see Appendix Z), we assumed that IP policies have stayed static over the years, funding data are from Canadian Association of University Business Officers (CAUBO), number of startups is from Association of University Technology Managers (AUTM).

CAUBO has nine income/expense categories as follows: C1 general operating, C2 special purpose and trust, C3 entities consolidated, C4 entities not consolidated, C5 subtotal, C6 ancillary enterprises, C7 capital, C8 endowment, C9 total fund. We use "total fund" for our data. Government funding is defined as: other federal, provincial, municipal, other provinces, and foreign. Private funding is defined as: individuals, business enterprises and not-for-profit organizations.

Appendix Z: Sources of Canadian University IP Ownership Policy

Institution name	IP Policy Web Links
Acadia University	https://www2.acadiau.ca/research-office.html
Bishop's University	https://www.ubishops.ca/wp-content/uploads/Policy-for-managing-intellectual-property-at-BU.pdf
Brandon University	https://www.brandonu.ca/research/files/OverheadPolicy.pdf
Brock University	https://brocku.ca/graduate-studies/wp-content/uploads/sites/181/ownership-of-student-created-intellectual_property_0507.pdf
Cape Breton University	https://www.cbu.ca/policies-procedures/research-policies-procedures/
Carleton University	https://carleton.ca/ips/for-researchers/carleton-researchers-4/
Concordia University	http://www.concordia.ca/content/dam/common/docs/policies/official-policies/VPRGS-9.pdf
Dalhousie University	https://www.univcan.ca/wp-content/uploads/2017/06/consultation-on-university-intellectual-property-technology-transfer-submission-june-2017.pdf
Guelph University	https://www.uoguelph.ca/research/for-researchers/patenting-commercialization/ip-policy
Lakehead University	https://www.lakeheadu.ca/faculty-and-staff/policies/research/intellectual-property
Laurentian University	https://laurentian.ca/intellectual-property-management-and-commercialization
Laval University	http://www.vrr.ulaval.ca/rech/Brevets_1974.html
Lethbridge University	https://www.uleth.ca/research/disclosure
Malaspina University College	Not available
McGill University	https://www.mcgill.ca/secretariat/files/secretariat/policy_on_inventions_and_software.pdf
Memorial University	https://www.mun.ca/policy/site/policy.php?id=143
Mount Allison University	https://www.mta.ca/Community/Governance_and_admin/Policies_and_procedures/Section_7000/Policy_7910/Policy_7910/
Mount Royal University	https://www.mtroyal.ca/Applications/PoliciesAndProcedures/view/0B2rB1ncpgWxvR3FtRTRUMG13U2M
Mount Saint Vincent University	Not available
Nipissing University	https://www.nipissingu.ca/sites/default/files/2018-05/NURES2011.02%20IPRenwlFinal13.pdf
Nova Scotia Agricultural College	Not available
NSCAD University	https://navigator.nscad.ca/wordpress/wp-content/uploads/2017/11/StudentsIntellectualPropertyRights.pdf
Ontario Tech University	https://usgc.ontariotechu.ca/policy/policy-library/policies/legal,-compliance-and-governance/intellectual-property-policy.php

Queen's University	http://www.queensu.ca/sgs/sites/webpublish.queensu.ca.sgswww/files/files/Students/Intellectual%20Property%20Guidelines%20at%20Queens%202013.pdf
Regina University	https://www.uregina.ca/presoff/vpadmin/policymanual/general/1095.html
Royal Roads University	http://policies.royalroads.ca/policies/intellectual-property-policy
Ryerson University	https://www.ryerson.ca/policies/policy-list/u-property-policy/
Saint Mary's University	https://smu.ca/webfiles/FacultyHandbook2017.pdf
Simon Fraser University	http://www.sfu.ca/policies/gazette/research/r30-02.html
St. Francis Xavier University	https://www.stfx.ca/research/research-policies-and-committees/internal-research-policies/intellectual-property
St. Thomas University	https://www.stu.edu/Portals/library/HowTo/docs/APC%208.3%20Intellectual%20Property.pdf
Trent University	https://www.trentu.ca/researchinnovation/researchers/graduate-students/intellectual-property
Universite de Moncton	Not available
Universite de Montreal	https://esp.umontreal.ca/english/postdoctoral-fellow/rights-and-responsabilities/
Universite de Sherbrooke	https://www.univcan.ca/wp-content/uploads/2017/06/consultation-on-university-intellectual-property-technology-transfer-submission-june-2017.pdf
Universite du Quebec	Not available
University of Alberta	https://www.ualberta.ca/graduate-studies/about/graduate-program-manual/section-10-intellectual-property/10-1-intellectual-property-guidelines
University of British Columbia	https://uilo.ubc.ca/researchers/commercialize-invention/inventions-inventorship-faq/ownership-inventions-ubc
University of Calgary	https://www.ucalgary.ca/policies/files/policies/Intellectual%20Property%20Policy.pdf
University of Manitoba	http://umanitoba.ca/admin/governance/media/Intellectual_Property_Policy_-_2013_10_01_RF.pdf
University of McMaster	https://milo.mcmaster.ca/policies/joint_ip_policy
University of New Brunswick	http://www.unb.ca/research/partner/intellectual-property.html
University of Northern British Columbia	https://www.unbc.ca/sites/default/files/assets/policy/provost/intellectual_property.pdf
University of Ottawa	https://www.uottawa.ca/administration-and-governance/policy-29-invention-and-technology-transfer
University of Prince Edward Island	http://files.upei.ca/research/upei_patent_policy.pdf
University of Saskatchewan	https://research.usask.ca/innovation-enterprise/documents/Innovators%20Guide.pdf
University of Toronto	https://www.utm.utoronto.ca/vp-research/information-researchers/policies-procedures
University of Victoria	https://www.uvic.ca/universitysecretary/assets/docs/policies/GV0215_1180_.pdf
University of Winnipeg	http://pace.uwinnipegcourses.ca/sites/default/files/pdfs/publications/Student%20Handbook.pdf

Waterloo University	https://uwaterloo.ca/secretariat/policies-procedures-guidelines/policy-73-intellectual-property-rights
Western University	https://www.uwo.ca/research/services/resources/policies/intellectual_property.html
Wilfrid Laurier University	https://www.wlu.ca/academics/research/office-of-research-services/intellectual-property-and-research-policies.html
Windsor University	http://www.uwindsor.ca/research-innovation-services/407/intellectual-property
York University	https://www.york.ac.uk/staff/research/external-funding/ip/policy/#2

Appendix AA: List of University of Waterloo Spinoffs & Professors with the USPTO Patents, 2000-2012

Inventor	Relation with the University of Waterloo	Spinoff Name	Spinoff Founding Year
Paul Terry	Alumnus	Abatis Systems	2005
Hongwei Liu	Alumnus	Abatis Systems	2005
Dave Kroetsch	Alumnus	Aeryon Labs Inc.	2007
George Tsintzouras	Alumnus	Alert Labs	2015
Trevor Bekolay	Alumnus	Applied Brain Research Inc.	2014
Adam Zimmer	Alumnus	Arius Software	1999
Alex Leyn	Alumnus	Aterica Digital Health	2012
Marc Morin	Alumnus	Auvik	2011
Coode Catherine	Alumnus	Binary Tattoo	2013
Hill Rosco	Alumnus	Blend Labs	2012
Taj Manku	Professor	Cognitive Systems	2014
Oleksiy Kravets	Alumnus	Cognitive Systems	2014
Gregory Saumier Finch	Alumnus	Culture Creates	2015
Bailey Kevin	Alumnus	Design 1st	1999
Marc Morin	Alumnus	Emforium Group	2008
Shyam Sheth	Alumnus	Fixmo Inc.	2009
Karthik Ramakrishnan	Alumnus	Gallop Labs	2013
Raafat Mansour	Alumnus	Integrated Circuit Scanning Probe Instruments	2007
Raafat Mansour	Professor	Integrated Circuit Scanning Probe Instruments	2007
Poutanen Tomi	Alumnus	Layer 6	2016
Owen Ward	Alumnus	Lystek International Inc	2000
Tony Barijpaul	Alumnus	Miovision Technologies Inc.	2005
Clayton Grassick	Alumnus	mWater	2011
Matthew Bailey	Alumnus	North	2012
Grant Hall	Alumnus	Nuvyyo Inc.	2010
Alex Solomon	Alumnus	PagerDuty	2009
Barbara A. Paldus	Alumnus	Picarro	1998
Marc Morin	Alumnus	PixStream	1996
Brad Siim	Alumnus	PixStream	1996
Roger Bertschmann	Alumnus	Rad3 Communications	2008
Douglas Beckett	Alumnus	Ranovus	2012
Lucas Skoczkowski	Alumnus	Redknee Solutions	1999
Akshay Nanduri	Alumnus	Reflexion Medical	2009
Gerald Van Decker	Alumnus	Renewability	2000

Prem Gururajan	Alumnus	RideCo	2012
Raymond Reddy	Alumnus	Ritual	2014
Simon Law	Alumnus	SALT Technology	2008
Marc Morin	Alumnus	Sandvine Inc.	2001
Bowman Don	Alumnus	Sandvine Inc.	2001
Lee Anthony	Alumnus	Spotivate	2011
Piron Cameron	Alumnus	Synaptive Medical	2012
Costa Tzoganakis	Professor	Tyromer Inc.	2009
Guy Cote	Professor	VideoLocus	2001
Anthony Gallo	Alumnus	Vizible Corporation	1999
James Wei	Alumnus	Worldview Technology Partners	1996
Ron Dembo	Alumnus	ZeroFootprint Inc.	2005
University of Waterloo Professor with Patents			
Amir Khajepour	En-hui Yang	Vassili Karanassios	Jonathan Kofman
Maurice Dusseaul	Benjamin Simon Thompson	Mehrdad kazerani	Duane S. Cronin
Simarjeet S. Saini	Bo Cui	Martin Karsten	Eihab Mohamed Abdel-Rahman
Karim S. Karim	Carolyn Gail Mac Gregor	Mark David Aagaard	G. Wayne Brodlan d
Otman Basir	Catherine Helen Gebotys	Marios Ioannidis	Gordon B. Agnew
Frank X. Gu	David Anthony Clausi	Marianna Foldvari	Jennifer Boger
Andrew C. Wong	Yuning Li	Kirsten Morris	John B. Medley
Alexander Sheung Wong	Vincent Gaudet	Kenneth Mark Salem	Jonathan David Kofman

Appendix BB: List of University of Alberta Spinoffs & Professors with the USPTO Patents, 2000-2012

Inventor	Relation with University of Alberta	Spinoff Name	Spinoff Founded Year
Linda Pilarski	Professor	Amplicet	2016
David Bressler	Professor	Animal Inframetrics	2013
Thava Vasanthan	Professor	Animal Inframetrics	2013
Allan Schaefer	Professor	Animal Inframetrics	2013
Ratmir Derba	Professor	48Hour Discovery Inc.	2017
Alexey Atrazhev	Professor	48Hour Discovery Inc.	2017
Alexey Atrazhev	Professor	48Hour Discovery Inc.	2017
David Wishart	Professor	Chenomx, Inc.	2000
Steven M. Kuznicki	Professor	Extraordinary Absorbents Inc.	2014
Mike Kouritzin	Professor	FastTrack Technologies Inc./ Random Knowledge, Inc.	2003
Bressler; David	Professor	Forge Hydrocarbons	2012
Vasanthan Thava	Professor	GrainFrac Inc.	2014
Sunwoo Hoon	Professor	IgY Incorporated	2003
Babita Agrawal	Professor	ImMed Biotechnologies	2010
Chen, Jie	Professor	IntelligentNano Inc.	2008
Norman Kneteman	Professor	KMT Hepatech	2001
Lorne Tyrrell	Professor	KMT Hepatech	2001
Afsaneh Lavasanifar	Professor	Meros Polymers Inc.	2009
Yatscoff; Randall W.	Professor	Metabolomics Technologies Inc.	2010
Cardien Ken	Professor	nanoBlue Devices	2013
John Fallavollita	Professor	nanoBlue Devices	2013
Walied Maussa	Professor	Nemsor Technologies	2011
Robert Wolkow	Professor	Quantum Silicon	2011
Robert Wolkow	Professor	Quantum Silicon	2011
Arthur Prochazka	Professor	Rehabtronics	2005
Darren Freed	Professor	Tevosol	2015
David Wishart	Professor	Tricca Technologies Inc	2018
Wayne Grover	Professor	TR Labs	1986
Philip Halloran	Professor	Transcriptome Sciences	2008
Christine Szymanski	Professor	VaxAlta Inc.	2013
Pedram Mousavi	Professor	WiDyne Technologies Inc.	2016
Antony G. Olekshy	Alumnus	Avra Software Lab	1998
Ken Westra	Alumnus	BigBangwidth	2000

Brian Moore	Alumnus	BigBangwidth	2000
M. Thomas Clandinin	Alumnus	BioLipids	2005
Richard Glickman	Alumnus	Isotechnika	1993
Andhe V.N. Reddy	Alumnus	NAEJAPharmaceutical	1999
Adam Bergen	Alumnus	Nanolog Audio	2015
Steven Slupsky	Alumnus	Scanimetrics Inc.	2001
Cristian Scurtescu	Alumnus	SmileSonica	2008

Appendix CC: List of Startups & Spinoffs Originated from the University of Waterloo

Name	Name	Name	Name	Name
AEMK Systems Inc.	AdvisorStream	Abatis Systems	A Thinking Ape	Building Rapport
Alchemy	Anikolab	AdHawk Microsystems	Acerta	Byzantium Tech Ltd.
Anue Systems	AOMS Technologies	Aeryon Labs Inc.	Acumetrics Business Intelligence Inc.	CAMplete Solutions Inc.
Arius Software	ApplyBoard	Antelope	Adaria	Canadian Posture and Seating Centre
Aterica	Arylla	Applied Brain Research Inc.	AdFlavour	Canadian V-Chip Design, Inc.
Auvik	Astute Networks	ARTsensing Inc	Advanced Scientific Computing	Cardinal Financial Advisors
Avvasi	Autonomic	Arvossa	Advantage Engineering	Carona Designs Inc.
Axiom Mobile Imaging	Benbria	asianrice.tv	Aggregate Knowlege	Cast ConneX Corporation
Babylon VR	Bering Media	Athos	AHBM Systems Inc.	Cayo Systems Inc.
Balute	Boltmade	B2Gold Corp.	AHU Innovations Ltd.	Cbeyond, Inc.
Bladetech Hockey Inc.	Bridgescale Partners	Bartesian	Airo Health	CellScale
BufferBox	Byte Craft Ltd	Binary Tattoo	Akina	CertClean
ContentDJ	CataLight	Blend Labs	alchemii	Certicom
Crowdriff	Cathy Labs	C3 Group	Alert Labs	Channel Portal
DarwinAI	ChargeSpot	Chalk.com (Planboard)	Algo Anywhere	Chapman Software Design Incorporated
Data Deposit Box	Clear Blue Technologies	Clarmedia	Alirus	Char Technologies
DDE Media Company	Design 1st	Clearpath Robotics Inc.	Alkemi Labs	Chatroll
Desire2Learn	DossierView	CoinTracker	Aloxsys	CHAYA
Eco Place Organics	E La Carte	Conekta	Amitel	Cherrypicks
Edgebotix	Energate	Culture Creates	Analysis Works	Chic.media
efabless.com	Epik Networks	DG Design	AngleMedia	CiRBA Inc.
Elucid Labs	Ethoca	Dunsire Developments Inc.	Angstrom Power Inc.	Circumference Technology Services Inc.
Embark	EyeCheck	Entact Robotics Inc.	Apartmint	Cistel Technology Inc
Emforium Group	Fastback Networks	Envision IT	Arbutus Technologies Inc.	CleanTech Geomechanics
EMJ Data Systems Ltd	Fastbite	Eve Tab	Architech Microsystems	CliftonGroup International

Extreme Venture Partners	Finesse	Exact Media Networks Inc.	Aspen Solar Management Inc.	Clothera
Fakespace Labs, Inc.	FleetCarma (CrossChasm)	Extranet User Manager	AtlasTrax	CMS Montera
Firmwater Inc.	Fly Easy Software	Flinja	Aurora International Telecommunications	Code Connect
Fixmo Inc.	Fundica.com	Flipp (Wishabi Inc.)	Automated Test & Automation Inc.	Cognitech
Fotofox	Fuzo Ltd.	Fresco Microchip	Avantel Consulting Inc	Cognitive Spark Games
FourAll Ice Cream	Genesis Advisers LLC	Fullerton, Sherwood Engineering ltd	Avidbots	Coins-e
Gallop Labs	Goosechase	Glacierclean Technologies	Babensee Controls Engineering	Comcor
Handshake VR	Grascan Construction Ltd.	Glowe Consulting Services	Ball Labs	CommonOffice.com
Harvan Engineering Ltd.	Grayscale Coatings	Green Brick Labs	Bankers Petroleum Ltd.	Comptrol Computer Control Incorporated
Heartwood	GreenLine Partners	Hackademy Canada	Baylis Medical Company Inc.	Conavi Medical Inc.
HiMama	Grobo	Hedgehog Products	BG Games	Concord
Hockey Robotics	Growth Mosaic	HGC Engineering	BicDroid	Connect Tech Incorporated
Hover Labs	hyperPad	iDreambooks	BioEndeavor	Conscia Corporation
HoverChat	Innopage	Ignis	BioFont Inc	Coop Interview
Hydrated World	InspecTerra	IndiGo	Biorem	Corman Technologies Incorporated
Hydroform Expertise Group	Instacart	Instaread	Bipsim Inc	Cortex Design Inc.
i2iQ Inc.	Intellijoint Surgical (Avenir Medical Inc.)	Integrated Circuit Scanning Probe Instruments	bitSIM.co	Counter Intuitive
Imara Research	Kerixa	Intelligent Mechatronic Systems	BlackBerry (Research in Motion)	Couple (Maide Inc.)
Imbue	Knowledgehook	InterGlobe	Blitzen (Marmot Labs)	Coursolve
Immediate Mobile	KYM4	Kiina Group	Bluefin Labs	Creekside Communications
Indigo Technologies Ltd.	M&M Food Market (M&M Meat Shops Limited)	Kik Interactive	Braun Consulting Engineers Ltd	CREZ Basketball Systems
Influenza Media	Maieutic	Kornersafe	Brykman Developments Inc.	Crouton Labs (Exquisine)
Innovate Advisory Inc.	Majik Systems	L. Forrest Mechanical Inc	Canvas Labs	Crystal Decisions
Inoventive	MetaConcepts	Landmine Boys	Careerify	CTO Sydus Pte Ltd.
InScene Systems	MetaLux	Lani	Cognitive Systems	Curiato

Inspire	Meya.ai	Learn From Apps	draftingSPACE	Curry Hydrocarbons
instream	Milq	Loose Button Inc.	Energent Inc.	CVF Technologies Corporation
Intelwaves Technologies	Mind Reef	Lystek International Inc	Engineers Without Borders	cVision Medical Solutions
Interactive SoftwareInc	MindR	Mattermost	Eurodata	Cyberaxiom
InterGlobal Solutions	Mobile Monkey	Meshlytics	Ex Vivo Technologies	D.B.M. Systems Inc.
International telepresence	Moment.Us	Metrics	Four Fox Sake	D.G Henderson & Associates ltd
Invuze	MoneyKey	MetricWire	GestSure	Dakemi Communications
Ionic Engineering Limited	Monstercat Media Group	Movellus	GHD (Conestoga-Rovers & Associates Limited)	DALSA
Isee3D Inc.	Morning Owl	NanoQuan Inc.	Ground News	Dantec Systems Corporation
ITRES Research Ltd	MU Patents (Engfield Patents and Trademarks)	Netskope	H2nan0	DataESP Inc.
JADE Engineers Inc.	Multiculture Bevco Inc.	Novela Inc.	Hastings, Boulding and Correia	DataTellIt Inc.
Janna Systems	Mustang Capital Partners	NowTen	Horizon Engineering Solutions	Datifex
Jarly	MWisdom	PadPiper	iExperienceit	Deeth Williams Wall LLP
Jasper.ai	MXI Technologies Limited	Pathway Intelligence	Imaggle	Dekalam Hire Learning Inc. (PolicePrep)
JoLi Cosmetics	My Top Fans	Peoplecount	Imply	Deskribed
Juntogroup Professional Consultants	MyLocal	Perch	Kiite	Digital Extremes
KFL Investment Management Inc.	Mythoja Consulting Inc.	PixStream	labforge	diPoll
Kinitics Automation	Nanodrivers	PlanLeaf	Lectorius	Doppel
Kitematic	Navcast Inc.	PNO Management Consultants	Legal Reach	Double Take
KiwiWearables	Navigate Design	PointerWare Innovations Ltd.	Loop Lab	Dreamcube
Knapkins	Next Page	Polar Mobile Group Inc.	Maplesoft	Dynajoin Corporation
Knudsen Engineering ltd	nModus	Poliplus Software	Miovision Technologies Inc.	Dynastream
Kofman Engineering ltd	nTerop Corporation	PolyGaze	NERv	Earthscape Creative Landscapes
KruzlTech	Nuvation Research	Ponder	Nexcem	Eat2Feed
Kue	OctigaBay Systems	PopHire	NexJ Systems Inc.	Eatlime Inc.

Kue Software Inc.	Oculis Labs	Precipo	Notewagon	Ecologix
Lakes Environmental Consultants Inc.	Offertunity	Prinova Technologies Inc.	Nuvation Engineering	EcoRio
Laplace Insights	Ohzone	Priority One Data	Nuvyyo Inc.	EightTwenty Group
Layer 6	Oikoi	Project Graphics	Pavement Management Systems	EMAGIN Inc.
LeafLot Inc.	Omisa Inc. (Segasist Technologies)	Purple Forge	Pebble	Enervac Corporation
Learn hub	OnCampus Mapping	PUSH Design Solutions Inc	PodiumIO	Eserro Inc.
LearnLaunch	OneSet	Pyxis Adler Technology Solutions Inc.	Practicure	eValueInsight
Lime Events	OneSpout	Qidni Labs	Precidia Technologies Inc.	ExecVis Spotlight
Lowe, Gravelle & Associates	OnLatte	Quadzilla Racing	Priiva Consulting Corporation	Exhibit.in
LSquared	Only Growth	Rad3 Communications	Pymetrics	Extreme Venture Labs
Lumotune	Open Options Corporation	RainboSolar	Ranovus	Farsightech Inc
Lyft	Open Portal	Raise the Brain	Renewability	Five Pumpkins LLC
MagClip	Open Screenplay	Rapid Mind (Intel)	Robinson Consultants Inc.	Flarion Technologies
Magellan Angel Partners	Optiac Solutions Inc.	rbonut	RVTR	Fleming Systems corporation
Manakn	OrganoWorld	Realmealz	Sage Care	Flowcare Engineering Inc.
MappedIn	Origin	Reden Labs	SiWorks	Fluent Engineering Inc.
Marketing on Demand	PaceFactory	Revel (The Madison Group)	Skimble	Get It Pty Ltd.
McKnight's Flowershoppe Inc.	Palette	Revsolutions Inc.	Slade Engineering Systems Ltd	GO DSP
MDT Engineering	PalGrid	RewardCat	Small Ideas	GoFastCab
Medella Health	Pam's Den Inc.	Rich Internet Group	SmartGames Ltd.	GoingAnyway
Mediaspot.me	Paragon Engineering Ltd	Richard Dray Engineering	SocialNav Inc.	Gotya
Medium One	Partnerpedia Solutions Inc.	RideCo	Solares Architecture	Greenworx
MEDL Technology Corp	Pathlynks	Rocket Launch Marketing	SolarTab	Gren Weis Architect & Associates
MENA Geothermal	PBJ Studios	rr Chocolats	SoThree	Group Effect
Mesh Equity	PC Automation (Geoware)	Rush Hydraulic Pneumatic	Spectronic Plating Corporation	Growple
mWater	Pebly Inc.	Rushing Tide Media	Spectrum 28	Top Hat
Nicoya Lifesciences	Peeristics	Salient Energy	SportsChimp	TravelGator
North	Peeta Consultants	SALT Technology	Squarify	Trexo Robotics

Nulogy Corporation	Perfect Bonus	Sandvine Inc.	Stealth	Tripzaar
Oopsmark	Pervasive Dynamics Inc.	SayGo Solutions	StockMarketStudent	TwitSprout
OverStats	PetroPredict	Schoolax	Storm8	TwitVid
PagerDuty	Picarro	Sciemetric Instruments Inc.	Strata	Ubiq
Pastel Dress Party	PinPress	SciGit	Strategy 2 Execution	uCiC
Pattern Discovery Technologies Inc.	Pitstop	SeaWell Networks Inc.	Streak	Unbounds
Perpetua Labs	Pixineers Inc.	Second Wave Games	Strike Face Technologies	Unlockly
PetDesk	Playfit Health Inc	Sector 5 Digital	Sybarus Technologies	Up in Front
PiinPoint	Pout	Seeq Corporation	Tactile Sight Inc	Upverter
PostRank	ProductWiki	Sendex Environmental Corp.	Taiwan Connection	Vena Medical
Prodigy Game	Qtech Hybrid Systems	Senseinnovation Inc.	TalentLab	Vertical
RAW Design	R&D Partners	Sentinelle Medical Inc.	Tallyfi	Vestec
Real-Time Engineering Simulation	Reccit	Sentry Scientific Inc.	Taly Mind Set	Virtual Materials Group, Inc.
reelyActive	Redknee Solutions	Sequoia Oil & Gas Trust	TaraSpan Group	Viryltech
Reflexion Medical	Reebee	Serdek Automated Systems	Targetivity	Visibli
Ross Video	Ritual	Sesame	TCA Technologies Inc.	VistaShift
Savvica	Rocky Creek Winery	SharePoint Delivery	TDS Dixon Inc	Vitameter
Scott Construction Limited	SannTek	Shogi Group	Tersano Inc.	Vizible Corporation
Ship Time Inc.	Second Funnel	ShufflePix	TeTechS Inc	Volker-Craig Technologies ltd
Shore Consulting Group	SharedBy.co	Shutterous	TextNow (Enflick)	Voltera Inc.
Skyline Sector 5	Shoebox	Sidecar.me	The Acorn Assignment	Waterloo Biofilter Systems Inc
Smarter Alloys	Siborg Systems Inc	Simply Good Technologies	The Black Box Institute	Waterloo Engineering Software
Snowball	SlipStream	Singspiel Inc	The Blueprint Growth Institute	Waterloo Groundwater Control Technologies
Sortable	Smile.io	Sinuwave Technologies	The Jack Project	Watlan
SparkGig	Snapdx	Sirific Wireless Corporation	The Rope Store	WatrHub

Spatial Vision Group	SocialDeck	SITE8 Technologies Inc.	They Innovate Inc.	Wattpad
SpinPunch Inc.	Solink	Social Capital Partnership	Thinkfree.ly	Well.ca
SSIMWave Inc.	Spotivate	SparkMatrix Technologies Inc.	TimeStep Corp	wellofchange.org
Stephenson & Company Capital Management	Springbot	Synaptive Medical	TJS Technical Services	West Side Labs
Taab	Structur3D Printing	SZE Straka Engineers	TMIG Ltd.	Wiebe Engineering Group Inc
Telly	Suncayr	Tangam Systems	Top Foil P.L.C.	Willis Energy Services
Togethr	TapTrack	TeaBOT	Total Rail Analysis Corporation	Willstream
TrendRadius	Tech Capital Partners	The New Energy Group	TransGaming Technologies Inc.	WiseUncle Inc.
TribeHR	The Shared Web	ThinkRF	Trigger Resources Limited	Woozilli
True&Co	The Shop Society	TritonWear	Triple H Construction	Worldview Technology Partners
Tulip Retail	Ticker	Trivaris Ltd.	Trisura	Wriber Inc.
Tutor Bright	WiFiSLAM	TRK Engineering Ltd.	uForis VR	YES.TAP
Tyromer Inc.	WIZ Communications	Trusted Positioning	VCi Green Funds	Zebroski Associates Ltd Architects
Virtual Button Technologies	WordStream	Tungle Corporation	VideoLocus	Zenreach
VivaSpire	XCG Consultants Ltd.	Two Mangoes	Vidyard	ZeroFootprint Inc.
Waterline Group	Yaletown Venture Partners			

Appendix DD: List of Startups & Spin-offs Originated from the University of Alberta

Name	Name	Name	Name
10 Pi Corp.	Chinook Multimedia	Metabolomics Technologies Inc.	Prophysis
48Hour Discovery Inc.	Darkhorse Analytics	MGHL Consulting Limited	ProTraining
AcuVector Group	DNA-Arts Inc.	Micralyne Inc.	Quantum Silicon
AdvEn Solutions	DNAB Therapeutics Inc.	MMHG Inc.	Qwogo Inc.
Afexa Life Sciences	DRAXware Inc.	Molecular You	RadTag Technologies
AltaCarbon	DriveABLE	MPB LaserTech	Raylo Chemicals (Gilead Alberta)
Altamat Inc.	Dynastream Innovations (acquired by Garmin)	MTI Meta Tech	Regional Data Management
AMC Technologies Corporation	Electronic Medical Procedure Reporting Systems	NAEJAPharmaceutical	Rehabtronics
Amplicet Inc.	EquiTech Corporation	nanoBlue Devices	Respirlyte
Animal Inframetrics	Extraordinary Absorbents Inc.	Nanolog Audio	ROAM Corporation
Aquila Diagnostics Systems	FastTrack Technologies Inc./ Random Knowledge,Inc.	Nanostics	Scanimetrics Inc.
Arch Biopartners	Forge Hydrocarbons	Nemsor Technologies	Shanghai Shifang Software
ArthroSci	GrainFrac Inc.	O.R. Science Inc.	SmileSonica
ATGCell	HistoBest Inc.	Omx Personal Health Analytics	Sonolight Pharmaceuticals Corp.(Altachem Pharma)
Aurora NanoDevices	IgY Incorporated	OncoMetabolics Inc.	Tevosol
Avra Software Lab	ImMed Biotechnologies	Oncothyreon Canada	TheraCarb Inc.
BigBangwidth	Immunocreations Inc.	Onlea	TR Labs
BioLipids	IntelligentNano Inc.	Oohoo IT Services Inc.	Transcriptome Sciences
Biomech Designs	IsoBrine Solutions Inc.	Osteometabolix Pharmaceuticals Inc.	Valens Pharma
Biomotion	Isotechnika (merged with AuriniaPhamaceuticals)	Pacylex	VaxAlta Inc.
Boreal Laser	KMT Hepatech (now part of PhoenixBio)	PBR Laboratories Inc.	VerteTrack (formerly Vertescan)
C-FER Technologies	L&R Wang Enterprises Ltd.	PFM Scheduling Services	VibeDx Diagnostic Corp.
CanBiocin	Literacy Services of Canada	PISA Inc.	WellnessRX
Ceapro	Meros Polymers Inc.	PrevBiotech	WiDyne Technologies Inc.
Chenomx, Inc.	Metabolic Modulators Research Ltd.	Progress Scientific Inc.	Wildlife Genetics International Inc.