Essays on Locational Patenting Behavior of Innovators

By

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Abstract

The last two decades have witnessed a sharp increase in patent applications filed abroad by domestic innovators. Understanding how firms decide where to patent helps policymakers design policies to encourage domestic innovators to patent abroad or attract foreign innovators to patent in the domestic economy. Studies of locational patenting decisions are limited due to confidentiality issues that prevent researchers from merging firm-level data to patent data across countries. This thesis overcomes this hurdle for Canadian firms' patenting in Canada and the U.S. under arrangements with Statistics Canada that maintain legal confidentiality requirements. This thesis aims to study firms' locational patenting behavior, both empirically and theoretically.

I start this thesis with a comprehensive literature review on innovators' decisions of whether to patent and where to patent. Based on the literature, I empirically analyze what factors affect Canadian firms' decisions to patent in Canada and the U.S. using a unique dataset in Chapter Two. Interestingly, when the Canadian Intellectual Property Office (CIPO) enhanced its cooperation with other patent offices, more Canadian firms were encouraged to patent in Canada. This finding motivated me to investigate further how CIPO's role as an International Search Authority (ISA) in the Patent Cooperation Treaty (PCT) affects Canadian firms' patenting decisions in Chapter Three. The empirical investigations do not answer how firm characteristics, business opportunities, and patent system design affect firms' locational patenting decisions. Thus, I develop a theoretical framework to investigate how firms decide where to apply for patents in Chapter Four.

Several empirical findings deserve our attention. First, Canadian firms' propensity to patent increases in firm size and research and development (R&D) intensity, but decreases in firm profitability and age. Second, the likelihood of patenting in both the U.S. and Canada is associated with past patenting experience, firm size, profitability, and patent scope. Third, while manufacturing firms in export intensive industries tend to patent in both countries, firms in Foreign Direct Investment (FDI) intensive industries are more likely to patent domestically only. Moreover, CIPO's role as an ISA was associated with an increase in the number of patent applications by Canadian firms.

Foreign-owned firms are the major contributor to the increased patenting.

Furthermore, my theoretical analyses show that high-quality innovations are more likely to be patented in multiple countries. As well, patent offices with lower application fees and tougher examination intensities face a trade-off between patent quality and application quantity. Besides, business opportunities in a country can be an important factor in determining innovators' locational patenting decisions. In particular, I compare a simultaneous application system, in which an innovator submits his patent applications simultaneously to several patent offices, with a sequential application system, where his applications are submitted sequentially. Moreover, if third parties can observe application outcomes of the same innovation at different patent offices, it refers to information availability. My results suggest that information availability and application sequence could increase the perceived quality of patents and encourage more firms to apply for patents.

Certain policy implications emerge from the results of this thesis. On the one hand, if the policy target is to attract firms to apply for patents in their home country, the domestic patent office may set preferential policies towards young and small firms. On the other hand, if the policy target is to encourage firms to apply for patents abroad, policymakers should design policies to reduce the barriers for firms to do business and enhance cooperation with other countries (e.g., PCT). The theoretical results also have several policy implications. First, if the policy target is to encourage firms to patent, one crucial direction is to improve firms' business environment to exploit their innovations. Second, patent offices can support cross-border patenting by increasing information availability and pushing innovators to apply for patents in sequence.

Preface

This dissertation consists of a literature chapter, two empirical articles, and a theoretical article. The empirical article, "Determinants of Locational Patenting Behavior of Canadian Firms", is a co-authored work with my supervisors Professor Andrew Eckert and Professor Corinne Langinier. This article has been accepted by *Economics of Innovation and New Technology* for publication. I was responsible for the empirical analysis, research methodology development, and manuscript drafting. My supervisors were involved in motivation, research methodology development, and manuscript editing. The other two articles are single-authored, but my supervisors have given suggestions and comments during every stage of the papers.

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BPS	Berkeley Patent Survey
CCA	Council of Canadian Academies
CDIA	Canadian Direct Investment Abroad
CIPO	Canadian Intellectual Property Office
CMS	Carnegie Mellon Survey
DID	Difference-in-Differences
EPO	European Patent Office
FDI	Foreign Direct Investment
HHI	Herfindahl-Hirschman Index
IPC	International Patent Classification
IPRs	Intellectual Property Rights
ISA	International Search Authority
ISR	International Search Report
JPO	Japanese Patent Office
NAICS	North American Industry Classification System
NALMF	National Accounts Longitudinal Microdata File
OECD	Organisation for Economic Co-operation and Development
PCT	Patent Cooperation Treaty
PPH	Patent Prosecution Highway
R&D	Research and Development
SIPO	State Intellectual Property Office of China
SMEs	Small and Medium-sized Enterprises
TRIPS	Trade-Related Aspects of Intellectual Property Rights
USPTO	United States Patent and Trademark Office
VIF	Variance Inflation Factors
WIPO	World Intellectual Property Office

INTRODUCTION

A patent grants its owner the right to exclude other entities from using newly developed technologies as well as improved products or processes within a specific period (20 years from the date of filing in the U.S. and Canada). National laws define patent rights; a patent granted in one country cannot protect the invention in another country. This requires firms to make locational patenting decisions (both patenting domestically and patenting abroad) to protect their inventions.

In the last two decades, the number of patent applications filed abroad by domestic innovators has doubled worldwide. In some countries like Canada, innovators apply for more patents abroad than in their own countries. For example, aggregate data show that in 2018, Canadian innovators filed 4,349 patent applications at the Canadian Intellectual Property Office (CIPO), compared to 13,045 in the U.S.[1]

Despite increasing importance, studies of firms' decisions on where to apply for patents are limited in the literature. Hanel (2005) is the only econometric analysis of Canadian firms' locational patenting decisions. For U.S. firms, Chan (2010) studies the locational patenting behavior of nine agricultural biotechnology firms. Policymakers need a comprehensive understanding of firms' locational patenting behavior to deal with increasing patenting abroad.

Studies of locational patenting behavior are particularly insightful for policymakers in Canada. According to a 2018 report by the Council of Canadian Academies (CCA, 2018), Canada is strong in its inventive capacity but weak in its innovative outputs (e.g., patents). The report points out that Canadian inventors sell their inventions abroad at an early stage of the inventions or explore business opportunities elsewhere. If a large portion of Canadian innovations is patented abroad but not domestically, domestic Canadian firms may lose chances to know and utilize their patented innovations within Canada. This is a potential loss to the Canadian economy. It is important to understand how Canada can change its innovative capacity into innovative outputs more effectively

[1]The numbers are taken from World Intellectual Property Organization (WIPO) statistics.

(Gallini and Hollis, 2019). Understanding what factors affect locational patenting decisions may help set policies to boost Canadian firms' operation in the domestic market.

Generally, the motives behind firms' locational patenting decisions also have potentially important policy implications. If locational patenting decisions are determined by firm-level characteristics such as age, size, and profitability, then if increasing domestic patenting is a policy objective, it may be best achieved by targeting firms with certain features. Likewise, if the patent system's design makes firms decide not to apply for patents at home, then policy intervention to increase domestic patenting could focus on patent rules and procedures. Finally, if the key determinant of domestic patenting is the industrial environment, policy changes should focus on improving domestic business opportunities.

This thesis focuses on firms' locational patenting decisions from both theoretical and empirical perspectives. The empirical papers focus on Canadian firms' patenting activities in the U.S. and Canada and their responses to changes in the patent system. The theoretical paper incorporates the key empirical findings into a theoretical framework.

Legal obligations and confidentiality issues prevent researchers from merging firm-level data to patent data across countries. As a result, studies on firms' locational decisions have been limited. This thesis contributes to the locational patenting literature by overcoming this hurdle for Canadian firms' patenting in Canada and the U.S. under arrangements with Statistics Canada that maintain legal confidentiality requirements. While previous studies have used surveys of selected firms (e.g., Hanel, 2005), my analysis makes use of patent data directly from the United States Patent and Trademark Office (USPTO) and CIPO for all Canadian firms.

This thesis aims to achieve a few objectives. The first is to investigate what has been done in the literature regarding innovators' decision of whether to patent and where to patent. I start with a comprehensive literature review regarding studies of firms' patenting and locational patenting decisions with a focus on studies of Canadian firms in Chapter One. This understanding of the literature allows me to carry out my investigation of locational patenting decisions from both empirical and theoretical perspectives.

The second objective is to investigate what factors may affect firms' locational decisions. Given the data availability, Chapter Two studies the effects of industry-level factors that affect business opportunities and profitability, firm-level factors such as firm age, firm size, and changes in patent system procedures and rules on locational patenting decisions. The factors are selected based on the literature reviewed in Chapter One.

The third objective is to examine the potential effects of cooperation among patent offices on firms' locational patenting decisions. Many countries have made efforts to facilitate innovators' patenting in several countries with the adoption of the Patent Cooperation Treaty (PCT). PCT is an international treaty signed by more than 150 states to help innovators obtain patents in multiple countries. Since 2006, PCT has become the main application channel for patenting abroad. However, we know little about how PCT affects firms' locational patenting behavior. The third chapter aims to provide an empirical investigation of how Canadian firms' patenting behavior is affected by Canada's participation in the PCT as an International Search Authority (ISA), which performs a search for prior art and prepares a report on the patentability of a PCT application.

One key motivation of Chapters Two and Three is the lack of empirical evidence on firms' locational patenting behavior. However, theoretical studies on firms' decisions on where to patent are even more limited. By incorporating the key factors found in the literature, the fourth objective of this thesis is to develop a theoretical framework to analyze firms' locational patenting. In Chapter Four, I consider how innovation quality, application fees, the intensity of examinations, and the economic opportunities, the information availability, and the application sequence affect firms' locational patenting decisions.

In Chapter Two, several findings are worth noting. First, Canadian firms are more likely to apply for patents at the office where they have already obtained patents. Second, Canadian firms with innovations of wider patent scope tend to patent in both countries. Third, the longer a Canadian firm has operated in the market, the more likely it will patent in both countries. Fourth, large Canadian firms tend to apply for patents at CIPO only. Fifth, while manufacturing firms in export intensive industries are more likely to patent in both countries, firms in FDI intensive industries tend to patent domestically only. Finally, CIPO's role as an ISA is associated with an increase in Canadian firms' use of PCT.

The last finding of Chapter Two motivated me to investigate further the role of the ISA and provide an in-depth analysis for Canadian firms in Chapter Three. A robust conclusion is that after becoming an ISA, CIPO has encouraged Canadian firms to apply for patents. This finding suggests that Canadian firms care about who is the ISA for their PCT applications. Further analysis shows that foreign-owned firms are the main contributors to the increase in patenting at CIPO.

The policy implication of these empirical findings is that if the policy target is to encourage firms to apply for patents in their home country, the domestic patent office may set preferential policies towards young and small firms. If the policy target is to encourage firms to apply for patents abroad, then the policy direction should be to reduce the barriers for firms to do business in foreign markets and to enhance the cooperation (e.g., PCT) with other countries.

In Chapter Four, the theoretical results show that high-quality innovations are more likely to be patented in multiple countries. As well, application fees and examination intensities are another two considerations. Besides, business opportunities in a country can be a factor that outweighs other factors to determine an innovator's locational patenting decisions. Furthermore, I investigate a simultaneous application system and a sequential application system. In the former system, innovators submit their applications simultaneously to several patent offices. However, in a sequential application system, applications are submitted sequentially. The key difference in these two application systems is that innovators can update their information regarding the innovation quality in the sequential application system. I also consider information availability in the model. Whether third parties can observe application outcomes of the same innovation at different patent offices depends on whether the information is available. The results show that information availability and application sequence can increase the perceived quality of patents and encourage more firms to apply for patents if the increase in the perceived quality of patents is big enough.

CHAPTER 1

WHY AND WHERE FIRMS PATENT: A LITERATURE REVIEW WITH AN APPLICATION TO CANADA

1.1 Introduction

Innovation has been recognized as a potential driving force for economic growth and productivity. An economy can benefit from not only domestic innovation but also foreign innovation. Eaton and Kortum (1996) find that ideas originated from foreign countries induce a majority of productivity growth in Organisation for Economic Co-operation and Development (OECD) countries other than the U.S. and countries vary in terms of their attractiveness to innovators. The Canadian Intellectual Property Office (CIPO) is seen as being an office of second filing: firms patent first elsewhere before patenting in Canada. According to Nikzad (2013), in 2010, domestic patent applications represented less than 15% of all patent applications in Canada, while the U.S. was the destination of 50% of Canadian applications; a similar conclusion is reached by Hanel (2005) for earlier years. Trajtenberg (2000) also shows that Canadian assignees own less than half of Canadian patents.

These findings suggest that Canadian inventions may not fully benefit the Canadian economy; if a large portion of Canadian innovations is patented abroad but not domestically, domestic Canadian firms may lose chances to know and utilize the patented innovations within Canada. Canada needs to take a new approach to its intellectual property rights to compete globally (Mazurkewich, 2011). Gallini and Hollis (2019) also argue that Canada needs to find effective ways to increase innovation outputs (e.g., patents).

There are various reasons for firms to apply for patents. Empirical studies using surveys find that firms may patent to patent to prevent copying, obtain licensing revenue, increase negotiation position, and avoid lawsuits (Levin et al., 1987; Cohen et al., 2000; Sichelman and Graham, 2008; Graham et al., 2009). Patents may also be used to avoid expensive imitation costs (Mansfield et al., 1981), to distort rival firms' decisions in R&D activities (Kortum and Lerner, 1999; Palangkaraya et al., 2008), to reduce the possibility of being held up by external patent owners (Hall and Ziedonis, 2001) and to increase the value of innovation (Arora et al., 2008). However, studies on locational patenting decisions are relatively rare. To my knowledge, Hanel (2005) is the only econometric analysis of Canadian firms' patenting decisions in the U.S. and Canada. For U.S. firms, Chan (2010) studies nine agricultural biotechnology firms' locational patenting behavior in Australia, Brazil, Canada, China, the European Patent Office, Japan, and South Africa.

To make effective policies to increase a country's attractiveness to innovators, the first step is to understand how firms make their locational patenting decisions. The purpose of this chapter is to provide a comprehensive review of the patent literature. The objective is to investigate what we know from the literature regarding innovators' decision of whether to patent and where to patent. The review provides a foundation for further studies on locational patenting behavior.

In this chapter, we first review the relevant economic literature to identify contextual explanations for this observation. As most Canadian patents are issued in the U.S. and Canada, we focus on Canadian firms' choices to patent at CIPO and/or USPTO. Nonetheless, our discussion likely extends to Canadian firms' decision to patent in other countries.

To understand why a particular Canadian firm would choose to apply for patents in the U.S. rather than, or in addition to, Canada, it is important first to overview the underlying economics of patents and the roles that patents were intended to play. Specifically, we discuss differences in patenting, patent policy and offices in Canada and the U.S., highlighting those differences that might be expected to explain location decisions. The review reveals that while regulations and rules regarding patents are consistent between CIPO and USPTO, certain differences exist, regarding for example, who has the right to patent, whether a separate examination request is required, and the degree of examination intensity. These differences may impact Canadian innovators' decisions on whether to patent in USPTO or CIPO or both.

Secondly, we review the incentives of firms to patent, since these incentives support which differences across countries and agencies could explain patenting location decisions. While innovators may patent to win reputation, block competitors, gain bargaining power, avoid lawsuits, and mislead rivals, they may also choose not to patent because of the disclosure of too much information, fees involved, or the fear that competitors will invent around their patents.

We then review the existing theoretical and empirical economic literature focusing specifically on locational differences in patenting, and a firm's choice of where to patent. Our review suggests that the decision on where to patent is as complex as the decision to patent per se. The entry to a foreign market acts as the primary motivation for firms to patent abroad, whereas the selection of a particular patent office can be complicated. At least three factors should be considered: the patent system in the foreign country, the quality of the innovation, and business opportunities in the destination country.

Finally, we conclude with a review of the main variables expected to influence locational patenting decisions. We also explore what empirical results would tell us about the patent quality of Canadian firms and the biases that arise from looking at patenting only in a single office.

This chapter is organized as follows. The next section overviews the basic economics of patents and patent system, then Section 1.3 reviews studies on incentives to patent and firms' locational decision of patenting. Section 1.4 focuses on Canadian firms' patenting; Section 1.5 summarizes key factors that may impact firms' decisions on where to patent. Section 1.6 concludes the paper with a policy discussion for Canadian patent policies.

1.2 Overview of Patent Systems

In this section, we first introduce patents and patent systems. Then, we provide some statistics about patenting in Canada and in the U.S. Discussions here are largely based on London Economics (2010); Maskus (2005); and Eckert and Langinier (2014).

1.2.1 Patents and Patent Systems

A patent grants its owner the right to exclude other entities from using newly developed technologies as well as improved products or processes within a specific period (20 years from the date of filing in the U.S. and Canada). Non-patented innovations may result in a free-riding problem as innovators bear the innovation cost while competitors can also benefit from an invention without paying for its discovery. Patents were introduced to address this free-riding problem and restore the incentives for innovation, by granting the patent holder a temporary monopoly right over the innovation.

Other social benefits to the existence of patents include assisting dissemination of knowledge, encouraging technological transfer and innovation commercialization, and facilitating the entry of small firms. On the other hand, social costs include the inefficiencies due to monopoly, duplication of spending, increased transaction costs, and costly monitoring of infringement (Eckert and Langinier, 2014).

To be patentable, an innovation must be novel, non-obvious, and useful. According to CIPO, novelty means that the innovation must be the first of its kind in the world. An innovation, whether a new development or an improvement of an existing technology, is non-obvious if it would not have been obvious to someone working in the area of specialty. Usefulness means that a valid patent cannot be obtained for something that does not work or that has no useful function.

In order to obtain a patent, the innovator submits an application to a patent office, along with a required fee. Examiners at the patent office read the application materials and search for prior art to examine if the claims stated in the application are valid. When the examination is complete, a patent is granted if no invalidating prior art is found or rejected if prior art is found. A patent may be granted with less valid claims than that stated in the original application since some claims may prove to be invalid. In most countries, the patent holder must pay subsequent renewal fees to maintain the patent in force.

Patent systems and procedures in Canada and the U.S. bear many similarities. In both countries, patents are granted to the first to file for a patent.[1] In both countries, small entities pay reduced fees. In addition, applicants in either country may choose to file an application under the Patent Cooperation Treaty (PCT). Under the PCT, applications go through an initial international examination procedure before proceeding to national patent offices, which decide whether to grant national patents. Finally, the patent system permits the involvement of third parties in both countries. When the patent application is published, the third parties such as competitors can report prior art to invalidate claims in the applications.

On the other hand, some important differences exist. One source of difference across countries regards what material is patentable. For example, Eckert and Langinier (2014) find that the U.S. utilizes a more liberal approach to patentable materials than Canada, and allows wider patentability in the areas such as the treatment of surgical and medical methods, and the treatment of software and business methods. Secondly, while U.S. applications proceed immediately to examination, in Canada the applicant must first submit a separate examination request to start the examination process within five years of the original application. Differences also exist in terms of application and renewal fees, with Canada requiring annual renewal fees up to nineteen years compared to three times in the U.S.[2]

The basic structure of patent offices in the U.S. and Canada are similar in terms of examiner groups of technological categories, the size of groups, and the career paths of examiners. However, internal incentives of patent examiners differ. In the U.S., examiners from different technological fields and with different experiences are paid under a formal bonus and award system based on the number of applications processed, hours per application, etc. Annual promotion is also conditional on whether examiners outperform their production quota by more than 10% on average with few errors, which is evaluated by random checks and routine checks by senior examiners. In contrast,

[1]Canada switched from a first-to-invent system in 1987, while in the U.S. the change took place on March 16, 2013.

[2]According to USPTO, “Maintenance fees are due three times during the life of a patent, and may be paid without surcharge at 3 to 3.5 years, 7 to 7.5 years, and 11 to 11.5 years after the date of issue. The fee cannot be paid early. Maintenance fees may also be paid with a surcharge during the ”grace periods” at 3.5 to 4 years, 7.5 to 8 years, and 11.5 to 12 years after the date of issue.”

Canada does not have such an incentive and promotion system.[3] In addition, USPTO examiners enjoy larger mobility in their career to move to private sectors than examiners in Canada (Eckert and Langinier, 2014).

1.2.2 PCT and ISA in the Context of Canada

PCT is a multinational patent law treaty whose mission is to facilitate multinational patenting. According to WIPO,[4] PCT may benefit applicants by giving them more time and information to amend their applications before entering national phases. Thanks to the report prepared by the relevant ISA, the examination and search efforts at national offices may be substantially reduced.

PCT applications involve two phases. First, a PCT application enters an international phase, during which an application is filed with a receiving office. In general, the receiving office is the national patent office where the applicant is a resident[5] or the International Bureau under WIPO.[6] At the receiving office, a PCT application goes through a search and examination process by an ISA selected by the applicant. This results in an ISR and written opinion on the patentability of the innovation.[7] If more than one ISA is available at the receiving office, applicants can choose which one will perform the examination and write the report.[8] If an application has applicants from different countries, filing with WIPO may result in a wider choice of ISAs.[9]

Second, upon receiving the examination results from an ISA, the applicant selects individual

[3]Note that while CIPO does not have a monetary incentive system, it has a strong quality oversight and review of work, and examiners at CIPO have quotas. These factors are strong determinants in promotion as well as opportunities to work on other projects or to telework at CIPO.

[4]Summary of the Patent Cooperation Treaty (PCT) (1970), http://www.wipo.int/treaties/en/registration/pct/summary_pct.html. Last accessed March 15 2019.

[5]A resident of a country which is party to the ARIPO Harare Protocol, the OAPI Bangui Agreement, the Eurasian Patent Convention or the European Patent Convention, can alternatively file his international patent applications with the regional patent office concerned, if permitted by the applicable national law.

[6]WIPO: Protecting Your Inventions Abroad: Frequently Asked Questions About the Patent Cooperation Treaty (PCT) http://www.wipo.int/pct/en/faqs/faqs.html. Last accessed March 20, 2019.

[7]At the applicant's request, an optional and additional patentability analysis can be carried out by an International Preliminary Examination Authority, which is usually carried out on an updated application after the applicant makes modifications according to the opinions stated in the report by an ISA.

[8]For example, if USPTO is the receiving office, the applicant can choose ISA from the Australian Patent Office, Russian Patent Office, Korean Intellectual Property Office, EPO and USPTO. In contrast, PCT applicants at CIPO could only choose EPO before 2004, while they can only choose CIPO after 2004.

[9]WIPO: Direct filing of PCT applications with the International Bureau as the PCT receiving Office (RO/IB) http://www.wipo.int/pct/en/filing/filing.html#4. Last accessed March 15, 2019.

countries in which to apply for patents. Once the individual patent offices are determined, each application enters a national phase. Although examiners at national offices may use ISA reports when deciding whether to grant a patent, they carry out their own search and examination in accordance with the patentability rules in their own countries.

Patent offices may differ in examination quality, speed and costs. EPO has a reputation for high quality search (Wada, 2016) and fast processing (Gimeno-Fabra and van Pottelsberghe de la Potterie, 2017), but charges high search fees (van Pottelsberghe de la Potterie, 2011a). In contrast, USPTO is perceived to grant too many low quality patents (Lemley and Shapiro, 2005; De Rassenfosse et al., 2016; Lei and Wright, 2017). De Rassenfosse et al. (2016) compare the examination toughness of major patent offices (EPO, USPTO, Japan Patent Office, State Intellectual Property Office of China (SIPO) and Korean Intellectual Property Office) and find that Japan has the toughest examination standard, whereas USPTO and SIPO have the loosest standard.

Although ISA is an important part of the PCT program, not every PCT contracting patent office is an ISA.[10] Therefore, one may wonder why CIPO became an ISA. According to Paquet and Roy (2005), becoming an ISA for CIPO was expected to have several potential advantages. First, ISA services at CIPO could lower the costs of obtaining foreign patents for Canadian firms, especially for small and medium enterprises. Second, CIPO's role as an ISA may encourage more Canadian firms to patent domestically. In addition, to prepare for ISA services, CIPO improved its information technology infrastructure and increased the examination capacity by recruiting more staff (De Vleeschauwer, 2013).

Despite these advantages, becoming an ISA could be a challenge for CIPO as large Canadian firms may be disinclined to switch from ISA services provided by other patent offices (Paquet and Roy, 2005); as a result, CIPO's role as an ISA may have limited effect on those Canadian firms' international patenting. In addition, CIPO had to consider the costs involved in becoming an ISA such as building a technical system and hiring new examiners.

[10]To date, 21 out of 152 PCT contracting patent offices are ISAs. The list of those states can be found on the WIPO website at
www.wipo.int/pct/en/pct_contracting_states.html. Last accessed March 12, 2019.

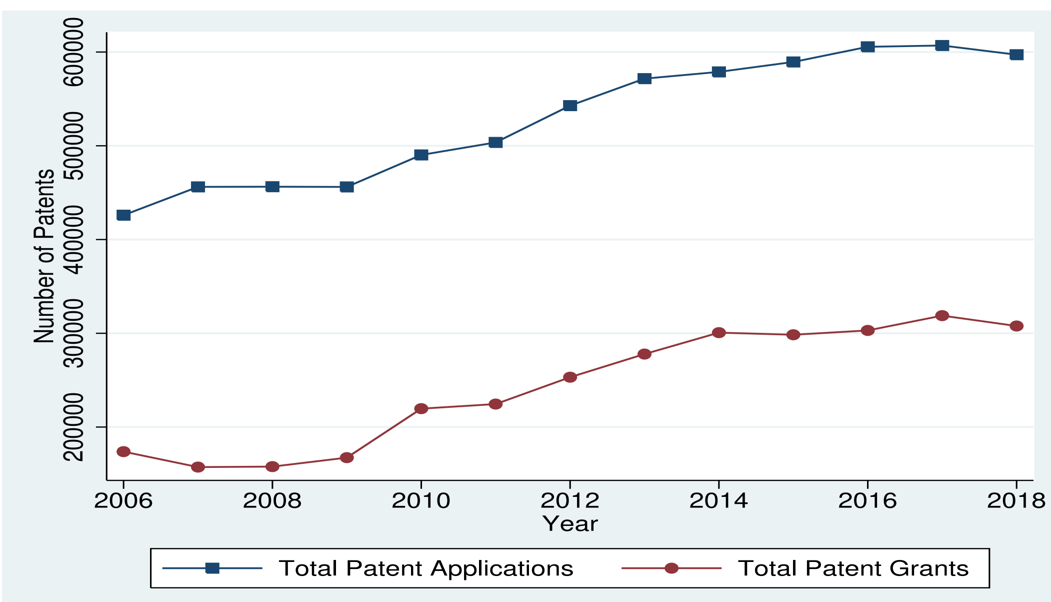
On July 26, 2004, CIPO began its services as an ISA under PCT. With this accreditation, CIPO would not only administer PCT applications that have entered the national phase in Canada but would also undertake PCT examinations for international applications filed by Canadian firms.

1.2.3 Statistics in CIPO and USPTO

The previous section compares Canada and U.S. in terms of their patent systems and notes that differences in procedures can lead to different levels of patent office performance, which can, in turn, affect incentives to patent. The purpose of this subsection is to compare differences in performance statistics across these two countries.

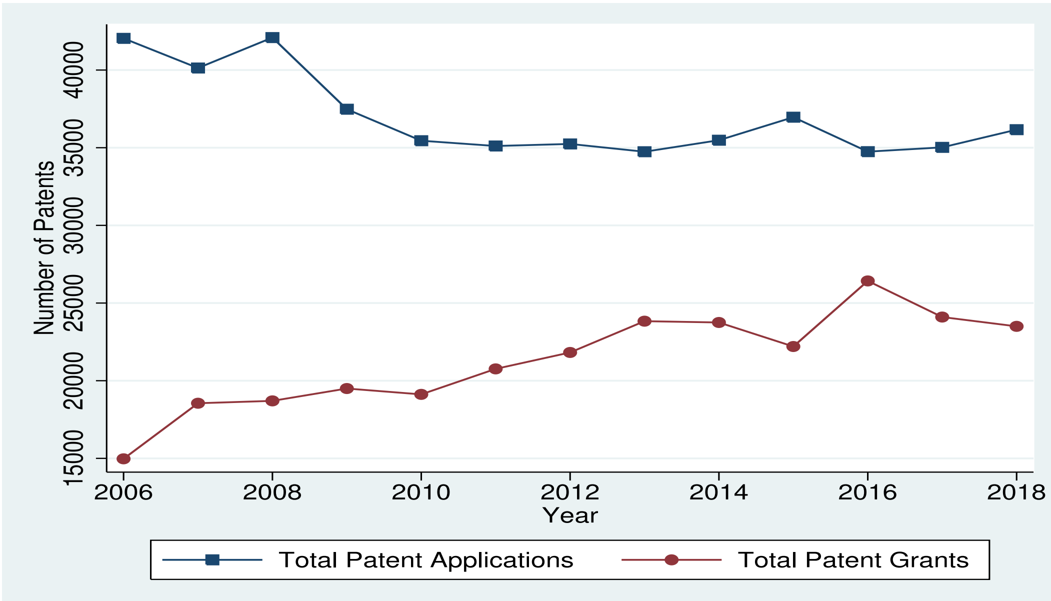
Figures 1.1 and 1.1 plot the number of patent applications and granted patents for USPTO and CIPO during the period 2006 to 2015. From the figures, the most noticeable difference between USPTO and CIPO is the number of applications and granted patents. The second observation is a steady growth in applications and patent granting in USPTO. In contrast, the numbers of applications and granted patents in Canada have been relatively stable.

Figure 1.1: Patent Applications and Grants in the U.S.



Source:WIPO statistics database.

Figure 1.2: Patent Applications and Grants in Canada



Source:WIPO statistics database.

Differences in the procedure and functioning of patent offices and the examination process can lead to differences in pendency time (time elapsed from patent application to granting), grant rate, and backlog (number of pending applications), which are often used as measures of patent office performance. According to the Annual Report 2014-2015 of CIPO,[11] the pendency time was reduced from 48.4 months to 40.3 months between 2011-2012 and 2014-2015, and the inventory of patent applications with a request for examination awaiting the first action was reduced by 37% between 2011-2012 and 2014-2015. In contrast, the 2016 Performance and Accountability Report by USPTO[12] indicates the average first action pendency dropped from 21.9 months in 2012 to 16.2 months in 2016 and the average total pendency time dropped from 34.7 months in 2012 to 25.3 months in 2016. In addition, USPTO continues to reduce the unexamined patent application backlog, decreasing the backlog from 608,283 [13] at the end of 2012 to 537,655 at the end of 2016.

Also, according to the IP Canada Report 2016, direct applications have declined for four con-

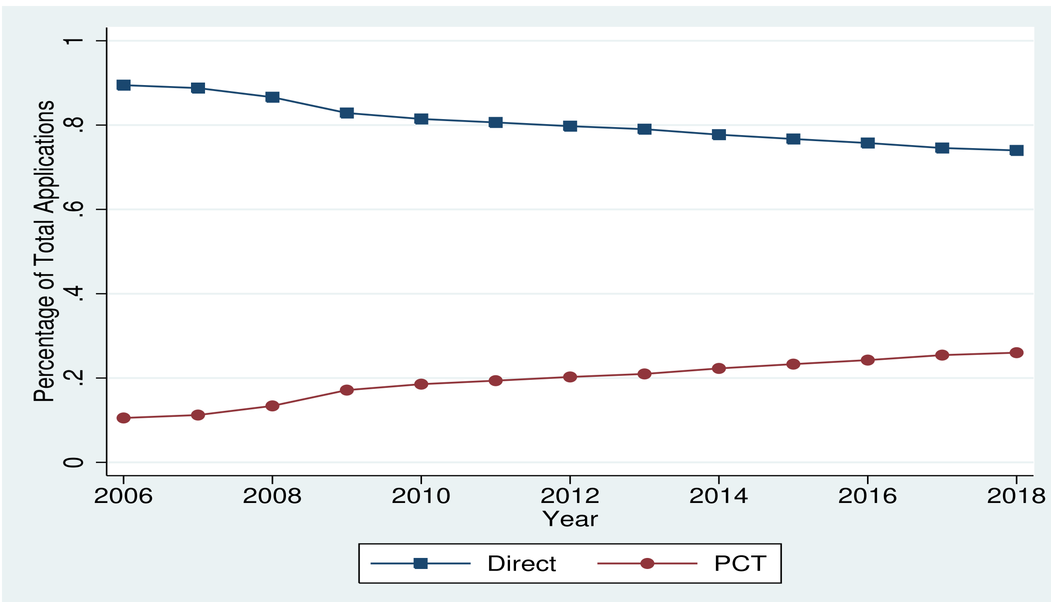
[11] Annual Report 2014–2015 Performance vs. objectives: https://www.ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04031.html (last accessed January 18, 2017).

[12] see, https://www.uspto.gov/sites/default/files/documents/USPTOFY16PAR.pdf(last accessed January 18, 2017).

[13] This number is reported in the 2012 Performance and Accountability Report by USPTO.

secutive years; a long-run trend which continued in 2015 was the shift away from direct applications and toward applications through the PCT. In 2015, 29,393 patents filed with CIPO entered through the PCT, accounting for 80% of all applications. In contrast, the percentage of patents filed with USPTO through the PCT is much lower. Figures 1.3 and 1.4 show a sharp difference during the period 2006-2015.

Figure 1.3: Patents Filed in the U.S. by Filing Mechanism (%)



Source: WIPO statistics database.

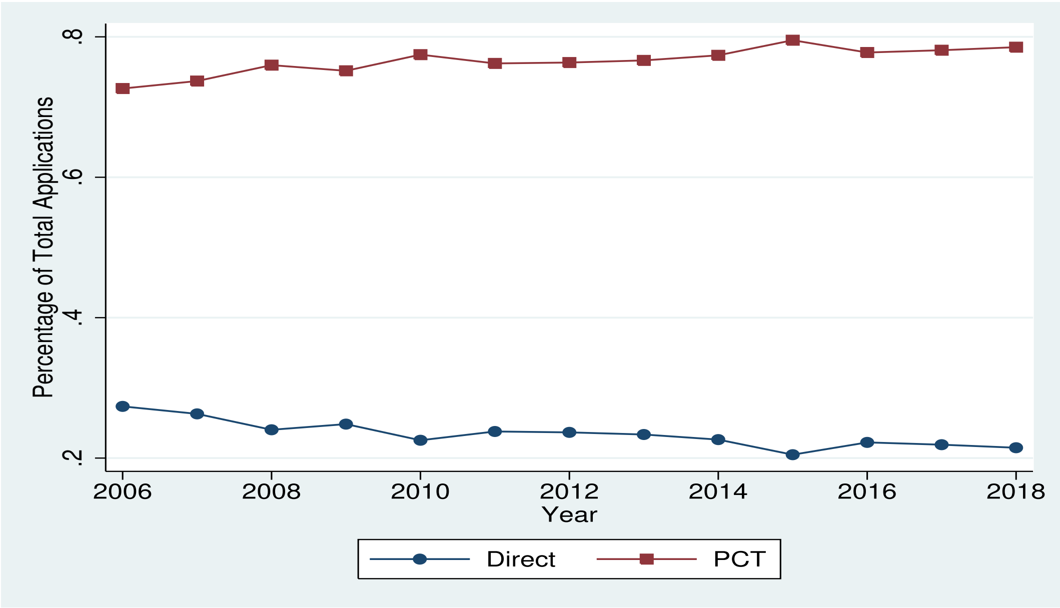
While the fee structure is similar in Canada and the U.S., there exist some differences. For instance, the application fee[14] at the USPTO for utility is US$ 280, with small entity paying US$ 140 and micro entity paying US$ 70. In contrast, the application fee and request fee at CIPO[15] is US$ 304, US$ 152, respectively, and small entities pay half. On the other hand, according to our estimation, renewing a patent for 20 years costs approximately US$ 15400 in 2016, whereas in Canada it is US$ 5767 (US$3074 for small entities). It is worth noting that these fees are standard and procedural, in practice, fees involved in patents can be larger. For instance, it is possible that

[14]USPTO Fee Schedule: https://www.uspto.gov/learning-and-resources/fees-and-payment/uspto-fee-schedule(last accessed January 18, 2017).

[15]CIPO Fees-Patent: https://www.ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr00142.html(last accessed January 18, 2017). Fees in Canadian dollar are converted to US dollar based on exchange rate on January 18, 2017.

the patentee will hire a patent attorney or a legal representative, which leads to additional expenses. In addition, before an applicant files a patent application, the drafting of the patent also incur a cost. To sum up, It is hard to quantify the costs of an application with accuracy (Schneider, 2007).

Figure 1.4: Patents Filed in Canada by Filing Mechanism (%)



Source: WIPO statistics database.

According to a calculation by Japan Patent Office, grant rates[16] at USPTO and CIPO do not differ significantly. From January 2016 to June 2016, the grant rate[17] is 64% at CIPO and 67% at USPTO. However, in general, grant rates have to be treated with caution. Patent offices do not necessarily measure grant rates in the same way, so it is hard to compare grant rates reported by different offices.

1.3 Incentives to Patent and Where to Patent

To understand the locational decisions of patenting, it is useful to first understand why firms apply for a patent. In this section, we provide a systematic review of incentives for firms to patent. Lastly, we review the literature on the location choice of firms to patent.

[16]Grant rates here are defined as: (number of granted patents)/((number of granted patents)+(number of decisions of refusal)+(number of withdrawal and abandonment after first office action)).

[17]see https://www.jpo.go.jp/ppph-portal/statistics.htm(last accessed January 18, 2017).

1.3.1 Incentives in Surveys

Surveys have been widely used to study firms' incentives to use Intellectual Property Rights (IPRs), including patents. This section focuses on incentives reporting directly from respondents' answers. The Yale Survey (Yale) employed in Levin et al. (1987) was aimed at high-level R&D managers from more than one hundred manufacturing industries. They find differences across industries and between product and process innovations in the effectiveness of innovation protection channels. In most industries, including the most R&D intensive industries (except pharmaceutical), firms did not report patenting as one of the important ways in which they profited from their innovations. Their results also show that patents for products were typically considered more effective than those for processes. Based on the Carnegie Mellon Survey (CMS), which was administered to 1478 R&D labs in the U.S. manufacturing sector in 1994, Cohen et al. (2000) also find that patents are the least emphasized channel to protect innovations.

Other important surveys by Graham et al. (2009) and Sichelman and Graham (2008) study the 2008 Berkeley Patent Survey (BPS). Their results show that while a large number of startups hold patents, company executives report that patents provide relatively weak incentives for core activities in the innovation process, such as invention and commercialization.

Table 1.1 summarizes the main incentives and disincentives to patent in these three surveys. For simplicity, reported incentives or disincentives to patent can be categorized into two main groups. The first one is the potential of patents to bring direct benefits to the firm. The other is that patents can be used strategically by firms. De Rassenfosse and van Pottelsberghe de la Potterie (2009) argue that the propensity to patent should be decomposed into the "appropriability propensity" and the "strategic propensity," which are just the right terms describing these two types of incentives to patent. It shows that patent applicants are more likely to use patents to prevent copying, obtain licensing revenue, and improve negotiation position. In contrast, patents are less likely to be used as a way to avoid lawsuits and direct profit from patented innovation. On the other hand, concerns that the innovation is not patentable, prosecuting and enforcing costs, and competitors' ability to invent around are the most popular reasons for innovators to not patent.

Table 1.1: Incentives Reported in Three Key Surveys

	Yale	CMS	BPS
Incentives to Patent			
Preventing Copying		✓	✓
Securing Investment			✓
Obtaining Licensing Revenue		✓	✓
Improving Liquidity			✓
Increase Negotiation Position		✓	✓
Enhancing Reputation/Image		✓	✓
Entry Condition to Some Countries	✓		
Avoiding Lawsuits		✓	
Patent Blocking		✓	
Defending Against Infringement Lawsuits			✓
Measuring Employees' Performance	✓	✓	
Patents as Valuable Assets	✓		
Profiting from Patented Innovations		✓	
Disincentives to Patent			
Technology Is Not Patentable	✓	✓	✓
Prosecuting and Enforcing Costs		✓	✓
Fear of Reverse Engineering			✓
Fear of Information Disclosure		✓	✓
Availability of other Forms of Protection			✓
Competitors' Ability to Invent Around	✓	✓	
Fear of invalidity if Challenged	✓		
Difficult Enforcement	✓		
Rapidly Changing Techonlogy	✓		
Application Costs		✓	

Yale: Yale Survey 1987; CMS: Carnegie Mellon Survey; BPS: 2008 Berkeley Patent Survey.
Note that ✓ indicates that this point is mentioned, otherwise, it is not mentioned

Surveys are also used in other countries. For example, based on data from the Survey of Intellectual Property Activities by the Japanese Patent Office (JPO), Motohashi (2008) find that around 50% of patents are not used, either internally or by licensing to other firms. Some firms hold patents just for future use and a large portion of unused patents are kept to prevent other firms from using such technology. Firms in industries where cross-licensing is common such as the electronics industry may also keep patents to gain bargaining power for future licensing negotiation (Hall and Ziedonis, 2001).

Incentives reported in those surveys are more general and broader than factors impacting locational decisions, but we can still get some insights about firms' locational decisions. While some firms patent abroad to enter a new market passively (for instance, Levin et al. (1987) find that as an entry condition to some countries, U.S. firms are required to license their technology to host-country firms, so that some patents are filed to gain access to foreign markets), other firms may proactively patent so as to increase their success in the new market.

1.3.2 Incentives in Theoretical Contributions

While the use of surveys is the most straightforward way to ask firms about their incentives to patent, it suffers from a few shortcomings. For example, incentives reported in surveys may be too subjective and, in some sense, are random because the answers may depend heavily on the respondents' own expertise, experience, and understanding. In addition, reported incentives are hardly connected to other factors to fully understand firm's patenting behavior. Theoretical models attempt to provide a more general and rigorous analysis of the incentives to patent. In this section, we review what economic theories contribute to incentives to patent.

Horstmann et al. (1985) explore innovator's decisions to patent or keep the innovation secret. They argue that innovating firms possess private information about the profitability of their innovation and can use this information to influence the behavior of their competitors. However, to be effective, the propensity to patent should be, to some extent, random, because if the propensity is unity, competitors will know for sure that the innovation is profitable. This explains partly why not all innovations are patented. The model also predicts that if the profitability of an innovation is high, the propensity to patent will be lower.

In contrast to Horstmann et al. (1985), Langinier (2005) argues that the leader in a patent race has more information about the improvability of an innovation and chooses to patent strategically. The innovator may behave randomly by patenting more frequently so as to mislead competitors. These two studies imply that patents can be used as strategic tools by firms. The key is that firms behave randomly in their patenting behaviors. It also points out the importance of information disclosure in the patent system.

Patent offices have an important role in the patenting process as patent examiners have the authority to grant patents. They can also have an impact on innovators' incentives to patent. For instance, the impacts of application fees on innovators' decisions to patent have been studied (see Atal and Bar 2010, 2014; Caillaud and Duchêne, 2011; Lemley et al., 2005; Lichtman and Lemley, 2007). Higher application fees may lower the net expected payoff from patenting (Atal and Bar, 2014), and increase the prior art search intensity and enhance welfare (Atal and Bar, 2010), whereas Caillaud and Duchêne (2011) argue that the impact of patent fees on incentives may be limited. Application fees are particularly important for small firms and firms with severe financial constraints.

Application fees are not the only tools that patent offices can use. In Canada and many other countries (e.g., U.K., Europe), after filing a patent application, applicants are allowed to submit an examination request to start the examination process within a predefined time frame. Applicants may have incentives to delay the examination strategically; even though the delay might be due to both applicants and examiners (Régibeau and Rockett, 2010). We discuss why and how firms may take advantage of this policy.

As Harhoff and Wagner (2009) discussed, the reasons behind strategical delay include delaying fees, allowing time to figure out how to turn the patent into technological and market development, and inflicting uncertainty on competitors. Régibeau and Rockett (2010) treat the delay as a function of applicants' effort. They conclude that applicants with valuable innovations have stronger incentives to make an effort to speed up the approval process and obtain patents faster and earlier.

Yamauchi and Nagaoka (2009) argue that faster request for examination would increase the workload of examiners since low-quality applicants are induced to request examination. The average quality of the applications for which examinations are requested decreases since the uncertainty increases. On the other hand, an increase in request fees and a decrease in renewal fees can improve the average quality of applications that are requested for examination. Régibeau and Rockett (2007) theoretically investigate the relationship between the examination duration and the importance of patents. They argue that shorter duration of patent examination improves social welfare as long as the incentive of firms to develop high-quality inventions is assured. Hall et al. (2003) argue that the occurrence of low-quality patents can bring uncertainty, decrease incentives to innovate, harm employment and growth, as well as social welfare.

Shorter examination duration lowers the accuracy of examination but still increases social welfare. Caillaud and Duchêne (2011) study the capacity of the patent office to deal with applications and the overload problem. After receiving an application, the patent office undertakes a costly search and examination, which depends on the volume of applications. As more bad applications will lower the examiner's effort for each application, it becomes easier to get a patent, which attracts more applications and worsens patent quality (Jaffe and Lerner, 1999). Atal and Bar (2014) claim that the patent quality is an important determinant of firms' decisions to patent since the quality of patents, to a large extent, determines the value of patents to their holders.

Two other important policy instruments employed by patent offices are the length and breadth of a patent. While the length refers to the duration of the patent protection, the patent breadth refers to the scope of patent protection. Larger breadth means a larger monopoly power. The maximum duration of a patent is fixed at 20 years in the U.S. and Canada, but patent holders might decide not to renew their patent and, hence reduce their patent duration. However, patent length and breadth can be important instruments that can be used by patent authorities to influence incentives to patent.

Gilbert and Shapiro (1990) show that an increase in the breadth is costly in terms of increasing the dead-weight loss; in contrast, controlling for the breadth but setting an infinite patent life may be socially optimal. Klemperer (1990) claims that if substitution costs between varieties of the product are similar across consumers, infinitely lived but very narrow patents are socially efficient; in contrast, if the difference between the value of the preferred variety and the value of consuming no variety is the same for all consumer, short-lived and wide patents are desirable.

In addition, Gallini (1992) theorizes that when costly imitation occurs, a rival's decision to imitate depends on the length of patent protection awarded to the patentee: the longer the patent life, the more likely it is that rivals will "invent around" the patented product. The policy implication of the model is that patent life should be short enough to discourage imitation but still provide incentives to innovate.

However, Owen-Smith and Powell (2001) endogenise imitation in a model of optimal patenting and find that shortening the length of patent life may affect innovators' incentives to patent. The authors argue that if the patent life is too long, it may encourage rivals to invent around and the patent holder may face more competitors. Consequently, longer patent life reduces incentives to undertake research and disclose innovation.

The above models consider patenting in a static perspective, which does not capture the complexity of the innovation process. Therefore, recent studies investigate incentives to patent in a sequential setting. Even though patents may increase welfare in a static case, Bessen and Maskin (2009) show that in a sequential framework, an equilibrium without patents provides a higher welfare than with patents. The original innovator can even be better off without patents because of spillovers from follow-up innovations. Additionally, inventor's prospective profit may actually be enhanced by competition and imitation. This implies that innovators in industries where innovation is cumulative might be better off not to patent at early stages.

Other studies also show that, for cumulative innovations, strong patent protection may lead to socially inefficient outcomes as it may harm future innovation (O'donoghue et al., 1998; Chang, 1995; Denicolo, 1996; Scotchmer, 1991). To improve social welfare in such cases, Lerner and Tirole (2004) show that patent holders can form patent pools, which are agreements among patent holders to license a set of their patents to one another or to third parties. Lerner and Tirole (2004) argue that patent pools work better if patents in the pool are complementary. However, patent pools may discourage substitute innovation of the pool (Lampe and Moser, 2010; 2013)

From the above discussion, information asymmetry between innovators and other parties, including examiners, and competitors, allows innovators to strategically patent. Besides, these theoretical contributions also emphasize the role played by patent offices. Since application fees, policy regarding examination procedure, patent breadth and length are different among patent offices in different countries, these factors also have to be taken into account by applicants.

1.3.3 Incentives in Empirics

Surveys and theories provide rich insights to understand factors that affect innovators' incentives to patent and decisions on where to patent. A large portion of innovative activities will not take place without patent protection (Mansfield et al., 1981; Taylor et al., 1973). The primary role of patents is to induce firms to invest in R&D; however, the impact of patents on the rate of innovation seems to be limited, with the exception of pharmaceutical and chemical industries (Mansfield, 1986). Nonetheless, firms tend to rely on patent protection for their innovation as reported in Mansfield et al. (1981) when a patent is possible.

Early studies found that the propensity to patent varies from industry to industry (Scherer, 1965; Scherer, 1967), and from firm to firm (Pakes and Griliches, 1980). Since Levin et al. (1987), scholars have challenged the long-standing view that patents or other property rights are effective in protecting invention and provide incentives for innovation activities. Cohen et al. (2000) find that patents are the least effective way to protect innovation and firms use patents not for profit appropriating but for strategical purposes such as blocking rivals, avoiding lawsuits.

According to Hall (2009), the value of patents consists of the value of the invention per se and the value of the patent rights. The latter can be viewed as the incremental value of patenting the inventions, or a "patent premium" (Arora et al., 2008). Arora et al. (2008) estimate that the patent premium is about 47% on average for patented innovations. However, if the disadvantage of information disclosure is considered, the patent premium is reduced to 40%. This explains partially why firms do not patent all inventions. Graham et al. (2009) show that early-stage companies hold patents as a competitive advantage and as an instrument for preventing technology copying, securing financing, and enhancing reputation.

While information disclosure is considered as a cost to innovators, in a recent study, Graham and Hegde (2015) argue that patent disclosure may bring innovators private benefits by deterring rivals' duplicative R&D investment; preempting competitors' efforts to patent similar technology; and reducing informational asymmetries between patentees and potential investors. This argument implies that when evaluating the firms' patenting behavior, private benefits from information disclosure should not be overlooked.

For individual firms, there exist multiple motivations to patent. Using a sample of German companies active in patenting, Blind et al. (2006) comprehensively study the motives of firms to patent in 2002. Their findings reveal that, apart from the traditional motives to protect their own inventions from imitation, strategic motives (e.g., improving the reputation of the company, its position in negotiations with other companies and to create incentives for its R&D employees or to measure their performance) are also important considerations for firms' decisions to patent, even though the degree of importance varies from sector to sector and changes with the firm's size. De Rassenfosse and van Pottelsberghe de la Potterie (2009) empirically find that the distinction between appropriability propensity and strategic propensity is important to understand firms' patenting behaviors. They also find that the most important motivation for the surge of patent applications across patent offices is the internationalization of patents rather than a burst of innovation.

As discussed above, some patent offices allow applicants to request an examination at some point after it has been initially filed and applicants may strategically delay the request. Using a matched sample of 9597 patent applications from various patent offices, Kortum and Lerner (1999) examine the effect of strategical delay and find that delaying examination can create investment uncertainty. Palangkaraya et al. (2008) show that the grant rate is negatively correlated with the timing of the examination request. Kortum and Lerner (1999) and Palangkaraya et al. (2008) state that applicants use their private knowledge about the quality of their inventions to distort the rival firms' R&D activities by delaying the timing of examination request. An empirical study by Harhoff and Wagner (2009) show that during the period 1982-1998, applicants at the European Patent Office (EPO) accelerate the grant process for their most valuable patents.

In the case of Japan, Yamauchi and Nagaoka (2009) find strong evidence that applicants indeed respond to patent policies regarding examination requests such as the length of request period and request fees. Harhoff (2016) also finds that applicants in EPO respond to changes in fees in patent applications. For instance, increases in claims fees allow EPO to reduce the complexity of filings and grants. Harhoff (2016) further claims that offering a menu of choices for different levels of delay for a fee may be workable to improve existing rules regarding the delay.

To examine the impact of ownership structure on innovation, Aghion et al. (2013) construct firm-level data on innovation and institutional ownership from a variety of sources, USPTO with Compustat lodged at the NBER. Their empirical results show that the presence of institutional ownership boosts innovation. The results also indicate the risk consideration at the managerial level is important for decisions to innovate. As product competition becomes tougher and managers are less entrenched, institutions are more important for innovation.

It has been empirically shown that there is a negative relationship between patent cost per claim and the number of claims filed (van Pottelsberghe de la Potterie, 2011b). With a small sample of firms, Mansfield et al. (1981) find that imitation can be very costly, especially with patented innovations. This finding implies that firms may invest in innovative activities and finally patent their inventions so as to avoid imitation costs.

Firm size seems to play an important role as large-sized firms are more likely to carry out innovation and enjoy competitive advantage regarding patenting issues (see more discussion in Cohen, 2010). Small firms are found to be less likely to innovate than large ones, and when they do, they are less likely to introduce the most original innovations. The cost of IPRs protection is a relatively larger burden for small and medium-size enterprises (Hanel, 2005).

The study of U.S. semiconductor firms by Hall and Ziedonis (2001) shows that firms patent to strengthen their patent portfolio so as to reduce concerns about being held up by external patent owners and to increase their negotiating access to external technologies on more favorable terms. Patents act as an instrument for firms to increase their chances of obtaining venture capital and securing financial liquidity (Hall and Harhoff, 2012). Helmers and Rogers (2011) assess the effects associated with a firm's decision to patent on its subsequent growth. They use data on all high- and medium-tech startups in the UK between 2001 and 2005. Their findings suggest that for these startups, patent holders do have a higher annual asset growth rate of between 8% and 27%.

Using renewal data of patents of U.S. patents and controlling for patent and owner characteristics, Bessen (2008) finds that patents held by small firms are less valuable than those by large corporations; litigated and highly cited patents are generally more valuable than otherwise.

As well, Hanel (2005) finds that firms tend to use patents more often to protect product innovation and use trade secrets for process innovations. Besides, Graham et al. (2009) also find that, in general, patenting is almost twice as important for product innovators than for process innovators. Duguet and Lelarge (2004) conclude that incentives to innovate in products are increased with an increase in the value of patent rights and, in turn, the value of products increases the incentive to patent. However, Duguet and Lelarge (2004) argue that this relationship does not hold for process innovations.

The above studies show that the effects of patents vary from case to case and are also different for product and process innovations. There are some explanations in the literature. First, while patent data contain rich information about innovation, however, measuring patent quality is not easy, which may cause biased findings in empirical studies. Second, by nature, while patents reward patent holders with monopoly rights and encourage further innovation, patents also bring social costs embodied in such a monopoly.

Another important issue is the incentives of patent examiners. Alcacer and Gittelman (2006) find that many citations for a patent are added by patent examiners, but Sampat (2010) claims that patent applicants know more about the innovation than examiners do. While the incentives of examiners definitely have an impact on incentives for applicants, a review of that stream of literature is beyond the scope of this chapter. Concerning incentives of patents see, for instance, Friebel et al., 2006; Langinier et al., 2009; Cockburn et al., 2003; Lemley, 2009; Alcácer et al., 2009.

To conclude, our review suggests that when firms decide to patent, they consider multiple dimensions. Specifically, to decide where to patent, an innovator needs to consider at least three aspects. First, the innovator has to evaluate the value of his innovation by considering its applicability in the country where he wants to protect it, the industry characteristics for that innovation, etc. Second, the innovator has to evaluate the patent policies of the patent office. As the strategical function is widely considered, the innovator should also consider offices that allow him to realize his strategic objectives. Finally, an innovator, of course, has to consider how to increase the chances of being granted a patent if he has chosen a certain office.

1.3.4 Where Firms Patent

Cross-border patenting is important for worldwide economies. Eaton and Kortum (1996) find that a majority of productivity growth in OECD countries other than the U.S. are induced by innovation ideas from foreign countries and they state that the decision of where to patent contains information of applicability of the innovation and its cost. Sharma and Saxena (2012) investigate the impact of patent protection on economic growth in developing countries, and conclude that developing countries can benefit from strong patent protection from two channels. The first one is the direct impact of patent rights on the innovativeness of developing countries which leads to economic growth. The second one is that patent rights in developing countries facilitate technology transfer from developed countries through trade, foreign direct investment and licensing.

To understand cross-country patenting behavior, we need to understand that the exclusive rights of patents are underpinned by patent laws, which are national laws. Consequently, patents granted by a patent office can only be protected within the territory of that country. To obtain additional protection in a different country, patent holders need to file a new application in that country. Seeking patent protection in other countries is costly, so in order to decide to patent abroad, innovators need to consider a variety of factors.

Danguy et al. (2014) argue that to understand the surge of worldwide patent applications, not only the decision to patent but also how many patents and in which offices to file should be taken into account. They conclude that the increasing number of applications in patent offices worldwide is due to the greater globalization of IPRs rather than to an improvement in research productivity. Besides, Chan (2010) finds that an increased harmonization of patent laws across countries does not significantly increase the number of patent applications a country receives. Instead, heterogeneities of countries have an important impact on firms' decisions to patent abroad. In this section, we review the literature to see what factors may have an impact on firms' cross-border patenting.

When an innovator decides to produce in, or export to, a foreign country, he should patent his innovation in that country to be protected from imitation. According to Schmidt (2013), the country of the first filing of a patent application is usually not a real problem; how to determine the maximum geographical coverage of a patent is the real issue. Lo and Sutthiphisal (2009) state that firms' locational decision to patent is largely determined by where the innovation is expected to be produced, manufactured, sold, and franchised. As a result, international patenting reveals information of the international competitiveness of firms as well as signals where innovations are likely to be used (Inkmann et al., 1998).

Schmidt (2013) and Lo and Sutthiphisal (2009) imply that firms may patent in a new country if patents are necessary for their entry in that country. To some extent, changes in patent policies in one country do not necessarily alter international patenting behaviors in that country. In a case study of Canadian patent reform, Lo and Sutthiphisal (2009) state that the impact of a switch from first-to-invent to first-to-file was not significant. Noticeably, Chan (2010) claims that the standardization of patent laws across countries will not make a significant impact on firm's decisions to patent abroad.

Instead, the business opportunities and economic environment should be more of a concern. Sláma (1981) concludes that the size of two economies and their physical distance explain a large fraction of the variation in international patenting flows. However, Archontakis and Varsakelis (2011) find that physical distances do not have a significant impact and they conjecture that internet use is a major reason. Furthermore, Yang and Kuo (2008) empirically investigate the national determinants of outbound international patenting using patent data from 30 member countries in the World Intellectual Property Organization over 1995 and 1998. Their results indicate strong and positive associations between the behavior of outbound international patenting and trade-related influences, like exports and outward foreign direct investments. The positive connection between cross-country patenting and trade flows is also found in Dosi et al. (1990) and Licht and Zoz (2000). As well, Bosworth (1984) finds a strong association between patenting and foreign direct investment. Nikzad (2012) also shows that import and foreign direct investment are important channels of technology transfer, whereas the distance between foreign countries and Canada hinders the impact of foreign patents.

However, Inkmann et al. (1998) find that the determinants of firms' export designation have limited impacts on firms' decisions to patent abroad. Xu and Chiang (2005) find that international patenting is connected not only to an economy's patent regime, its openness but also to the technology gap between the home country and the destination country. Archontakis and Varsakelis (2011) find that, a smaller technology gap between the U.S. and a destination country will increase the incentive to patent abroad because narrow technology gaps increase imitation risk.

In the above studies, the quality of patent systems in the destination country has not been addressed. However, the quality of patent systems[18] plays an important role. By investigating patent application decisions of nine agricultural biotechnology firms from 1990 to 2000 in Australia, Brazil, Canada, China, EPO, Japan and South Africa, Chan (2010) finds that the major determinants of the decision to patent abroad include difference across countries (such as enforcement of patent, production, and consumptions), firms' valuation of incremental revenue from extra geographical coverage and the quality of patents. Lemley and Shapiro (2005) state that when firms consider a cross-border patent application, the target country's ability to defend the patent's claims and rights is assessed before filing the application. A country with stronger IPRs protection tends to receive more patent applications from foreign inventors (Yang and Kuo, 2008) and the quality of patent protection at the receiving country has a significant impact on international patenting (Park, 1999). In addition, Rafiquzzaman (2002) finds that Canadian firms tend to export more to countries with stronger patent rights protection.

[18]Lerner (2000) explores explanations for the differences across sixty countries in terms of the strength of patent protection over a 150-year period. The author concludes that patent systems are more likely to exist in rich nations and also patent life is longer in these countries. As well, he finds that due to historical factors, countries with democratic political institutions are also more likely to have patent protection. While countries with patent system tend to ratify treaties assuring equal treatment of other nations, the origin of a country's commercial law has an important impact on the restrictions on patentees' privileges and discriminatory provisions against foreign patentees. In addition, by constructing a data set from two historical events around the 1890s, Moser (2005) finds that the existence of patent laws did not increase patent activities. Instead, patent laws have significant effects on the direction of innovation. Particularly, without patent laws, innovation may concentrate in areas that secrecy was effective to protect innovation, such as food process and scientific instruments. In addition, Moser (2012) find that patenting decisions are not responsive to differences in patent laws.

However, the impacts of strengthening patent protection are questioned by Lerner (2009). According to Lerner (2000), if a country's patent protection is weak, further strengthening the patent system will enhance patent activities. Nonetheless, if a country's patent protection is already strong, further strengthening of the patent system may not stimulate patent activities. Instead, a negative relationship is possible. Budish et al. (2016) call for further research on the elasticity of R&D investment to better understand the effects of changes in patent term.

In addition, Bessen and Thoma (2014) find that for the same innovation, a patent from EPO for Germany generates a larger markup than a patent from USPTO, especially for small investors. This finding contrasts with the argument that the U.S. patent system favors small firms and independent inventors. This implies that the patent system in the destination country may not be the most important consideration for firms' locational decisions. Instead, it is the benefits that can be generated from patents that seem to matter most.

Besides these external factors, factors from firms and innovations can also have an impact on firms' decisions on where to patent. Fernández-Ribas (2010) studies a sample of patent applications of U.S.-owned small and large businesses at the World International Patent Organization from 1996 to 2006 in the emerging field of nanotechnology. The author finds that small-firm patents tend to be more novel and embedded in domestic innovation networks than large-firm patents. This implies that the more novel an innovation is, the more likely it will be patented internationally.

In addition, Jaffe and Lerner (2011) suggest that the fundamental qualities are different across innovations, implying that not all innovations are worth multiple patent applications. Indeed, Chan (2010) finds that application frequency across countries varies largely. From the 1999 survey data, Hanel (2005) also observe that a firm patents in the U.S. or Canada is associated with the originality of its innovation. To better present these discussions, we summarize these studies in Table 1.2

In another paper in progress, we theoretically investigate the effects of sequential applications. Some preliminary results show that there exist at least two effects from application results at the first-filing office. The first is that the applicant will re-evaluate the patentability of his innovation. If a patent is granted in the first-filing office, the innovator will become more confident in his

Table 1.2: Studies on Where Firms Patent in the Literature

Reasons	Description and Studies
Reason 1	Differences in business opportunities across countries: Chan (2010); Sláma (1981); Bessen and Thoma (2014)
Reason 2	Production in or export to a foreign country: Yang and Kuo (2008); Lo and Sutthiphisal (2009); Inkmann et al. (1998)
Reason 3	Technology gap between the home country and the destination country: Archontakis and Varsakelis (2011)
Reason 4	Differences in the quality of patent system across countries: Rafiquzzaman (2002); Lemley and Shapiro (2005); Yang and Kuo (2008); Park (1999)
Reason 5	Difference in the quality of patents: Jaffe and Lerner (2011); Hanel (2005) ; Fernández-Ribas (2010)

innovation, and it is more likely that he will file in the second office. If his application is rejected, the applicant will lower his innovation valuation and he might be reluctant to apply in the second office. On the other hand, with harmonization policies, the second office will adjust its examination intensity for applicants that have applied somewhere else. As a result, sequential applications will result in different patent qualities and also different application volumes at patent offices.

1.4 Patenting of Canadian Firms

While in the previous sections we have discussed patenting behavior in general, this section reviews studies on patenting behavior of Canadian firms. Our review focuses on the effectiveness of patents in Canada, where Canadian firms patent, and factors that determine Canadian firms' patenting behavior, and Canadian firms' response to changes in patent systems.

Firstly, we look at how patents are used in Canada. By using the Economic Council of Canada survey, De Melto et al. (1980) document that in the 1960s and 1970s, only 32% of major innovations of Canadian firms were patented. Trajtenberg (2000) investigate Canadian firms' performance based on Canadian patents in USPTO over 1968-1997. Their results indicate that during that particular period, Canada stands midway relative to the other G7 countries in terms of relative measures of innovative outputs such as patents per capita and patents/R&D ratios. Besides, the "rate of success" of Canadian patent applications in the U.S. is relatively low.

Using data from major patent data sources (CIPO, USPTO, EPO), Nikzad (2013) compares Canadian patent profiles with other selected countries. The author finds that Canadian firms are not using patents as frequently as in other countries. Canada ranks low in terms of patent measures such as the number of resident filing, the number of worldwide patent applications, the number of patent families, and the number of foreign-oriented patent families. However, Canada is strong when innovation is measured as the share of university patents.

In addition, based on a survey of firms in the telecommunications, financial and technical business service industries in Canada, Baldwin et al. (1999) report that patents are considered less important than other forms of IPRs protection. Nikzad (2015) reports that Canadian small and medium-sized enterprises (SMEs) are less likely to apply for patents compared to other industrialized countries, and that trademarks are more popular in Canada.

Secondly, the literature has explored Canadian firms' locational patent decision. Using the 1999 innovation survey, Hanel (2005) finds that two-thirds of Canadian firms that apply for a patent in Canada also apply in the U.S. Less than 10% of the firms apply only in the U.S., around 20% apply only in Canada and around 5% apply elsewhere. According to Nikzad (2013), in 2010, domestic patent applications represented less than 15% of all patent applications in Canada, while the U.S. was the destination of 50% of Canadian applications. Similarly, Trajtenberg (2000) shows that less than half of Canadian patents are owned by Canadian assignees, which means that Canadian inventions may not fully benefit the Canadian economy. Using patent data from CIPO, for the period from 1990 to 2008, Nikzad (2011) estimates that Canadian applications during that period account for only 13% of total applications.

Thirdly, the above review shows that: patents are not very popular in Canada and that Canadian firms tend to patent outside Canada. As a result, a question arises: what kind of firms would patent in Canada?

Firm size seems to be important for Canadian firms' decisions to patent. Nikzad (2015) show that small and medium-sized firms in Canada hold patents as a competitive advantage and as an instrument for preventing technology copying, securing financing, and enhancing reputation. Using data from the 1993 manufacturing survey, Baldwin (1997) finds that the use of patents and the assessment of their effectiveness are significantly connected with firm size. As well, foreign firms are more likely to use patents and report high effectiveness.

Besides, De Melto et al. (1980) find that foreign-controlled firms were more likely to patent in Canada. Nikzad (2015) also reports that patents are more frequently used by export-oriented and foreign-owned SMEs. In addition, Nikzad (2011) finds that non-PCT and more complex patent applications, as well as applications from small firms and foreign firms, tend to survive longer. Small firms are less likely to innovate than large ones, and when they do, they are less likely to introduce the most original innovations (Hanel, 2005).

Apart from firm size and foreign ownership, the costs involved in patenting is an important consideration. De Melto et al. (1980) state that the propensity to patent was positively related with costs involved in the innovation. Hanel (2005) claims that the cost of IPRs protection is a larger burden relatively for small and medium-size enterprises.

Additionally, Hanel (2005) finds that the innovation behavior of manufacturing firms in Canada is also related to the innovation status, the type of innovation, the originality of the innovation, and technology sectors. Firms tend to use patents more often to protect product innovations and use trade secrets for process innovations.

Finally, we investigate how Canadian firms' response to changes in patent systems. Lo and Sutthiphisal (2009) analyze the impact of the 1987 Canadian Patent Reforms from first-to-invent to first-to-file systems. They find that 1) the reform did not change R&D efforts by Canadian inventors; 2) had a small negative impact on patenting of Canadian domestic-oriented industries in Canada, US, and Europe; 3) that the first-to-file system seems unfavorable to individual inventors and small businesses. They suggest that a switch from first-to-invent to first-to-file may harm the inventive activity of a country. Lo and Sutthiphisal (2009) challenge the merits of adopting a first-to-file patent regime.

1.5 Implications for Geographical Coverage of Patents

Our review suggests that firms' locational decisions to patent can be affected by these types of factors: firm characteristics, patent features, business opportunities, and patent policy in the destination countries. This section discusses factors under each of these categories.

1.5.1 Determinants from Firm Characteristics

First, firm size seems to be one key determinant of a firm's patenting behavior. On the one hand, internal funding is more easily available and stable for large firms; large firms enjoy the complementarities between R&D and other non-manufacturing activities; economies of scope in large firms reduce risks of innovations. On the other hand, large firms suffer from the loss of managerial control, which diverts the attention of scientists and technologists, as well individual incentives are blunted as firms grow large (see Cohen (2010) for more discussion of this issue). Besides, large firms have more financial resources than small firms and startups. However, it is not necessarily the case that large firms face little financial constraints. Managing a very large patent portfolio can be expensive, and the decision on which patents to renew and which ones to abandon is made from a fiscal perspective. Otherwise, large firms would maintain all of their patents for the full 20 years, which we know is not the case.[19]

Second, the age of a firm may be important because of at least three reasons. First, as discussed earlier, some technologies are cumulative and need continuous investments from the firm. The longer a firm has been operating, the larger is the probability that the firm can finally accumulate enough innovations. Secondly, long-lived firms may gain experience in prior art searches, application statements, and how to deal with patent regulations and rules (they can hire agents with patenting experience and knowledge). Finally, along with a firm's continuous operation, the firm may be granted several patents, which allows it to build a good patent portfolio.

Third, Aghion et al. (2013) find that the ownership structure has significant impacts on firm's innovative activities. When a firm has multiple owners, the risk to innovate will be diversified

[19] We thank Collette, Elias from Industry Canada for pointing out this argument.

and managers may be able to make decisions to undertake innovation that will not take place, otherwise. On the other hand, a firm with multiple ownerships is unlikely to be dominated by individuals, which further reduces innovation risk and increases chances to innovate.

Fourth, the patenting behavior of firms differs if their business is multinational. For instance, a firm focusing only on the domestic market has less incentive to seek patent protection in a foreign country. In contrast, if a firm is exporting to a foreign country, it will have incentives to patent in that country. As a result, it is important to consider the operational structure of firms.

Fifth, firms' R&D expenditure directly influences firms' ability to invent. Although R&D expenditure is neither a necessary nor sufficient condition for innovation, Mansfield (1986) shows that R&D is important for firms' decision to patent, especially firms in the pharmaceutical and chemical industries.

Finally, Arundel and Kabla (1998) point out that sector effects are important determinants of the propensity to patent, even though the importance may be smaller than firm-level characteristics. The propensity to patent and technology opportunities differ vastly from industry to industry (Hanel, 2005; Arundel and Kabla, 1998). Besides, the effectiveness of patents differs largely across industries. For example, patents seem to be more effective for the appropriation of innovation benefits in chemical and pharmaceutical industries than in other industries (Levin et al., 1987; Charles et al., 2001). This is partly explained by differences in the outcomes of patent litigation by both technology and industry. Allison et al. (2015) find that during litigation, owners of patents in the pharmaceutical industry have a larger chance to win than do owners of patents in the computer and electronics industry.

1.5.2 Determinants from Patent Characteristics

The first patent level characteristic relevant to locational decisions is whether the application is for a process innovation or a product innovation. We have seen in our review that the propensities to patent product and process innovation are different. Mairesse and Mohnen (2010) argue that process innovation directly affects the average cost of production, but product innovation may take time to replace existing products and realize its effects on firm's performance. Graham et al. (2009) also find that, in general, patenting is almost twice as important for product innovators than for process innovators.

Second, Atal and Bar (2014) argue that the quality of a patent is an important consideration for firms when they seek patent protection. Our review suggests that not all innovations are worth being patented in multiple offices. Hanel (2005) show that innovations of the highest quality are likely to be patented at both CIPO and USPTO. However, measuring patent quality is not an easy task. As Lerner and Seru (2015) point out, problems exist in patent data due to time, technology class and the region of inventors. Various measures have been proposed in the literature based on patent citations (generality[20] and originality[21]), patent time lags, patent breadth, patent claims, and patent scope[22] (Squicciarini and Criscuolo, 2013).

Third, average patent quality is determined by patent offices, so characteristics of the patent system might be important. In the literature, there is no consensus on how to define patent quality. It has been defined as a perception of third parties and the quality will determine the effectiveness of patents (Atal and Bar, 2014). Cohen et al. (2002) compare Japan and the U.S., and they find that while patents are perceived to be as effective as other property protection mechanisms in Japan, the U.S. firms perceive patents to be less effective. Cohen et al. (2002) argue that different characteristics of patent systems may cause these perceived differences. According to Ordover (1991), the underlying reason for the difference is due to the U.S.'s emphasis on the exclusive rights versus Japan's emphasis on information diffusion.

In addition, as already discussed, patent offices differ. For instance, USPTO is believed to be more "innovator-friendly" than CIPO in terms of patent laws, patentable materials, opposition, and

[20]Trajtenberg et al. (1997) have proposed a generality index by incorporating information of the number and distribution of citations received (forward citations) and the technology classes of these citing patents into a modified Hirschman-Herfindahl Index (HHI). If a patent is cited by subsequent patents belonging to a wide range of fields, the index will be high.

[21]The patent originality index, first proposed by Trajtenberg et al. (1997) measure the diversification of technology fields that the patent relies on. If a patent cites previous patents that belong to a large number of technology classifications, the originality index will be higher.

[22]Lerner (1994) defines the patent scope in terms of the number of subclasses of international patent classification the invention is allocated to. He finds that the patent scope is positively related to the technological and economic value of patents.

litigation process (Maskus, 2005). The U.S. emphasizes more on the exclusive rights of patent, but Japanese patent system aims to induce firms to disclose information of patents (Ordover, 1991). While exclusive rights motivate firms to hold patents, information diffusion is not in their interests. From the previous sections, we have seen that patent offices can also be different in terms of pendency time, backlog, policies regarding examination policy, etc. As a result of these different characteristics, firms' propensity to patent is expected to differ from country to country (Cohen et al., 2002). In empirical studies that investigate firms' locational choice of patent applications, these factors should be carefully controlled.

1.5.3 Determinants from Destination Countries

In addition to the above factors, innovators' locational decisions are influenced by a country's economic environments and business opportunities. As found in Bessen and Thoma (2014), earnings from the same innovation in different countries are different. For instance, emerging economies may have more business opportunities and may encourage firms from other countries to patents. However, an analysis looking only at two countries might not be able to consider country-level differences. Instead, geographic information about the locations of provinces or cities may be used to control for such effects.

1.6 Conclusions

As stated in the Intellectual Property Canada Report 2016 (p. 9), "while not definitive on its own, patenting is an important indicator of innovation and a key factor in the knowledge economy." A thorough understanding of the patenting behavior of Canadian firms relies on the development of new patent data sets. Current studies on Canadian patents use survey data, or patent data from USPTO (Trajtenberg, 2000). While USPTO is the destination for a large portion of Canadian patent applications, using USPTO data solely to analyze patenting by Canadian firms may lead to misleading results.

This chapter reviews both the theoretical and empirical contributions that attempt to analyze why firms patent and where they patent. While the ultimate target is to explore Canadian firms' patenting behavior, our review is not restricted to Canadian cases. The review reveals that the incentives to patent in empirical and theoretical studies are multi-dimensional and complex. Theoretical models predict that application fees, patent life, patent breadth, and delaying examination can have strong effects on decisions to patent. Empirical evidence suggests that patents are not as effective as expected. However, empirical studies cannot explore the potential strategical use of patents or measure patent quality. While some scholars make use of information contained in citation data or renewal data to patent quality, such methods are problematic.

Most studies confirm that a patent is not an effective mechanism to protect and boost innovations regarding Canadian firms. However, patents may play a role for Canadian firms, especially small and startup firms. To explain why CIPO acts as a second filing office, it is fundamental to have a better understanding of which firms patent in Canada vs. elsewhere by studying patent data from patent offices. This is important for several reasons.

First, the analysis of Canadian patenting in the U.S. only or in other major patent offices only may give a misleading picture of patenting and innovation in Canada. As demonstrated above, existing evidence suggests that smaller firms tend to patent only at CIPO and larger firms patent both in Canada and the U.S. In addition, the literature has found that firms with multinational business tend to patent at USPTO. As a result, only data from multiple patent offices can give unbiased results for our understanding of Canadian firms' patent behaviors.

Second, understanding which firms patent in the U.S. vs Canada and which types of innovations are patented may have important implications for the effects of harmonization policies such as the Patent Cooperation Treaty, which facilitates applications in multiple countries. Webster et al. (2007) find that the outcome from the first-filing country has a strong effect on the outcome of decisions at both the JPO and, to a lesser extent, the EPO, implying that substantial disharmony exists in patent office decisions. They suggest that more efforts need to be made to ensure that patent offices make consistent decisions with regard to patent applications. In addition, understanding the underlying reasons firms choose to apply for a patent in different countries can help patent offices better design patenting policies. Fernández-Ribas (2010) appeal putting international patenting on the policy agenda and helping highly innovative small companies to explore foreign commercial opportunities in new markets.

CHAPTER 2

DETERMINANTS OF LOCATIONAL PATENTING BEHAVIOR OF CANADIAN FIRMS

2.1 Introduction

Inventors make several decisions at different stages of the invention and patenting process. At the outset, an inventor decides whether to innovate. Once an invention has been discovered, the inventor must decide whether to patent it or not. When a patenting decision has been made, the inventor decides where to patent its invention . Patent rights are defined by national laws; a patent granted in one country cannot protect the invention in another country. This requires firms to decide on the geographical coverage of patent protection for their inventions. While the decision to patent has already been studied in the literature, locational patenting decisions have received little attention at the firm level. Understanding firms' locational patenting decisions is important for a country if its target is either to attract foreign inventors to patent in the home country or encourage domestic inventors to patent abroad.

World Intellectual Property Office (WIPO) statistics suggest that typically applicants apply for patents in their own countries.[1] However, Canadian firms have applied more frequently for patents in the U.S. than in Canada (Greenspon et al., 2017). Patent applications by Canadian firms at the United States Patent and Trademark Office (USPTO) keep increasing, whereas those at the Canadian Intellectual Property Office (CIPO) have decreased. CIPO is known to be an office of second filing as firms tend to apply for patents elsewhere before filing with CIPO. While this phenomenon is well established, the literature has rarely addressed this issue at the firm level due to the lack of data.

The purpose of our paper is to investigate the factors that affect Canadian firms' decisions to

[1] For example, in 2018, 55% of patent applications by Japanese applicants were submitted in Japan, 57% of patent applications by U.S. applicants were submitted in the U.S., and 70% of patent applications by Korean applicants were submitted in Korea, respectively.

apply for patents at home or abroad. We focus on potential explanations for locational patenting decisions that emerge from the existing literature on patenting. A firm's decision to patent at home or abroad may be related to firm level features, industry characteristics, and the design of the patent system. The motives behind Canadian firms' locational patenting decisions have potentially important policy implications. If locational patenting decisions are determined by firm level characteristics such as age and size, then if increasing domestic patenting is a policy objective, it may be best achieved by targeting firms with certain characteristics. Likewise, if the decision not to patent at home is caused by the design of the patent system, then policy intervention to increase domestic patenting could focus on patent rules and procedures. Finally, if the key determinant of domestic patenting is the industrial environment, policy changes should focus on improving business opportunities.

Existing studies on locational patenting decisions have been limited due to legal obligations and confidentiality issues that prevent researchers from merging patent data with firm level data. We overcome this hurdle for Canadian firms' locational patenting in Canada and the U.S. under arrangements with Statistics Canada that maintain legal confidentiality requirements. As well, while previous studies have used surveys of selected firms (e.g., Hanel, 2005) , our analysis makes use of patent data directly from USPTO and CIPO for all Canadian firms. We use panel data for Canadian firms over the period 2000-2008 to estimate models of the decisions to patent, and if so where, in order to examine how these decisions are associated with firm and industry characteristics and patent system design.

Our paper contributes to the patent literature in three ways. First, our paper investigates what factors affect firms' patenting decisions by directly linking patent data and firm characteristics at the firm level, whereas existing studies either use surveys to ask firms directly why they patent or theoretically discuss motivations behind firms' patenting decisions (e.g., Cohen, 2010; Eckert and Langinier, 2014). In the case of Canada, firms' decisions to apply for patents are significantly associated with firm age, firm size, profitability, and research and development (R&D) intensity. For instance, our findings indicate that older firms may have developed their approaches to protect their inventions and are less likely to apply for patents, and that if they do, they are less likely than younger firms to apply for patents only domestically.

Second, our paper complements the literature on the decision to patent by providing evidence on firms' decisions on where to patent, which is rarely addressed in the literature (Hanel, 2005). Our findings suggest that the likelihood of only applying for patents abroad is mainly associated with the past patenting experience, R&D intensity, firm size, and patent scope. In addition, manufacturing firms in export-oriented sectors are more likely to patent in Canada as well as in the U.S., whereas firms in Foreign Direct Investment (FDI) intensive sectors are less likely to patent in both patent offices.

Third, we provide empirical evidence about how a country's participation in the Patent Cooperation Treaty (PCT) as an International Search Authority (ISA) can affect firms' decisions to patent, and where to patent. PCT is an international treaty contracted by more than 150 countries aiming to facilitate firms' patenting in several countries. Our results suggest that after CIPO became an ISA, Canadian firms were more likely to apply for patents at CIPO, and less likely to apply for patents at USPTO.

Our analysis so far is restricted to Canadian firms' patenting in Canada and the U.S. However, we can get some understanding of the decision of Canadian firms to apply for patents outside of Canada and the U.S. by considering their use of PCT. According to WIPO statistics, the ratio of patent applications by Canadian applicants that were made through PCT was 8% at USPTO, 63% at the European Patent Office (EPO), 78% at the Australian Patent Office, 75% at the National Intellectual Property Administration in China, and 81% at the Japan Patent Office during 2004-2008. This suggests that the use of PCT is linked to patent applications by Canadian firms to countries other than the U.S. and Canada. Our findings suggest that the use of PCT by Canadian firms is mainly connected with firm age, patenting experience, profitability, patent scope and firm size. Notably, CIPO's role as an International Search Authority (ISA) is associated with an increase in PCT applications by Canadian firms; however, after CIPO became an ISA, Canadian firms have been less likely to patent at both offices.

The rest of the paper is organized as follows. In Section 2.2, we review the relevant patent literature, with a focus on explanations for locational patenting decisions. Section 2.3 focuses on the econometric framework whereas Section 2.4 describes the data sources and explanatory variables and presents our main expectations and hypotheses regarding these variables. Section 2.5 presents the empirical findings. Section 2.6 carries out robustness checks and Section 2.7 concludes.

2.2 Literature

This paper contributes to three strands of the patent literature. First, our study is related to the literature on incentives to patent.[2] Empirical studies using surveys (Levin et al., 1987; Cohen et al., 2000; Sichelman and Graham, 2008; Graham et al., 2009) find that firms patent to prevent copying, obtain licensing revenue, increase negotiation position, and avoid lawsuits. Empirical evidence also suggests that patents are used to avoid expensive imitation costs (Mansfield et al., 1981), to distort rival firms' decisions in R&D activities (Kortum and Lerner, 1999; Palangkaraya et al., 2008), to reduce the possibility of being held up by external patent owners (Hall and Ziedonis, 2001) and to increase the value of innovation (Arora et al., 2008).

In addition, patenting has shown significant impacts on firm performance. Among others, Balasubramanian and Sivadasan (2011) find that the patent stock of U.S. firms is positively associated with firm growth. Using data on West Germany during the period 1953-1988, Lanjouw (1998) concludes that patenting increases returns to firms' R&D expenditure by about 10%. In the case of France, Schankerman (1998) finds that the returns to R&D generated from patents can be as high as 25%. Ortiz-Villajos and Sotoca (2018) find that British manufacturing firms' survival is positively associated with the number of their patent applications. However, the impact of patents on the rate of innovation seems to be limited (Cohen, 2010), with the exception of pharmaceutical and

[2]Theoretical models have been proposed to understand why firms patent. For instance, Horstmann et al. (1985) argue that innovating firms possess private information about the profitability of their inventions and their decisions to patent can influence rivals' behavior. Langinier (2005) suggests that when the leader in a patent race has more information about the improvability of an innovation, he can choose to patent strategically. In the context of sequential innovations, Bessen and Maskin (2009) argue that patents can be used to block potential rivals in their subsequent research.

chemical industries (Cohen et al., 2000; Mansfield, 1986). Studies on firms' incentives to patent provide us with a theoretical base to select firm level variables for our empirical analysis.

Second, our study is related to the literature on firms' locational patenting behavior. Much of this empirical literature focuses on the role of exporting and the importance of patenting in jurisdictions where the innovation will be used or sold. For example, Palangkaraya et al. (2017) find that whether a firm gets patents in a foreign country affects its decision to trade patentable goods. While Bosworth (1984) finds a strong correlation between patenting and FDI, Dosi et al. (1990), Licht and Zoz (2000), and Yang and Kuo (2008) conclude that cross-country patenting is positively associated with trade flows. As well, the decision of where to patent is related to innovation costs (Eaton and Kortum, 1996) and the sizes of inventor s' economies and distance (Sláma, 1981). Following this line of research, we consider industry level factors such as industrial competition, whether an industry is export oriented, and whether an industry is FDI intensive.

The literature also suggests that the decision of where to patent an innovation depends in part on its quality, as not all innovations are worth multiple patent applications (Jaffe and Lerner, 2011). In a study of nine agricultural biotechnology firms in the U.S., Chan (2010) finds that the major determinants of the decisions to patent abroad include the quality of innovations and the firms' valuation of incremental revenue from extra geographical coverage.

In addition, the literature suggests that locational patenting decisions may be influenced by the perceived quality of patent protection in different jurisdictions. Cohen et al. (2002) find that while patents are perceived to be effective by managers of R&D units of manufacturing firms in Japan, R&D managers of U.S. manufacturing firms perceive patents to be less effective than other protection mechanisms. Furthermore, when firms consider applying for patents abroad, the target country's ability to defend the patent's claims and rights is assessed before applying (Lemley and Shapiro, 2005). Yang and Kuo (2008) and Park (1999) show that a country with strong Intellectual Property Rights (IPRs) protection tends to receive more patent applications from foreign inventors.

Finally, our study has a particular focus on Canadian firms' patenting behavior. Only a few empirical studies have been conducted on the patenting behavior of Canadian firms. In line with the broader patent literature, most of this research has focused on why firms patent and the characteristics of firms that patent. In general, Canadian firms are less likely to view patents as effective instruments to protect their innovations, and are less likely to patent their innovations, than firms in other countries (Baldwin et al., 1999; Trajtenberg, 2000; Nikzad, 2013). In particular, Nikzad (2015) finds that Canadian small and medium size firms are less likely to apply for patents than comparable-sized firms in other countries.

Some empirical analysis documents the extent to which Canadian firms apply for patents at home versus abroad. Using data on a survey of innovation in Canadian manufacturing by Statistics Canada in 1999, Hanel (2005) finds that 65.8% of Canadian manufacturing firms apply for patents both in Canada and the U.S., 9.8% apply only in the U.S., 19.3% apply only in Canada, and 5.1% apply elsewhere. During the period from 1990 to 2008, Canadian applications account for only 13% of total applications at CIPO (Nikzad, 2011) and in 2010, domestic patent applications represent less than 15% of all patent applications in Canada, while the U.S. is the destination of 50% of Canadian applications (Nikzad, 2013). Similarly, Trajtenberg (2000) shows that less than half of Canadian patents are owned by Canadian applicants. However, the underlying explanations for these observations are rarely addressed in the patenting literature.

To summarize, this paper complements studies on firms' patenting incentives, international patenting decisions, and particularly, Canadian firms' patenting. Meanwhile, these three strands of literature provide us with a theoretical foundation to select our right-hand side variables for our empirical analysis. In addition, we consider the effect of CIPO's role as an ISA on Canadian firms' locational patenting.

2.3 Econometric Framework

This section presents the econometric framework we use to address Canadian firms' decisions to patent, their locational patenting behavior and their use of PCT applications.

2.3.1 Canadian Firms' Decisions to Patent

When a firm has discovered an innovation, it has to decide whether to apply for a patent. For the empirical analyses, we define $Patent\_us_{ijpt}$ as the number of patent applications by firm i that belongs to industry j and operates in province p in year t at USPTO, and $Patent\_ca_{ijpt}$ at CIPO.[3] Consequently, $Patenting_{ijpt}$ can be constructed as follows

$$Patenting_{ijpt} = \begin{cases} 0 & \text{if } Patent\_us_{ijpt} = 0 \text{ and } Patent\_ca_{ijpt} = 0, \\ 1 & \text{if } \max(Patent\_us_{ijpt}, Patent\_ca_{ijpt}) > 0. \end{cases} \tag{2.1}$$

To decide whether to patent, the firm will evaluate the net benefit from patenting. Let an underlying latent variable $Patenting^{*}_{ijpt}$ denote the net benefit between the choice to patent and not to patent for firm i that belongs to industry j and operates in province p in year t. The observable variable $Patenting_{ijpt}$ as defined is associated with this latent variable in the following way,

$$Patenting_{ijpt} = \begin{cases} 1 & \text{if } Patenting^{*}_{ijpt} > 0, \\ 0 & \text{Otherwise.} \end{cases} \tag{2.2}$$

For each firm i, $i = 1, ..., N$ in year t, $t = 2000, ..., 2008$, the latent variable is determined by an independent variable vector X_{ijpt} such that

$$Patenting^{*}_{ijpt} = X_{ijpt}\alpha + \delta_j + \delta_p + \delta_t + \varepsilon_{ijpt}, \tag{2.3}$$

where α is a parameter vector, δ_j, δ_p, and δ_t are the industry, province and year fixed effects, and ε_{ijpt} is an error term following the logistic distribution.

[3] As described later, we only consider patent applications that are ultimately granted because we only have access to USPTO data that have information on granted applications.

2.3.2 Canadian Firms' Decisions on Where to Patent

Our data are restricted to patenting by Canadian firms in Canada and the U.S. For this reason, our main empirical analysis of patenting location focuses on whether a Canadian firm patents in either Canada, the U.S., or both, without considering patenting in other countries. This can be justified by the fact that Canada and the U.S. are the destinations of the majority of Canadian applications; according to WIPO statistics, 74% of patent applications by Canadian firms went to one of these two countries during the period 2000-2008. Our approach to analyzing indirectly the decision of firms to apply for patents outside of Canada and the U.S., through the use of the PCT, will be discussed in Section 3.3 below. For the subsequent analysis, we define Canadian firms' locational patenting decisions, $App\_location_{ijpt}$ for firm i in year t as

$$App\_location_{ijpt} = \begin{cases} 1 & \text{if } Patent\_us_{ijpt} = 0 \text{ and } Patent\_ca_{ijpt} > 0, \\ 2 & \text{if } Patent\_us_{ijpt} > 0 \text{ and } Patent\_ca_{ijpt} = 0, \\ 3 & \text{if } Patent\_us_{ijpt} > 0 \text{ and } Patent\_ca_{ijpt} > 0, \end{cases} \tag{2.4}$$

where a value of 1, 2, and 3 means that at time t, firm i patents only at CIPO, only at USPTO, and at both USPTO and CIPO, respectively.

The latent variable $App\_location^*_{ijpt,k}$ denote firm i's profit associated with the kth choice, $k = 1, 2, 3$, at time t, where $k = 1$ refers to patenting at CIPO only, $k = 2$ to USPTO only, and $k = 3$ to both. The observable variable $App\_location_{ijpt}$ is determined as $App\_location_{ijpt} = k$ if $App\_location^*_{ijpt,k} = max(App\_location^*_{ijpt,1}, App\_location^*_{ijpt,2}, App\_location^*_{ijpt,3})$.

Given this setup, we assume that the latent variable $App\_location^*_{ijpt,k}$ is connected with the independent variables Z_{ijpt} in the following manner

$$\forall k \in (1, 2, 3) : App\_location^*_{ijpt,k} = Z_{ijpt}\beta_k + \delta_j + \delta_p + \delta_t + \mu_{ijpt,k}, \tag{2.5}$$

where β_k is the coefficient vector that will be estimated and $\mu_{ijpt,k}$ is the error term capturing unobserved variation. Because of our definition of $App\_location_{ijpt}$, our dependent variable has three discrete outcomes: patent in Canada only, the U.S. only or both. Our analysis employs a Multinomial Logistic Regression model due to Chamberlain (1980). As shown in Maddala (1986), if $\mu_{ijpt,k}$ follows the type-1 extreme value distribution with density $f(\mu_{ijpt,k}) = exp(-\mu_{ijpt,k} - exp(-\mu_{ijpt,k}))$, the probability that firm i chooses the baseline patenting location (CIPO only) is

$$\Pr\left(App\_location_{ijpt} = 1 | Z_{ijpt}\right) = \frac{1}{1 + \sum_{k=2}^{k=K} e^{Z_{ijpt}\beta_k + \delta_j + \delta_p + \delta_t}}. \tag{2.6}$$

The probabilities of choosing the other two patenting locations (USPTO only and both CIPO and USPTO) are given by

$$\Pr\left(App\_location_{ijpt} = k | Z_{ijpt}\right) = \frac{e^{Z_{ijpt}\beta_k + \delta_j + \delta_p + \delta_t}}{1 + \sum_{k=2}^{k=K} e^{Z_{ijpt}\beta_k + \delta_j + \delta_p + \delta_t}}, \text{for } k = 2, 3. \tag{2.7}$$

This implies that we can compute the log-odds as follows

$$ln\frac{\Pr\left(App\_location_{ijpt} = k | Z_{ijpt}\right)}{\Pr\left(App\_location_{ijpt} = 1 | Z_{ijpt}\right)} = Z_{ijpt}\beta_k + \delta_j + \delta_p + \delta_t, \text{for } k = 2, 3. \tag{2.8}$$

Our objective is to empirically estimate β_k. The explanatory covariates Z_{ijpt} include all variables in X_{ijpt} and include variables measuring patenting experience and patent scope.

2.3.3 Canadian Firms' Use of PCT Filing

PCT is a multilateral treaty that includes more than 150 countries and is administered by WIPO to facilitate multinational patenting. Through PCT, a patent applicant is enabled to seek patent protection for his innovation in multiple countries. A PCT application first goes through a search and examination process by an ISA in an international phase, which will result in an International Search Report (ISR) on the potential patentability of the innovation. When an applicant receives the ISA report, he then decides whether to submit his application at individual patent offices. Thus, applicants use PCT in order to facilitate patenting in foreign countries. As already mentioned, Canadian firms appear to file patent applications in countries other than Canada and the U.S. through PCT. By investigating Canadian firms' use of PCT, we gain some insights about Canadian firms' patenting decisions outside of Canada and the U.S. To simplify the notation, from now on, we omit jp and only keep it. We denote PCT_num_{it} the number of applications filed through PCT, and $Direct\_num_{it}$ the number of applications filed through the direct application channel by firm i in year t at CIPO. Similarly, we construct three filing choices,

$$PCT\_location_{it} = \begin{cases} 1 & \text{if } PCT\_num_{it} > 0 \text{ and } Direct\_num_{it} = 0, \\ 2 & \text{if } PCT\_num_{it} = 0 \text{ and } Direct\_num_{it} > 0, \\ 3 & \text{if } PCT\_num_{it} > 0 \text{ and } Direct\_num_{it} > 0, \end{cases} \tag{2.9}$$

where a value of 1, 2, and 3 indicates that in year t, firm i files PCT applications only, direct applications only, and both PCT and direct applications, respectively. With this definition, we will use a similar Multinomial Logit model as described in Section 3.2.

Despite the U.S. has been a PCT member since 1978, Canadian inventors applied for patents at USPTO mostly through the direct application channel. Our data show that during the period 2000-2008, Canadian innovators filed 10251 patent applications at USPTO, among which 1049 were filed through PCT. Meanwhile, 7334 PCT applications were submitted at CIPO. Thus, if we observe that a Canadian firm has filed a PCT application at CIPO, this PCT application is likely to enter the national phase of other patent offices than USPTO with probability 86%. In addition, we do not have information on whether a USPTO patent application was filed through PCT. As a result, we only focus on CIPO data to investigate Canadian patenting firms' use of the PCT program. However, considering the small fraction of PCT applications aiming for US patents, this should have a limited impact on our analysis.

2.4 Data, Variable Construction, and Summary Statistics

We use data on the patenting activities in Canada and the U.S. of firms that are registered and file taxes in Canada as well as data on firm level and industry level characteristics. While patent data are from USPTO and CIPO, other data are obtained from Industry Canada and Statistics Canada. In the following sections, we present in detail the data sources and variable construction.

2.4.1 Data and Sample Construction

This study makes use of firm level panel data on Canadian firms over the period 2000-2008. Our data set merges information on firm characteristics with data on their patenting behavior. Data on Canadian firms come from the National Accounts Longitudinal Microdata File (NALMF), maintained by Statistics Canada. NALMF provides information on firms' business activities such as employment, locations where they operate, revenue, and total assets. Statistics Canada links patent data at CIPO and USPTO to NALMF based on firms' names and addresses.[4] Note that data from CIPO and USPTO and the NALMF datasets are confidential and can only be accessed at Statistics Canada, under arrangements that maintained legal confidentiality requirements.[5]

Our main sample of patenting firms contains 2,501 firms that obtained a total of 13,084 granted patents during the sample period (5,527 from CIPO and 7,557 from USPTO); our sample consists of 4,797 observations, where an observation refers to a patenting firm in a year (patenting firm-year). Information on patent technological classifications used to construct patent scope as a proxy for the quality of patents was obtained using the EPO Worldwide Patent Statistical Database (PATSTAT) (Squicciarini and Criscuolo, 2013).[6] Data to measure business opportunities were obtained from Industry Canada for exports,[7] and Statistics Canada for direct investment in the U.S. by in-

[4]The NALMF dataset only contains data on Canadian firms. Therefore, we exclude patents applied for or held by individuals and universities. In addition, some patents cannot be matched to any firm in NALMF. Overall, approximately 20 percent of observations in patent data cannot be matched to NALMF.

[5]Patent data are transferred to Statistics Canada from Industry Canada, which financially supports this project.

[6]PATSTAT Data are combined with USPTO data internally by Statistics Canada so that the matching was done by Statistics Canada.

[7]Data on exports were downloaded from the website of the Government of Canada: Search by industry (NAICS codes) - Trade Data Online.

dustry,[8]

Since USPTO data only report granted patents, for each firm we count the number of patent applications filed in each country during a given year that were eventually granted. As the application year better captures when the innovation has been discovered (Griliches et al., 1986), our analysis is based on application years. After an application has been submitted, it will be automatically examined at USPTO. In contrast, to be examined at CIPO, an applicant needs to submit a request for examination within 5 years. On average, it takes 2.8 more years at CIPO than at USPTO for a patent application to receive a granting decision. Consequently, for USPTO patent data, we consider patents granted by 2011 and for CIPO patent data, we consider patents granted by 2014. After 2008, the number of patent applications declined sharply due to truncation issues. In our regression analyses, we use data for the period 2000-2008.

2.4.2 Variable Construction

In this subsection, we describe how the variables are constructed. We identify factors at the firm and industry level, with a special attention to business opportunity measures. Specifically, for firms' decisions to patent, the variable X_{ijpt} includes *Firm Age*, *Firm Size*, *Country of Control*, *R&D Intensities*, *Profitability*, *Financial Constraints*, *Business Opportunities*, *Industry Concentration* and *Policy Changes at CIPO*. For firms' decisions on where to patent, the variable Z_{ijpt} further includes *Patent Scope* and *Patenting Experience*, which are specific to patenting firms. Definitions of all variables are summarized in Table 2.1.

Insert **Table 2.1: Definition of Variables**

https://www.ic.gc.ca/app/scr/tdst/tdo/crtr.html?productType=NAICSlang=eng. Last accessed January 2, 2018.

[8]Data on direct investment were downloaded from the website of Statistics Canada: Table 36-10-0009-01 (formerly CANSIM 376-0052).
http://www5.statcan.gc.ca/cansim/a26?lang=engretrLang=engid=3760052tabMode=dataTablep1
=1p2=-1srchLan=-1customizeTab. Last accessed January 2, 2018. which is classified using the North American Industry Classification System (NAICS) 2012. The industries in NALMF were also classified using NAICS 2012. As a result, data on industrial business opportunities were merged with NALMF by NAICS industry and year.

Characteristics of Firms

Patent Scope: No consensus has been reached in the patent literature on how to measure the quality of a patented innovation (Squicciarini and Criscuolo, 2013). Due to data limitations, we adopt Squicciarini and Criscuolo (2013)'s approach to measure firms' innovation quality based on 'patent scope', which corresponds to the number of International Patent Classification (IPC) codes listed in the description of any granted patent. IPC is a hierarchical system for the classification of patents according to the different areas of technology to which they pertain. The larger the number of distinct IPC a patent receives, the broader the patent is (Squicciarini and Criscuolo, 2013). Our first measure ($average\ patent\ scope_{it}$) is the average scope of patents filed by firm i in year t. The second measure ($maximum\ patent\ scope_{it}$) is the maximum number of 4-digit IPC classes into which one of the firm i's patents falls in year t. As discussed in Lerner (1994), because the distribution of patent values is highly skewed, the value of a firm's patents may be measured by the breadth of the firm's broadest patent. Note that Lerner (1994)'s regression of firm value on the broadest patent has a low goodness of fit with an adjusted R-squared of 0.12. As IPC assignment at USPTO and CIPO may be different, we weight our patent scope measures by the average number of patent scopes at each patent office annually. As inventions of high quality are more likely to have a higher market value (Jaffe and Lerner, 2011), we expect that firms with high quality inventions are more likely to apply for patents in several countries.

Patenting Experience: Patenting experience is expected to influence patenting decisions in two ways. First, firms with more patenting experience are more likely to be innovative and have more innovations to patent. Second, experienced firms have accumulated valuable knowledge of the patent system (patentability, application filing, etc.) where they have been patenting. As a result, firms are more likely to patent in a location where they have experience. To measure patenting experience at each of CIPO and USPTO, we use the variables $experience\ at\ CIPO_{it}$ and $experience\ at\ USPTO_{it}$, which count the total number of patents applied by firm i at each office during the past five years with reference to year t (Yanadori and Cui, 2013). We expect that greater experience at CIPO (respectively, USPTO) will more likely induce a firm to patent at CIPO (respectively, USPTO).

Firm Age: We measure firm age by the natural logarithm of the number of years since its establishment in year t, $log(firm\ age + 1)_{it}$. Firm age has been related to firms' patenting (Balasubramanian and Lee, 2008; Kotha et al., 2011; Coad, 2018). Peeters and van Pottelsberghe de la Potterie (2006) argue that young firms may patent more to compensate for their low market power, while older firms have more resources to sustain their patenting activities. They find a U-shaped relationship between a firm's age and its patenting activity, with young and old firms patenting more than firms of intermediate ages. The effect of firm age on firms' locational patenting has not been studied in the literature. We would expect that as a firm operates longer, it knows more about where the market is for its production technology. As a result, an older firm might have a narrow list of countries to patent its inventions. [9]

Firm Size: Firm size is an important factor in patenting behavior. While the literature has widely found that large firms are more likely to have patentable inventions and to patent (Cohen, 2010), the effect of firm size on locational patenting decisions has been rarely studied. We measure firm size by the logarithm of total number of employees $log(employee)_{it}$ and the logarithm of total assets $log(total\ assets)_{it}$. As large firms are more likely to have business activities across countries, we expect that large firms are more likely to patent in both Canada and the U.S.[10]

Country of Control: The locational patenting decision of a firm might depend on whether it is owned by a foreign entity (Baldwin, 1997) . To differentiate Canadian-owned firms from firms owned by foreign entities, we create a dummy $Canadian\ control_{it}$. This variable equals 1 if firm i is registered in Canada and owned by a Canadian entity in year t; it equals 0 if firm i is registered in Canada but is owned by a foreign entity in year t . Baldwin et al. (2002) find that foreign-owned firms patent more at CIPO than domestic firms. As a subsidiary of another firm that has its headquarter in a foreign country, a foreign-owned firm may be more likely to patent at CIPO, as patenting the same invention in another patent office would be managed by the headquarter

[9] We have explored if the effect of firm age is monotonic by including a squared term in the regressions. It turns out that the squared term is not significant. In what follows, we keep firm age in its logarithm form.

[10] We have explored if the effect of firm size is monotonic by including a squared term in the regressions. It turns out that the squared term is not significant. In what follows, we keep firm size in its logarithm form.

(Balasubramanian and Lee, 2008).[11]

R&D Intensities: We measure firms' R&D intensity as a ratio between total R&D expenses and total assets, $R\&D\ intensity_{it}$.[12] We expect that R&D intensive firms are more likely to use patents to protect their inventions as patenting is positively related to R&D expenditure (Lerner and Zhu, 2007). As patenting in multiple countries makes it possible to appropriate extra revenue from inventions , we expect that an increase in R&D expenditure would increase firms' propensity to apply for patents in both countries .[13]

Profitability: We measure $profitability_{it}$ as the ratio between gross profit (the difference between sales and cost of sales, or gross margin) and total assets. Tian and Wang (2011) find a strong and positive relationship between a firm's profitability and the number of its patents. In addition, a firm's profitability can be sustained through patenting even before the firm enters the market (Zaby, 2010). The same invention may have different market values in different countries. As a result, whether an invention can generate profits is a key consideration when a firm considers where to patent.

Financial Constraints: As small firms are more likely to face financial constraints, both CIPO and USPTO have different fee structures for small firms. Specifically, application fees for small firms are half of these for large firms at CIPO and USPTO. To control for the impact of such a constraint, ideally we should look at the cash flow of a firm. However, because we do not have data on the cash flow, we use the debt ratio between total liabilities to total assets as a proxy ($debt\ ratio_{it}$) , which allows us to mitigate the potential correlation between firm size and firm liabilities. A large debt ratio might imply heavy financial burdens, leading to firms' reluctance to patent or to patent in multiple locations.[14]

[11]Note that a Canadian firm might use a U.S. subsidiary to be the patentee in the U.S. However, in this case, we do not have information to check whether a firm belongs to another firm in our data.

[12]While reporting R&D is not mandatory, staff at Statistics Canada told us that if a Canadian firm invests in R&D, it usually would report it. As a result, if a firm does not report any R&D expenses, it is reliable to assume that this firm has not done any R&D.

[13]The logarithm of R&D expenditure is also used to indicate R&D intensity. As the results are consistent, in all regressions, we use the current definition.

[14]The ratio of total current liability and total current assets is alternatively used. The results will remain, so we use the current definition in all regressions.

Industrial Characteristics

Business Opportunities: As discussed in the literature review, incentives to patent in a country are linked to business opportunities in that country. We construct two measures of business opportunities at industry level. We only focus at industry level as we do not have data on exports and FDI at the firm level. Our first business opportunity measure, $log(industrial\ export)_{it}$, is the natural logarithm of annual exports of Canadian products to the U.S. of firm i's 3-digit NAICS industry. It is a proxy for the demand for Canadian products in the U.S. as exporting involves production in Canada but selling products in the U.S. To protect innovations embedded in these exporting products, we expect that Canadian firms in export intensive industries might be more likely to patent in both countries.

For our second business opportunity measure, we consider $log(industrial\ FDI)_{it}$, which is the natural logarithm of the annual FDI in the U.S. of firm i's 3-digit NAICS industry. This measure captures Canadian firms' business prospects in the U.S. As production through FDI will take place in the U.S., we expect that Canadian firms in FDI intensive industries are more likely to patent in the U.S.

Industry Concentration: We measure industry concentration through a Herfindahl-Hirschman Index (HHI_{it}) at the 3-digit NAICS level. The predicted effect of industrial concentration on the incentives to patent is ambiguous. On the one hand, monopoly power brings profits to firms; in order to maintain their monopolistic position and avoid losing monopoly power to innovating entrants, firms might have incentives to patent (Gilbert and Newbery, 1982). This implies that firms in a concentrated industry might be more likely to patent. On the other hand, in a monopolistic market, firms may have less incentive to innovate for two reasons. First, the marginal gains from innovations in a competitive market are larger than in a monopolistic market. Second, if a monopoly firm introduces a new innovation, it may displace part of its existing monopoly rents (Arrow, 1962; Cohen, 2010).

Policy Changes at CIPO

In July 2004, CIPO became the ISA for PCT applications filed by Canadian firms at CIPO.[15] This new service was expected to reduce the costs of obtaining foreign patents for Canadian firms; meanwhile, improved information technology infrastructure and increased examination capacity may also have encouraged Canadian firms to submit more patent applications at CIPO (Paquet and Roy, 2005). In addition, Canadian applicants might be in contact with the same examiner during the international and national phases.[16] This could make it easier for Canadian firms to obtain patents through the PCT program.

On the one hand, firms that have been patenting at CIPO might be aware of changes in the patent system and, thus, be more likely to respond to CIPO's role as an ISA than firms that have never patented at CIPO. On the other hand, if lawyers are drafting patent applications for their clients, they will be well aware of the changes at CIPO. In the latter case, firms patenting at CIPO may not necessarily have a different response from firms that have never patented at CIPO.

In this paper, we investigate whether CIPO's role as an ISA has an impact on firms' patenting at CIPO. To do so, we compare two group of firms. The first group contains firms that have applied for at least one patent at CIPO during the period 1995-2003; the second group contains firms that did not apply for any patent during the same period. We generate a dummy variable, $CIPO\_2004_{it}$, which equals 1 for the first group and 0 for the second group. We also generate a dummy variable, ISA_{it}, which equals 1 for years after 2004. In our analyses, we include the interaction term, $isaxcipo_{it}$, which is the product of $CIPO\_2004_{it}$ and ISA_{it}. This interaction term allows us to investigate if firms patenting at CIPO react to CIPO's role as an ISA differently from those that did not patent at CIPO.

[15] CIPO's application to be an ISA was approved by WIPO in 2002 but started its service as an ISA in July 2004.

[16] Archived — Joint Liaison Committee – Meeting #126, https://www.ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr03542.html. Last assessed January 18, 2019.

2.4.3 Locational Patenting Patterns and Summary Statistics

Table 2.2 shows the distribution of patenting decisions by industry and location, where "CIPO" represents $App\_location = 1$, "USPTO" represents $App\_location = 2$ and "Both" represents $App\_location = 3$. Panel A represents the frequencies of patenting locations by industry over the sample period. For each industry, we display the frequencies of each of these three locational patenting choices: CIPO only, USPTO only, and both. Industries with less than 10 observations are combined as "Other industries". For instance, in the construction industry, 41 observations (patenting firm-year) correspond to firms that patented at CIPO only, 37 at USPTO only and 14 at both CIPO and USPTO over the sample period.[17] Firms in most industries choose to patent at USPTO only and then at CIPO only, except for firms in the construction industry and the mining, quarrying, and oil and gas extraction industry who are more likely to patent at CIPO only. Only a small fraction of firms choose to patent at both USPTO and CIPO.

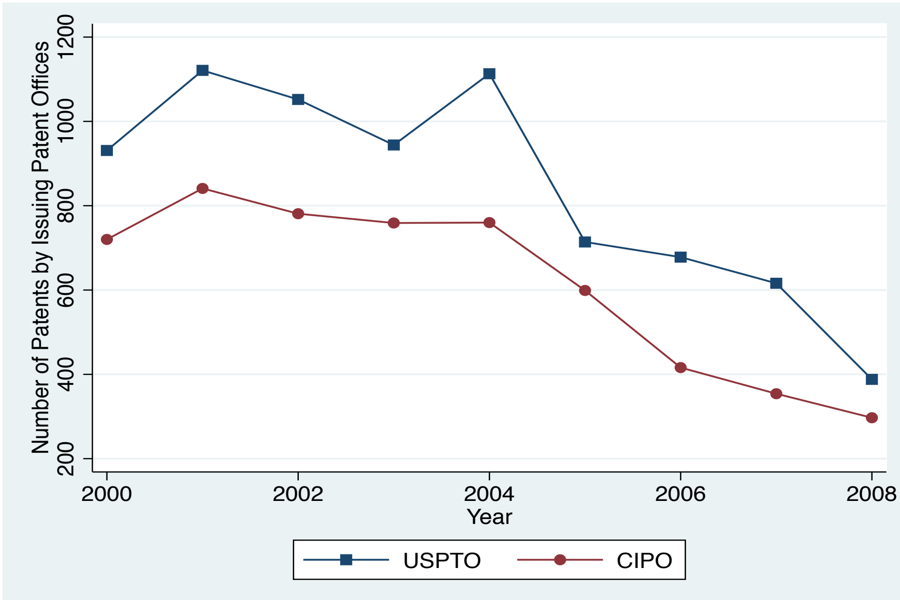
Insert **Table 2.2: Distribution of Patenting Decisions by Industry and Location**

To understand the patenting intensity in each industry by different patenting locations, Table 2.2 Panel B calculates the number of patents corresponding to each incidence in Panel A. For instance, consider again the construction industry, 45 CIPO patents have been granted to the 41 observations (patenting firm-year) of Panel A. Panel B shows that firms that apply for patents at both USPTO and CIPO file the largest fraction of total patent applications. Another pattern is that patents are largely concentrated in the manufacturing industries, which include industries with 2-digit NAICS classification codes 31-33, and the industry providing professional, scientific and technical services, even though these two industries show a rather different locational patenting behavior. Manufacturing firms patent intensively in both countries, whereas firms providing professional, scientific and technical services patent more at USPTO only. These differences might be due to the fact that business methods are more likely to be patented at USPTO. In contrast, firms in the mining, quarrying, and oil and gas extraction industry patent more widely at CIPO only. The

[17] Note that it could be the same firm in different years.

remaining categories do not show evident differences across these three patenting locations.

Figure 2.1: Total Number of Patents Granted at Patent Offices to Canadian Firms



To visualize the trend of locational patenting over time, Figure 2.1 plots the number of granted patents by USPTO and CIPO during 2000-2008. It shows that Canadian firms are granted more U.S. patents than Canadian patents; on average the number of U.S. patents granted to Canadian firms is 1.4 times that of Canadian patents. In our sample, we focus on application dates of granted patents and, therefore, as granting decisions take patent offices a few years to complete, the declining in late years is caused by the truncation issue.[18]

Figure 2.2 plots the number of firms that apply for patents at CIPO only, USPTO only and both offices during the period 2000-2008. This figure shows that over time, more Canadian firms apply for patents at USPTO than at CIPO. The number of firms patenting in both countries has declined after 2004, while the number of firms that patent at CIPO only has increased in 2005 before declining after 2005. Meanwhile, the number of firms patenting at USPTO only experienced a slight decrease in 2005 and a moderate increase in 2006 and then started to decline after 2006. Overall, in terms of the number of firms, USPTO was the patenting choice for the largest fraction of Canadian firms.

[18]We carry out a robustness check in the subsequent section regarding the truncation issue.

Figure 2.2: Distribution of Patenting Firms by Patenting Locations

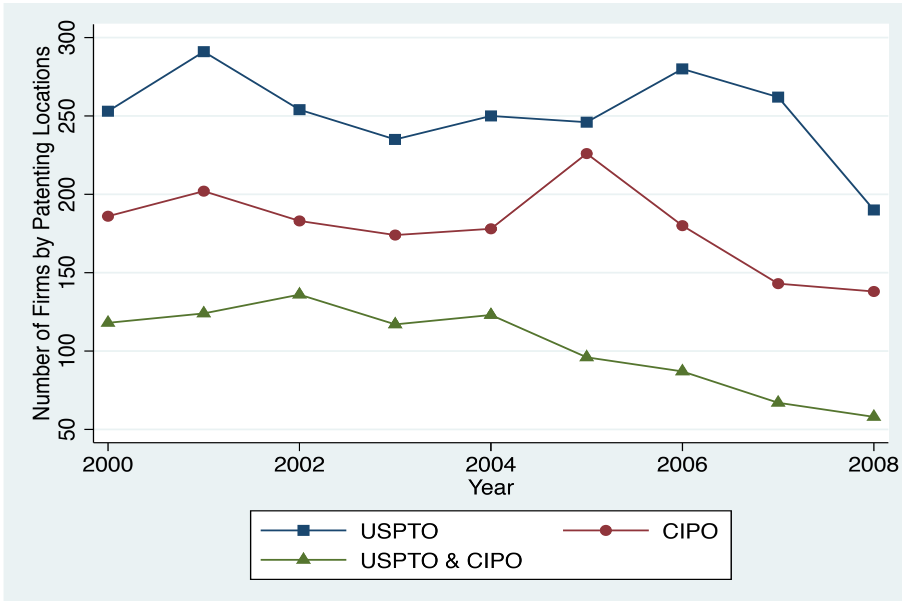


Table 2.3 provides summary statistics to compare non-patenting firms and patenting firms. Even though the data set from NALMF contains data on all Canadian firms, only a small fraction of them are patenting (roughly 0.1%). The numbers indicate that compared with non-patenting firms, patenting firms are older, larger, and are in more concentrated industries. Patenting firms spend more on R&D, and on average they have a lower profitability than non-patenting firms. There is no substantial difference in debt ratio between patenting and non-patenting firms.

Insert **Table 2.3: Summary Statistics for Non-patenting Firms and Patenting Firms**

2.5 Results

This section summarizes the key findings from the empirical estimation of our econometric models. For each regression, we tested for the presence of multicollinearity using the Variance Inflation Factors (VIF). For all reported specifications, the VIF scores are below 5, suggesting that there are no strong correlations among the independent variables that may bias our estimations. As our data are highly unbalanced, with over 50% of firms appearing only once, serial correlation should not be a concern. In addition, we carried out the score test proposed by Gourieroux et al.

(1985) and no serial correlation was detected in our models.

We explore several factors that may be related to Canadian firms' patenting behavior. Among these factors, firms' profitability and debt ratios may be affected by unobservable factors. For example, the province of Ontario has a strong relationship with the U.S. in the auto industry. Changes in the economic conditions of the U.S. will likely have a more sizable impact on firms' profitability in the auto industry than firms' profitability in other sectors of other provinces. We include industry fixed effects, year fixed effects, and province fixed effects to mitigate the endogeneity concern.

Our analysis starts with Canadian firms' decisions to patent. Then, we study Canadian firms' locational patenting choices. We end our empirical analysis with a focus on Canadian firms' use of PCT, with a particular attention on CIPO's role as an ISA. As shown in Table 2.2 Panel B, about 58% of patents were applied by manufacturing firms. In addition, manufacturing firms are more likely to export to foreign countries. As a robustness check, we compare the results using the whole sample and the sub-sample of manufacturing industries. All the regressions control for the industry fixed effects, the province fixed effects and the year fixed effects.[19]

2.5.1 Canadian Firms' Decisions to Patent

Table 2.4 Panel A reports estimates of the factors affecting firms' patenting decisions using the whole sample. Our results suggest that newly established firms, large firms, and Canadian controlled firms are more likely to protect their innovations with patents. Likewise, while profitable firms are reluctant to patent, firms with intensive R&D are inclined to patent. The coefficient of the dummy variable $isaxcipo_{it}$ is negative and statistically significant, suggesting that Canadian firms that have been patenting at CIPO are less responsive to CIPO's role as an ISA than those that have never patented at CIPO. This suggests that CIPO's role as an ISA is associated with an increase in the propensity of Canadian firms to patent.

[19] As the number of observations in the provinces Newfoundland and Labrador (NL), Prince Edward Island (PE), Yukon (YT) and Nunavut (NU) is very small, we exclude observations in these provinces. In the empirical analysis, we control for two digits NAICS fixed effects. However, as a few industries have a very small number of observations, we combine a few industries according to their similarities. In particular, we combine NAICS 44 and 45 together to represent retail trade, NAICS 48 and 49 to represent transportation and warehousing and NAICS 61 and 62 to represent educational and other social assistance services.

Insert **Table 2.4: Regressions on Canadian Firms' Decisions to Patent**

Table 2.4 Panel B reports the estimates focusing on manufacturing industries, where we have included two more variables (industrial export and FDI) in our regression analysis to capture the potential effects of business opportunities. Overall, results of manufacturing industries are consistent with those of the whole sample. One difference is that the coefficient of $isaxcipo_{it}$ becomes insignificant. Firms in manufacturing industries have intensively patented in both countries, so they may not be responding to CIPO's role as an ISA. In addition, the probability of a firm deciding to patent is positively associated with the industrial export of the manufacturing sector, whereas firms in FDI intensive sectors do not show a preference for patenting.

Results in Table 2.4 are based on all firms with available information. One concern is that the fraction of patenting firms is very small. There might be two reasons for a firm to have no patents. On the one hand, the firm might not do any R&D or its R&D might not be successful, and thus the firm has no invention to patent . On the other hand, the firm might have reported R&D, but might have decided not to patent. The first situation may result in an overestimation of firms' decisions to not patent. In order to mitigate such a potential problem, we re-estimate Canadian firms' decisions to patent by considering firms that have patented or report to be doing some R&D during our study period (we call those firms innovating firms).

With this treatment, the number of observations is reduced from 3,998,293 to 230,444 for the whole sample, and from 322,747 to 80,521 for the manufacturing industries as shown in Table 2.5. This suggests that only a very small fraction of Canadian firms reported that they were doing R&D or applied for patents during our study period. Table 2.5 also suggests that our findings are not sensitive to how many non-patenting firms are included in our sample. While the results are consistent, the only exception is the impact of the industrial export. This suggests that for R&D intensive firms, the impact of R&D may dominate the impact of industrial export.

Insert **Table 2.5: Regressions on Decisions to Patent by Canadian Innovating Firms**

2.5.2 Canadian Firms' Locational Patenting Decisions

Individual Patenting Locations

Table 2.6 presents the average marginal effects of multinomial Logistic regression models for firms' locational patenting choices. Overall, firm characteristics such as firm age, country of control, patenting experience, profitability, R&D intensity, patent scope, firm size, industrial export, FDI as well as CIPO's role as an ISA are significant factors affecting Canadian firms' locational patenting behavior.

Table 2.6 Panel A reports results based on the whole sample. First, the estimates imply that, on average, with one percent increase in firm age, the probability of a firm patenting at CIPO only decreases by 1.41%. However, from the marginal effects, we have no further evidence on whether these firms tend to patent at USPTO only or patent in both countries. As well, firms with innovations of broader patent scope are less likely to apply for patents in the U.S. only. Instead, these firms tend to patent in both countries.

Second, the more patents a firm has obtained at USPTO (respectively, CIPO), the more likely the firm will patent only at USPTO (respectively, CIPO) and the less likely it will patent only at CIPO (respectively, USPTO). This suggests that Canadian firms may stick to their locational patenting decisions. In other words, firms that have been intensively patenting at one patent office are less likely to stop applying at this office. Moreover, the patenting experience in one country may also reflect the fact that those firms had business activities in the past in that country. Nonetheless, patenting experience at either patent office increases firms' likelihood to patent in both countries.

Third, firms with intensive investment in R&D tend to patent at USPTO only rather than at CIPO only. However, there is no evidence to indicate whether these firms are more likely to patent in both countries. This may suggest that firms with intensive R&D are more likely to produce or sell in larger markets, the U.S. market or the U.S. and Canadian markets rather than the Canadian market only. Moreover, the coefficients of $isaxcipo_{it}$ are significantly positive for decisions to patent in Canada only, but significantly negative for decisions to patent at both offices. This would suggest that CIPO's role as an ISA might have encouraged Canadian firms to apply for more patents at CIPO, which in turn may have reduced firms' patenting at USPTO.

Furthermore, our results also suggest that one percent increase in firm size increases the probability of a firm patenting at CIPO only by 2.41% but decreases the probability of a firm patenting at USPTO only by 2.12%. Although we expect that large firms are more likely to patent in both countries, we do not find evidence to support this argument. However, our finding is consistent with Hanel (2005) who finds that large firms are less likely to patent in both countries. This suggests that large firms operating in Canada depend on CIPO to protect their innovations (Paquet and Roy, 2005).

Insert **Table 2.6: Multinomial Locational Choice Regressions**

Table 2.6 Panel B reports results for manufacturing industries. While the results are consistent with those in Panel A, a few differences are worth noting. First, the results suggest that older manufacturing firms tend to patent in both countries rather than in Canada only. Second, firms in FDI intensive industries are more likely to patent at CIPO only and less likely to patent in both countries, whereas firms in export intensive industries are less likely to patent at USPTO only and more likely to patent in both countries. Furthermore, profitability and Canadian control are not significantly associated with locational patenting choices of manufacturing firms. As well, firms' debt ratio and industrial concentration do not have significant impacts on locational patenting decisions for the whole sample and manufacturing firms.

Patenting Abroad Against Patenting at Home

One advantage of multinomial Logit regression models is that it allows us to compare individual choices to a baseline choice. This comparison can be realized by calculating the relative risk ratio of multinomial Logit regressions. If the relative risk ratio of a variable for an individual choice is larger than 1, it means that its impact on this individual choice is larger than that on the baseline choice. Table 2.7 reports the relative risk ratio of the multinomial Logit model with patenting at CIPO only as the baseline choice.

Results in Table 2.7 indicate what factors are associated with Canadian firms' patenting at home but not abroad. In particular, the first columns of Panel A and B report the corresponding relative risk ratio for the multinomial Logit regressions in Table 2.6. The other columns report results with alternative measures of firm size and patent scope. The results show that our findings are robust to alternative measures of these two variables.[20]

The results suggest that with reference to patenting at CIPO only, Canadian firms' decisions to patent in the U.S. are significantly affected by their patenting experience and R&D intensity. Likewise, compared with domestic patenting, large firms are less likely to patent in the U.S. only or patent in both countries. This could suggest that thanks to large production scale, these firms might produce at lower costs than their rivals. As a result, even if they only patent at CIPO, their competitors cannot compete with them due to a lack of scale efficiency. However, production scale is outside the scope of this study and we cannot confirm if scale efficiency is the actual reason.

In addition, our results suggest that as a firm operates on the market longer, or if it has innovations of broader patent scope, it is more likely to patent in both countries. Regarding the potential impacts of CIPO's role as an ISA, for firms that have been patenting at CIPO before 2004, they are less likely to patent in both countries. The estimates suggest that after 2004, the odds of a Canadian firm patenting in both countries is 57.20% of that in Canada only. Moreover, our results suggest that these firms seemed to be indifferent between patenting at CIPO only and USPTO only after CIPO became an ISA.

Insert **Table 2.7: Relative Risk Ratio of Multinomial Logit Regressions**

Panel B summarizes the findings for manufacturing industries. As the impacts of most of the variables are consistent, unlike the previous analysis we only focus on the impacts of industrial FDI and export. Our results suggest that firms in FDI intensive industries are less likely to patent in both countries. However, the relative risk ratios suggest that Canadian firms have no strong preference for patenting at CIPO only or at USPTO only. This may reflect the fact that firms patent

[20]We have run regressions by excluding the largest 5% and 10% of firms in our sample and results are consistent with current findings. In other words, our findings are not driven by extremely large firms.

their innovations in Canada first before going to the U.S. through FDI or they patent their FDI products directly at USPTO. As our data is highly unbalanced and we cannot keep track of the same innovation at CIPO and USPTO, we cannot confirm this finding. Besides, if a Canadian firm uses FDI, it may have a U.S. subsidiary and if patents are filed by these subsidiaries, we may underestimate the patenting of the firms in the U.S. In other words, with our data we cannot observe patenting in the U.S. by FDI subsidiaries.

2.5.3 Canadian Firms' PCT Use

Canadian Firms' Patent Filing Strategies

This section focuses on how Canadian firms are using PCT for patent applications. Specifically, we investigate how firms make decisions to file their patent applications: PCT applications only, direct applications only, or both PCT and direct applications. While a PCT application at CIPO may not ultimately go to a foreign patent office, to some extent it suggests the applicant's intention to do so. Consequently, a firm's use of PCT may indicate that it might intend to apply for a foreign patent in the future. Table 2.8 reports the average marginal effects of multinomial Logit models for Canadian firms' filing strategies. Panel A uses the whole sample and Panel B focuses on manufacturing sectors. The results for manufacturing industries are in general consistent with the findings from the whole sample.

First, we find that older firms, Canadian controlled firms, profitable firms, and firms with greater experience at CIPO are less likely to file PCT applications only. Likewise, firms with broad patent scope, large debt ratio, and high R&D intensity are more likely to file PCT applications. The coefficient of $isaxcipo_{it}$ is significantly positive, suggesting that CIPO's role as an ISA might have induced firms to use more PCT applications.

Second, regarding Canadian firms' decisions to file direct applications only, our results suggest that while firm age, Canadian ownership, profitability show positive impacts, the effects of R&D intensity, patent scope, firm size and CIPO's role as an ISA are negative. Except for firm size, the effects of other variables on the decisions to file PCT applications only are different from the effects on the decision to file direct applications only.

Finally, we consider the case of using both PCT and direct applications together. Older firms are less likely to use both channels to apply for patents, whereas experienced and large firms are more likely to use both. While debt burdens do not have a strong effect on firms' choice of direct applications only, it suggests a strong negative impact on the choice of filing through both channels. Additionally, we find that firms in FDI intensity industries are more likely to use both PCT and direct applications or PCT applications only. Conversely, no significant impacts of export are found.

Insert **Table 2.8: Multinomial Logit Regressions on Canadian Firms' Use of PCT**

PCT Applications versus Direct Applications

To compare individual choices to a baseline choice, Table 2.9 reports the relative risk ratio of multinomial Logit models in Table 2.8. In this analysis, we compare PCT applications only and both PCT and direct applications with direct applications.

First, compared to direct applications only, large firms are more likely to file both PCT and direct applications. In Section 5.2, we found that large firms are less likely to patent at USPTO only. This suggests that Canadian firms probably do not apply for USPTO patents through PCT at CIPO. In other words, PCT may be used by Canadian firms to apply for CIPO patents or patents in countries other than the U.S.

Second, older and profitable firms, and Canadian controlled firms are more likely to file direct applications than PCT applications. Firms with greater patenting experience are more likely to file PCT and direct applications. Nonetheless, firms with higher debt ratio seem to be less likely to use both application channels. Instead, they are more likely to use direct applications only rather than PCT applications.

Third, as firms devote more resources to R&D, they are more likely to have patentable innovations. Our results suggest that compared with direct applications only, R&D intensive firms are more likely to patent through PCT applications. Furthermore, they do not even consider using both

PCT and direct applications together.

Moreover, our results suggest that after CIPO became an ISA, Canadian firms who have been patenting at CIPO are more likely to file PCT applications than direct applications. This further suggests that Canadian firms are responsive to CIPO's new role as an ISA and take advantage of changes in the patent system. Besides, firms with broad patent scope are more likely to patent through PCT applications with potential consideration to patent in multiple countries.

In the case of manufacturing industries, our finding indicates that firms in FDI intensive industries are more likely to use PCT applications or PCT and direct applications together. However, firms in export intensive industries do not show a strong preference for the use of PCT or direct applications.

Insert **Table 2.9: Relative Risk Ratio of Multinomial Logit Regressions for PCT**

2.6 Robustness

For all multinomial Logit regressions, we carry out corresponding Logit regressions by combining either two of these three locational choices. Estimations from binary dependent variables are consistent with the previous analyses so we do not report results from the Logit models. As there is a time lag between application date to grant date, it is possible that firms in our sample have more patent applications than the number of patents used in our analysis. In this section, we carry out a set of robustness checking regressions to investigate whether our findings are sensitive to the number of patents included in our sample.

First, we only have data from USPTO on patents that are granted by 2011. Although we have data on non-granted patents from CIPO, our analysis is based on granted patents from CIPO. To investigate if including only granted patents affects our analysis, we add data on non-granted CIPO patents. The results are reported in the first column of Table 2.10. Our results based on only granted CIPO patents are highly consistent with those based on all CIPO patents. The results suggest that our findings are not sensitive to how many patents a firm holds in one location. As long as the firm has more than one patent in a location, our analysis will not be affected.

Second, USPTO and CIPO differ in terms of their examination procedure, patentability and granting lag. In our data, some patents were granted within one year, whereas others were granted after more than 10 years. To test if our study is sensitive to the grant lags, we construct a data set by excluding patents with grant lags of more than five years, which is roughly one standard deviation above the average granting lags. The results, reported in the second column of Table 2.10, show that our findings are not sensitive to grant lags.

Third, we shorten our study sample by cutting data in 2000 and 2008. The results with data for the period 2001-2007 are reported in the third column of Table 2.10. The findings are consistent with our main findings.

As an additional robustness check, we re-estimate the model using lagged values of firm characteristics in the last column of Table 2.10. As our data is highly unbalanced with more than half of the firms that only appear once in our data set, our sample size will be reduced substantially with lagged terms. We make use of firms that appear at least twice to check if there are systematic differences. As shown in the last column of Table 2.10, a few variables become insignificant. This sub-sample represents firms that frequently patent. This indicates that for firms frequently using patents, they seem to consider fewer factors than those who patent less often.

Insert **Table 2.10: Regressions on Robustness Checking**

2.7 Conclusion

Locational patenting behavior at firm level has been rarely studied due to data limitation. Using firm level patent data for the 2000-2008 period, we document the effects of industry level factors that affect business opportunities and profitability, firm level factors such as firm age, firm size, and changes in patent system procedures and rules on locational patenting decisions. Thanks to a unique dataset at the firm level, we can analyze the factors affecting locational patenting behavior of Canadian firms. Our analysis is descriptive in nature. Our sample is highly unbalanced, we do not run our models as panel regressions. As a result, actual causal relationships, reverse causality, and endogeneity were not tested.

Overall, Canadian firms tend to be more likely to patent at the office with which they have past experience. Moreover, as a firm accumulates more patents both from CIPO and USPTO, it will probably patent at both USPTO and CIPO. Patent scope plays an important role in firms' decisions of where to patent. Our analysis suggests that Canadian firms with innovations of wider patent scope are more likely to patent in both countries. The longer a firm has operated in the market, the more likely it will patent in both countries. This finding might suggest that patent offices may consider providing younger firms preferential treatments to encourage them to innovate and patent.

We have studied firms' locational patenting decisions in manufacturing industries. When interaction with the U.S. economy is considered, R&D expenditure becomes an important consideration. The findings indicate that an increase in R&D expenditure is associated with an increase in a firm's decision to patent at USPTO only. Besides, large firms are reluctant to patent at USPTO only. Instead, our results indicate that large firms have a tendency to patent at CIPO only. Our findings are robust to different measures of firm size, total asset and total number of employees. Additionally, we find that manufacturing firms in export intensive industries are more likely to patent in both countries, firms in FDI intensive industries are more likely to patent domestically. However, limited by data availability, we cannot identify the impacts of firms' decision to export or use FDI. This can be a potentially important area to explore when data are available.

CIPO's role as an ISA has motivated Canadian firms to use PCT, which induced Canadian firms to patent at CIPO, although the evidence is weak. Possibly the intuition is that with CIPO's new role, it might be easier for Canadian firms to obtain patents through PCT. The focus of this paper is to investigate the factors influencing Canadian firms' locational patenting decisions, so we do not explore in details the potential impacts of CIPO's new role as an ISA. However, this issue deserves to be studied, especially as we find strong evidence that after CIPO became an ISA, Canadian firms sharply reduced their applications in both countries.

According to a 2018 report by the Council of Canadian Academies (CCA, 2018), Canada is strong in its inventive capacity but weak in its innovative outputs (e.g., patents). In fact, many Canadian inventors sell their inventions abroad at an early stage of the inventions or explore business opportunities for their inventions elsewhere. To some extent, this is a loss to the Canadian economy. As a result, Gallini and Hollis (2019) argue that it is important to understand how Canada can change its innovative capacity into innovative outputs more effectively. Understanding what factors affect firms' locational patenting decisions will help set policies to encourage firms to explore business opportunities in the domestic market.

Finally, while our analysis helps understand how the locational patenting decisions are related to firm and industry characteristics and CIPO's role as an ISA, it has several limitations due to data availability. When data become available, some areas for future research could be explored. For instance, for a firm that has patented in multiple countries, it would be insightful to investigate where it patents an invention , and where the invention is patented first if multiple locations are chosen. It may be more accurate and informative to study the impact of patent quality at the patent level rather than at firm level. As well, if data are available, it would be interesting to explore the relationship between firms' decisions to export or use FDI and decisions to patent internationally. In addition, in this paper, we include a dummy variable to capture CIPO's role as an ISA. However, given the current data set, we cannot make causal inference on the impact of an ISA on patenting behavior. As ISA is an important policy initiative for collaboration among patent offices worldwide, it deserves to be investigated further.

Table 2.1: Definition of Variables

Variables	Definition	Data Sources
Patenting Variables		
$Patent\_ca_{it}$	Count of granted patents filed by firm i at CIPO in year t	CIPO
$Patent\_us_{it}$	Count of granted patents filed by firm i at USPTO in year t	USPTO
PCT_num_{it}	Count of patent applications filed through PCT by firm i at CIPO in year t	CIPO
$Direct\_num_{it}$	Count of patent applications directly filed at CIPO by firm i in year t	CIPO
$Patenting_{it}$	Dummy variable, which equals 1 if firm i applies for patents at t	CIPO & USPTO
$App\_location_{it}$	Firm i's multinomial locational patenting in year t: USPTO only, CIPO ony, and both	CIPO & USPTO
$PCT\_location_{it}$	Firm i's multinomial application filing choice in year t: PCT only, Direct only, and both	CIPO
Firm Characteristics		
$Canadian\ control_{it}$	Dummy variable that indicates if firm i is Canadian controlled in year t	NALMF
$log(employee)_{it}$	Natural logarithm of employees of firm i in year t	NALMF
$log(total\ assets)_{it}$	Natural logarithm of total assets of firm i in year t	NALMF
$experience\ at\ CIPO_{it}$	Number of patents filed at CIPO in the past 5 years by firm i in year t	CIPO
$experience\ at\ USPTO_{it}$	Number of patents filed at USPTO in the past 5 years by firm i in year t	USPTO
$R\&D\ intensity_{it}$	Ratio of R&D expenditure to the amount of tangible asset of firm i in year t	NALMF
$Debt\_ratio_{it}$	Ratio of total liabilities and total assets of firm i in year t	NALMF
$log(firm\ age+1)_{it}$	Number of years since the firm was established of firm i in year t	NALMF
$profitability_{it}$	Return on assets ratio defined as gross profits divided by total assets of firm i in year t	NALMF
$Average\ patent\ scope_{it}$	Average number of distinct 4-digit subclass of the International Patent Classification (IPC) of patents of firm i filed in year t	CIPO & USPTO
$maximum\ patent\ scope_{it}$	Maximum number of distinct 4-digit subclass of the International Patent Classification (IPC) of one of patents filed by firm i in year t, adjusted by average of year-industry patent scope at CIPO and USPTO	CIPO & USPTO
HHI_{it}	Herfindahl-Hirschman Index: sum of squared market share of each firm in the same industry of firm i in year t. This index is multiplied by 100 to adjust for the magnitude of estimators	NALMF
$log(industrial\ export)_{it}$	Canadian export to the U.S. in the 3-digit NAICS industry that firm i belongs to in year t, in millions of Canadian dollar	Industry Canada
$log(industrial\ FDI)_{it}$	Canadian investment in the U.S. in the 3-digit NAICS industry that firm i belongs to in year t, in millions of Canadian dollar	Statistics Canada
Characteristics of CIPO		
$CIPO\_2004it$	Dummy variable indicating if a firm has been patenting at CIPO before 2004	CIPO
ISA_{it}	Dummy variable indicating years after 2004	CIPO
$isaxcipo_{it}$	The product of $CIPO\_2004it$ and ISA_{it}	CIPO

Table 2.2: Distribution of Patenting Decisions by Industry and Location

	Panel A: by frequencies				Panel B: by patents			
	CIPO	USPTO	Both	Total	CIPO	USPTO	Both	Total
Construction	41 (45%)	37 (40%)	14 (15%)	92 (100%)	45 (35%)	40 (31%)	43 (34%)	128 (100%)
Manufacturing	839 (36%)	993 (43%)	501 (21%)	2333 (100%)	1625 (21%)	2072 (27%)	3893 (51%)	7590 (100%)
Wholesale trade	129 (36%)	172 (48%)	61 (17%)	362 (100%)	185 (28%)	234 (35%)	244 (37%)	663 (100%)
Information and cultural industries	37 (31%)	68 (56%)	16 (13%)	121 (100%)	78 (28%)	111 (40%)	86 (31%)	275 (100%)
Mining, quarrying, and oil and gas extraction	76 (37%)	66 (33%)	61 (30%)	203 (100%)	598 (62%)	102 (11%)	257 (27%)	957 (100%)
Professional, scientific and technical services	345 (28%)	714 (57%)	195 (16%)	1254 (100%)	501 (20%)	1249 (50%)	744 (30%)	2494 (100%)
Health care, educational services and social assistance	33 (30%)	58 (53%)	18 (17%)	109 (100%)	49 (16%)	183 (59%)	77 (25%)	309 (100%)
Administrative and support, waste management, remediation services	20 (37%)	23 (43%)	11 (20%)	54 (100%)	23 (31%)	29 (39%)	23 (31%)	75 (100%)
Other industries	90 (33%)	130 (48%)	49 (18%)	269 (100%)	151 (25%)	186 (31%)	256 (44%)	593 (100%)
Total	1610 (34%)	2261 (47%)	926 (19%)	4797 (100%)	3255 (25%)	4206 (32%)	5623 (43%)	13084 (100%)

Notes: Numbers are aggregated over the period 2000-2008. Percentages are reported in parentheses. Industry classification follows the North American Industry Classification System (NAICS) Canada 2012.

Table 2.3: Summary Statistics for Non-patenting Firms and Patenting Firms

	Non-patenting Firms	Patenting Firms
log (firm age+1)	1.9763 (0.8413)	2.0094 (0.8323)
Canadian control	0.9949 (0.0711)	0.9742 (0.1587)
debt ratio	0.7495 (0.7090)	0.7895 (0.9508)
profitability	0.8757 (0.7647)	0.3977 (0.4666)
R&D intensity	0.0049 (0.0572)	0.1177 (0.2482)
HHI	1.4921 (3.7353)	1.7266 (2.9755)
log(total assets)	12.6546 (1.7286)	16.3242 (2.8163)
log(employee)	1.4426 (1.1766)	4.0012 (2.1575)
isaxcipo	0.0002 (0.0158)	0.1019 (0.3026)
experience at CIPO		2.7690 (15.1123)
experience at USPTO		4.3142 (15.0144)
average patent scope		1.0406 (0.5774)
maximum patent scope		1.1806 (0.7521)
No. of observations	3994818	4797

Means of variables are reported and standard deviations are in parentheses. HHI index is multiplied by 100 to adjust for the magnitude of estimators.

Table 2.4: Regressions on Canadian Firms' Decisions to Patent

	Panel A: All industries	Panel B: Manufacturing
log(firm age+1)	-0.4187***	-0.3276***
	(0.0320)	(0.0549)
Canadian control	0.5132***	0.4205**
	(0.1420)	(0.1827)
debt ratio	0.0236	0.0778
	(0.0291)	(0.0573)
profitability	-0.9581***	-0.7106***
	(0.0488)	(0.1010)
R&D intensity	1.8295***	1.7582***
	(0.0782)	(0.1651)
isaxcipo	-0.2130**	-0.1439
	(0.1063)	(0.1583)
HHI	0.0060	0.0085***
	(0.0011)	(0.0027)
log(employee)	1.0823***	1.1260***
	(0.0190)	(0.0329)
log(industrial FDI)		0.0520
		(0.0410)
log(industrial export)		0.2348***
		(0.0580)
No. of observations	3998293	322747
No. of firms	859923	65476

This table reports average marginal effects of Logit models. The dependent variable is the dummy variable $patenting_{it}$. Panel A reports results using the whole sample of firms in all industries. Results in Panel B are restricted to firms in manufacturing industries. All regressions include 2 digits industry fixed effects, firms' operating province fixed effects and year fixed effects. Standard errors are in parentheses. *indicates significance at 10% level. **indicates significance at 5% level. ***indicates significance at 1% level.

Table 2.5: Regressions on Decisions to Patent by Canadian Innovating Firms

	Panel A: All industries	Panel B: Manufacturing
log (firm age+1)	-0.3158***	-0.3286***
	(0.0437)	(0.0654)
Canadian control	0.3383**	0.1254
	(0.1551)	(0.1953)
debt ratio	-0.0137	0.0578
	(0.0324)	(0.0650)
profitability	-0.9825***	-0.6008***
	(0.0646)	(0.1202)
R&D intensity	0.5186***	0.8924***
	(0.1006)	(0.1898)
isaxcipo	-0.4550***	-0.1147
	(0.1125)	(0.1710)
HHI	0.0034	0.1366***
	(0.0156)	(0.0310)
log (employee)	0.7002***	0.8822***
	(0.0258)	(0.0395)
log(industrial FDI)		-0.0241
		(0.0483)
log(industrial export)		0.0968
		(0.0710)
No. of observations	230444	80521
No. of firms	39179	16003

This table reports average marginal effects of Logit models. The dependent variable is the dummy variable $patenting_{it}$. Panel A reports results using the whole sample of firms in all industries that have reported R&D. Results in Panel B are restricted to firms in manufacturing industries that have reported R&D. All regressions include 2 digits industry fixed effects, firms' operating province fixed effects and year fixed effects. Standard errors are in parentheses. *indicates significance at 10% level. **indicates significance at 5% level. ***indicates significance at 1% level.

Table 2.6: Multinomial Locational Choice Regressions

	Panel A: All industries			Panel B: Manufacturing		
app_location	1: USPTO only	2:CIPO only	3: Both	1: USPTO only	2:CIPO only	3: Both
log (firm age+1)	0.0042	-0.0141*	0.0099	-0.0042	-0.0295**	0.0337***
	(0.0090)	(0.0081)	(0.0075)	(0.0134)	(0.0122)	(0.0120)
Canadian control	-0.0357	-0.0518	0.0876**	-0.0887	0.0235	0.0652
	(0.0468)	(0.0422)	(0.0446)	(0.0556)	(0.0557)	(0.0509)
experience at CIPO	-0.1011***	0.0707***	0.0304***	-0.1009***	0.0817***	0.0191***
	(0.0050)	(0.0044)	(0.0024)	(0.0067)	(0.0065)	(0.0036)
experience at USPTO	0.1004***	-0.1314***	0.0311***	0.0931***	-0.1282***	0.0351***
	(0.0041)	(0.0053)	(0.0018)	(0.0054)	(0.0072)	(0.0027)
debt ratio	-0.0032	0.0055	-0.0023	-0.0122	0.0091	0.0030
	(0.0071)	(0.0066)	(0.0059)	(0.0141)	(0.0126)	(0.0119)
profitability	-0.0113	-0.0126	0.0239**	-0.0247	0.0045	0.0202
	(0.0136)	(0.0127)	(0.0109)	(0.0261)	(0.0246)	(0.0221)
R&D intensity	0.0946***	-0.0755***	-0.0191	0.1787**	-0.1938***	0.0151
	(0.0294)	(0.0283)	(0.0266)	(0.0747)	(0.0743)	(0.0705)
isaxcipo	-0.0148	0.0596**	-0.0448**	0.0330	0.0200	-0.0531*
	(0.0289)	(0.0280)	(0.0216)	(0.0393)	(0.0388)	(0.0306)
HHI	0.0033	-0.0029	-0.0005	0.0082	-0.0067	-0.0015
	(0.0029)	(0.0029)	(0.0023)	(0.0061)	(0.0057)	(0.0050)
average patent scope	-0.0540***	-0.0004	0.0544***	-0.0793***	0.0162	0.0631***
	(0.0108)	(0.0100)	(0.0079)	(0.0180)	(0.0161)	(0.0134)
log (employee)	-0.0212***	0.0241***	-0.0029	-0.0219***	0.0223***	-0.0004
	(0.0040)	(0.0036)	(0.0031)	(0.0060)	(0.0057)	(0.0050)
log(industrial FDI)				0.0116	0.0183**	-0.0300***
				(0.0099)	(0.0092)	(0.0081)
log(industrial export)				-0.0236*	-0.0002	0.0238**
				(0.0127)	(0.0116)	(0.0106)
No. of observations		4797			2086	
No. of firms		2501			1094	
Pseudo R-Squared		0.2492			0.2939	

This table reports average marginal effects of multinomial Logit regressions. The dependent variable is $app\_location_{it}$. Panel A reports results using the whole sample of firms in all industries. Results in Panel B are restricted to firms in manufacturing industries. All regressions include 2 digits industry fixed effects, firms' operating province fixed effects and year fixed effects. Standard errors are in parentheses. *indicates significance at 10% level. **indicates significance at 5% level. ***indicates significance at 1% level.

Table 2.7: Relative Risk Ratio of Multinomial Logit Regressions

	Panel A: All industries			Panel B: Manufacturing		
Baseline: CIPO only	USPTO only	USPTO only	USPTO only	USPTO only	USPTO only	USPTO only
log (firm age+1)	1.0759	1.0356	1.0767	1.1325	1.0890	1.1345
Canadian control	1.1394	1.1772	1.1454	0.6864	0.6921	0.6975
experience at CIPO	0.5566***	0.5539***	0.5559***	0.5048***	0.5011***	0.5070***
experience at USPTO	2.3414***	2.3386***	2.3421***	2.4014***	2.4054***	2.4069***
debt ratio	0.9676	0.9504	0.9665	0.9239	0.9064	0.9214
profitability	1.0249	0.9509	1.0269	0.9092	0.8429	0.9095
R&D intensity	1.8030***	1.6472***	1.8044***	4.2129***	4.2373***	4.1866***
isaxcipo	0.7393	0.7386	0.7394	1.0063	0.9971	0.9844
HHI	1.0218	1.0229	1.0214	1.0577	1.0529	1.0568
average patent scope	0.8646**	0.8808*		0.7304***	0.7480**	
log (employee)	0.8488***		0.8503***	0.8440***		0.8482***
log(total assets)		0.8936***			0.8868***	
maximum patent scope			0.9084			0.7965**
log(industrial FDI)				0.9512	0.9671	0.9530
log(industrial export)				0.9322	0.9294	0.9301
constant	1.1818	4.5224***	1.1254	6.6466*	24.2751***	5.8176*
	Both	Both	Both	Both	Both	Both
log (firm age+1)	1.1360*	1.1280*	1.1412*	1.4204***	1.4105***	1.4195***
Canadian control	2.2418**	2.2392**	2.2638**	1.3565	1.3068	1.4210
experience at CIPO	0.8966***	0.8955***	0.8914***	0.7725***	0.7706***	0.7698***
experience at USPTO	2.1883***	2.1904***	2.1790***	2.2677***	2.2750***	2.2634***
debt ratio	0.9610	0.9396	0.9618	0.9771	0.9502	0.9834
profitibility	1.2384**	1.1221	1.2428**	1.1131	0.9925	1.1151
R&D intensity	1.2284	1.0953	1.2309	2.7065	2.4311	2.6423
isaxcipo	0.5720***	0.5742**	0.5762**	0.6504	0.6545	0.6524
HHI	1.0095	1.0157	1.0087	1.0222	1.0267	1.0217
average patent scope	1.4354***	1.4600***		1.3845**	1.4061**	
log (employee)	0.8822***		0.8767***	0.8989**		0.8949**
log(total assets)		0.8927***			0.8974**	
maximum patent scope			1.4247***			1.3982**
log(industrial FDI)				0.7593***	0.7671***	0.7538***
log(industrial export)				1.1644	1.1642	1.1675
constant	0.2332***	1.0408	0.2283***	0.2344	0.9418	0.2293
No. of observations	4797	4797	4797	2086	2086	2086
No. of firms	2501	2501	2501	1094	1094	1094
Pseudo R-squared	0.2492	0.2483	0.2494	0.2939	0.2928	0.2941

This table reports Relative Risk Ratio of multinomial Logit regressions. The dependent variable is $app\_location_{it}$ for each column. Panel A reports results using the whole sample of firms in all industries. Panel B is restricted to firms in manufacturing industries. All regressions include 2 digits industry fixed effects, firms' operating province fixed effects and year fixed effects. Standard errors are in parentheses. *indicates significance at 10% level. **indicates significance at 5% level. ***indicates significance at 1% level.

Table 2.8: Multinomial Logit Regressions on Canadian Firms' Use of PCT

	Panel A: All industries			Panel B: Manufacturing		
PCT_location	1: PCT only	2: Direct only	3: Both	1: PCT only	2: Direct only	3: Both
log (firm age+1)	-0.0147***	0.0246*	-0.0099*	-0.0379***	0.0404***	-0.0025
	(0.0077)	(0.0082)	(0.0051)	(0.0106)	(0.0124)	(0.0085)
Canadian control	-0.1012*	0.0580***	0.0431**	-0.0923	0.0642***	0.0280
	(0.0296)	(0.0331)	(0.0212)	(0.0354)	(0.0430)	(0.0270)
experience at CIPO	-0.0001*	-0.0009	0.0010***	-0.0004	-0.0001	0.0005***
	(0.0005)	(0.0005)	(0.0001)	(0.0006)	(0.0005)	(0.0002)
debt ratio	0.0000**	0.0129	-0.0129**	-0.0017**	0.0332	-0.0314**
	(0.0053)	(0.0062)	(0.0051)	(0.0104)	(0.0145)	(0.0136)
profitability	-0.1039***	0.1514***	-0.0475***	-0.0879***	0.1437***	-0.0557***
	(0.0127)	(0.0136)	(0.0108)	(0.0229)	(0.0268)	(0.0204)
R&D intensity	0.0777***	-0.0865***	0.0087	0.1370***	-0.1876***	0.0506
	(0.0221)	(0.0261)	(0.0174)	(0.0465)	(0.0639)	(0.0360)
HHI	0.0013	-0.0028	0.0016	0.0092**	-0.0126***	0.0034
	(0.0025)	(0.0026)	(0.0015)	(0.0049)	(0.0054)	(0.0032)
isaxcipo	0.0394***	-0.0848**	0.0454***	0.0281**	-0.0694	0.0414**
	(0.0180)	(0.0194)	(0.0112)	(0.0237)	(0.0274)	(0.0180)
average patent scope	0.1182***	-0.1484***	0.0303***	0.0876***	-0.1259***	0.0383***
	(0.0093)	(0.0102)	(0.0060)	(0.0135)	(0.0159)	(0.0102)
log (employee)	-0.0090**	-0.0080***	0.0170***	-0.0148	-0.0079***	0.0227***
	(0.0034)	(0.0035)	(0.0021)	(0.0046)	(0.0053)	(0.0034)
log(industrial FDI)				0.0133***	-0.0276	0.0143**
				(0.0084)	(0.0094)	(0.0061)
log(industrial export)				0.0068	-0.0050	-0.0019
				(0.0100)	(0.0111)	(0.0069)
No. of observations		6119			2619	
No. of firms		3539			1485	
Pseudo R-squared		0.1467			0.1218	

This table reports average marginal effects of multinomial Logit regressions for patent filing strategies. The dependent variable is $PCT\_location_{it}$. Panel A reports results using the whole sample of firms in all industries and results from Panel B are restricted to firms in manufacturing industries. All regressions include 2 digits industry fixed effects, firms' operating province fixed effects and year fixed effects. Standard errors are in parentheses. *indicates significance at 10% level. **indicates significance at 5% level. ***indicates significance at 1% level.

Table 2.9: Relative Risk Ratio of Multinomial Logit Regressions for PCT

	All industries	Manufacturing
Baseline: Direct only	PCT only	PCT only
log (firm age+1)	0.8954**	0.7646***
Canadian control	0.5941***	0.5516**
experience at CIPO	1.0013	0.9983
debt ratio	0.9729	0.9362
profitability	0.4813***	0.4925***
R&D intensity	1.6319***	2.8335***
HHI	1.0111	1.0724**
isaxcipo	1.3994***	1.3054
average patent scope	2.1836***	1.9664***
log (employee)	0.9821	0.9377**
log(industrial FDI)		1.1242**
log(industrial export)		1.0453
constant	0.1825	0.3654
	Both	Both
log (firm age+1)	0.8372**	0.9065**
Canadian control	1.5196	1.2472
experience at CIPO	1.0144***	1.0058***
debt ratio	0.8267***	0.6521**
profitibility	0.3974***	0.4050***
R&D intensity	1.3435	2.5059*
HHI	1.0621	1.0638
isaxcipo	2.1224***	1.8349**
average patent scope	2.0115***	1.9490***
log (employee)	1.2604***	1.3242***
log(industrial FDI)		1.2410***
log(industrial export)		0.9866
constant	0.0222	0.0048***
No. of observations	6119	2619
No. of firms	3539	1485
Pseudo R-squared	0.1467	0.1218

This table reports Relative Risk Ratio of multinomial Logit regressions for patent filing strategies. The dependent variable is $PCT\_location_{it}$ for each column. The first column reports results using the whole sample of firms in all industries. Results in the second column are restricted to firms in manufacturing industries. All regressions include 2 digits industry fixed effects, firms' operating province fixed effects and year fixed effects. Standard errors are in parentheses. *indicates significance at 10% level. **indicates significance at 5% level. ***indicates significance at 1% level.

Table 2.10: Regressions on Robustness Checking

	nongranted	subset	short	lagged
USPTO only				
log (firm age+1)	0.0063 (0.0061)	-0.0021 (0.0093)	0.0036 (0.0099)	0.0117 (0.0164)
Canadian control	-0.0342 (0.0289)	-0.0405 (0.0484)	-0.0536 (0.0569)	-0.1795 (0.1381)
experience at CIPO	-0.0420 (0.0024)***	-0.1079 (0.0060)***	-0.0919 (0.0053)***	-0.0456 (0.0040)***
experience at USPTO	0.0730 (0.0025)***	0.1014 (0.0044)***	0.0936 (0.0041)***	0.0388 (0.0028)***
debt ratio	-0.0020 (0.0044)	0.0008 (0.0075)	-0.0044 (0.0078)	-0.0010 (0.0146)
profitability	0.0121 (0.0088)	-0.0077 (0.0142)	0.0014 (0.0152)	0.0151 (0.0284)
R&D intensity	0.0291 (0.0167)*	0.0765 (0.0323)**	0.0827 (0.0310)***	0.0524 (0.0654)
isaxcipo	0.0311 (0.0176)*	-0.0185 (0.0319)	-0.0311 (0.0319)	-0.0022 (0.0491)
HHI	0.0009 (0.0018)	0.0061 (0.0032)*	0.0058 (0.0037)	0.0030 (0.0063)
average patent scope	-0.0333 (0.0079)***	-0.0568 (0.0113)***	-0.0497 (0.0123)***	-0.0178 (0.0199)
log(employee)	-0.0078 (0.0027)***	-0.0228 (0.0041)***	-0.0269 (0.0045)***	-0.0315 (0.0074)***
CIPO only				
log (firm age+1)	-0.0193 (0.0067)***	-0.0160 (0.0085)*	-0.0101 (0.0089)	-0.0464 (0.0138)***
Canadian control	-0.0425 (0.0345)	-0.0630 (0.0443)	-0.0435 (0.0517)	-0.0250 (0.1291)
experience at CIPO	0.0353 (0.0024)***	0.0759 (0.0051)***	0.0629 (0.0047)***	0.0313 (0.0033)***
experience at USPTO	-0.1275 (0.0037)***	-0.1294 (0.0056)***	-0.1228 (0.0054)***	-0.0505 (0.0038)***
debt ratio	0.0081 (0.0048)*	-0.0046 (0.0071)	0.0079 (0.0072)	-0.0042 (0.0126)
profitability	-0.0121 (0.0098)	-0.0169 (0.0134)	-0.0277 (0.0142)*	-0.0224 (0.0243)
R&D intensity	-0.0527 (0.0192)***	-0.0571 (0.0304)*	-0.0549 (0.0291)*	-0.0172 (0.0559)
isaxcipo	0.0091 (0.0201)	0.0521 (0.0310)*	0.0680 (0.0308)**	0.0611 (0.0438)
HHI	0.0003 (0.0020)	-0.0027 (0.0031)	-0.0049 (0.0036)	0.0009 (0.0052)
average patent scope	-0.0321 (0.0084)***	0.0121 (0.0105)	-0.0049 (0.0113)	0.0078 (0.0171)
log(employee)	0.0158 (0.0031)***	0.0226 (0.0038)***	0.0301 (0.0041)***	0.0176 (0.0064)***
Both				
log (firm age+1)	0.0131 (0.0058)**	0.0181 (0.0076)**	0.0065 (0.0082)	0.0348 (0.0153)**
Canadian control	0.0767 (0.0302)**	0.1034 (0.0458)**	0.0972 (0.0550)*	0.2045 (0.1569)
experience at CIPO	0.0067 (0.0013)***	0.0321 (0.0026)***	0.0290 (0.0026)***	0.0143 (0.0024)***
experience at USPTO	0.0545 (0.0019)***	0.0280 (0.0017)***	0.0292 (0.0018)***	0.0117 (0.0014)***
debt ratio	-0.0061 (0.0043)	0.0038 (0.0059)	-0.0035 (0.0067)	0.0052 (0.0134)
profitability	0.0000 (0.0087)	0.0246 (0.0109)**	0.0263 (0.0122)**	0.0073 (0.0258)
R&D intensity	0.0236 (0.0166)	-0.0194 (0.0280)	-0.0277 (0.0292)	-0.0352 (0.0674)
isaxcipo	-0.0402 (0.0149)***	-0.0336 (0.0214)	-0.0369 (0.0235)	-0.0588 (0.0447)
HHI	-0.0012 (0.0017)	-0.0034 (0.0027)	-0.0009 (0.0031)	-0.0039 (0.0051)
average patent scope	0.0654 (0.0064)***	0.0447 (0.0081)***	0.0547 (0.0091)***	0.0100 (0.0179)
log(employee)	-0.0080 (0.0026)***	0.0003 (0.0031)	-0.0032 (0.0035)	0.0139 (0.0064)***
No. of observations	7753	4448	3854	1546
No. of firms	4029	2385	2142	727
Pseudo R-squared	0.2247	0.2451	0.2529	0.2438

This table reports average marginal effects of multinomial Logit models. The first column ("nongranted") uses data including non-granted patents. The second column ("subset") uses data on patents that were granted within 5 years. The third column ("short") uses data during the period 2001-2007. The fourth column ("lagged") use one year lagged independent variables. All regressions include 2 digits industry fixed effects, firms' operating province fixed effects and year fixed effects. Standard errors are in parentheses. *indicates significance at 10% level. **indicates significance at 5% level. ***indicates significance at 1% level.

CHAPTER 3

THE EFFECTS OF INTERNATIONAL SEARCH AUTHORITY ON PATENTING: EVIDENCE FROM CANADA

3.1 Introduction

Innovation is an important driving force of economic and productivity growth (Romer, 1990; Aghion and Howitt, 1992; Schumpeter, 2010). Innovations used in one country can be created by domestic or foreign firms (Eaton and Kortum, 1996), and can be introduced in other countries through patenting. To facilitate innovators' multinational patenting, many countries have signed numerous international agreements such as the Trade-Related Aspects of Intellectual Property Rights (TRIPS)[1] and the Patent Cooperation Treaty (PCT).[2] One important principle of these agreements is domestic and foreign patent applicants must be treated equally by each national patent office ("national treatment" principle). However, Webster et al. (2014) and Lehmann-Hasemeyer and Streb (2018) find empirically that patent offices favor domestic over foreign applicants.

The last two decades have witnessed an increasing use of PCT for international patenting. According to World Intellectual Property Organization (WIPO) statistics, in 2000, PCT applications worldwide accounted for 33% of total applications for foreign patents, and this ratio increased to 58% in 2018. A PCT application first enters an international phase, during which the PCT application goes through a search and examination process by an International Search Authority (ISA) selected by the applicant.[3] This results in an ISA report on the patentability of the innovation. Based on the ISA report, the applicant decides whether to apply for patents at individual patent

[1]The TRIPS Agreement is a multilateral agreement on IPRs that sets out minimum standards of IP protection in member countries of the World Trade Organization.

[2]PCT is a multinational patent law treaty designed to facilitate international patenting. Innovators can apply for patents in PCT contracting countries through a unified procedure instead of directly applying at individual offices.

[3]If more than one ISA is available at the receiving office, applicants can choose which one will perform the examination and write the report. If an application lists applicants from different countries, filing with WIPO may result in a wider choice of ISAs.

offices, corresponding to the national phase. The search and examination process during the international phase follows the unified criteria set by WIPO, so the identity of the ISA should not affect innovators' patenting decisions. However, are ISAs treated equally by innovators? This paper aims to investigate this issue both theoretically and empirically.

This paper's first contribution is to model how a country's participation in PCT by becoming an ISA affects firms' patenting behavior in this country. I develop a two-stage model of filing patent applications in three countries. In the first stage, a firm decides whether to patent in a country through PCT or directly. With a direct application, the firm can either be granted or rejected a patent at the end of the examination process in the country. However, with a PCT application, the firm obtains an ISA report about the patentability of its innovation in the first stage. In the second stage, it decides whether to apply for patents at individual patent offices.

The results of the model indicate that PCT might encourage firms to apply for patents, and that the extent of this effect depends on which patent office is the ISA. According to WIPO, patent offices may assign the same examiner to an application during the international and national phases, if they can.[4] This practice implies that the probability that a firm gets the same examiner in the international and national phases might affect its decision making when it plans to enter the national phase at a patent office, which is an ISA.

The European Patent Office (EPO) was the ISA for PCT applicants in Canada until CIPO started its service as an ISA in July 2004. De Vleeschauwer (2013) argues that to become an ISA, CIPO improved its information technology infrastructure and increased its examination capacity, which may encourage more Canadian firms to apply for patents at CIPO (Paquet and Roy, 2005). As well, Paquet and Roy (2005) argue that ISA services at CIPO could lower the costs of obtaining foreign patents for Canadian firms, leading to more patenting abroad through PCT at CIPO (Eckert et al., 2019). Moreover, as an ISA, CIPO in general follows the practice that the same examiner is assigned to a given PCT application at both the national and international phases.[5]

[4]WIPO: Meeting of International Authorities under the Patent Cooperation Treaty (PCT), http://www.wipo.int/edocs/mdocs/pct/en/pct_mia_21/pct_mia_21_22.pdf. Last assessed June 19, 2020.

[5]CIPO: Archived — Joint Liaison Committee – Meeting 126, https://www.ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr03542.html. Last assessed June 19, 2020.

Legal obligations and confidentiality issues prevent researchers from matching patent data with firm-level data in Canada. Under arrangements with Statistics Canada that maintain legal confidentiality requirements, I was granted access to data on Canadian firms' patenting in Canada and the U.S., data on firms' Foreign Direct Investment (FDI), and data on firm-level characteristics. This unique data allow me to evaluate how CIPO's role as an ISA has affected Canadian firms' patenting decisions. I use a difference-in-differences approach with publicly-listed U.S. firms in the Compustat dataset being the control group.

Thus, the second contribution of this paper is to provide empirical evidence about the effect of CIPO's participation in PCT as an ISA on Canadian firms' patenting bahavior. A robust result is that Canadian firms' domestic patenting, particularly patenting through PCT, at CIPO increased significantly due to CIPO's role as an ISA, which is consistent with the theoretical prediction and the conjecture in the literature. The implication of this finding is that who is the ISA matters for Canadian firms; as an ISA, EPO and CIPO are not treated equally by Canadian patent applicants. Moreover, if the policy target is to encourage firms to apply for patents in the home country, the domestic patent office may be worth becoming an ISA.

The primary function of PCT is to facilitate either foreign firms' patenting in the home country or domestic firms' patenting abroad.[6] Canadian firms are identified as either domestic or foreign-owned to investigate if foreign-owned firms differ from domestic firms in their response to CIPO's role as an ISA. My analysis shows that foreign-owned firms filed more patent applications at CIPO than domestic firms after CIPO became an ISA. This evidence suggests that CIPO's role as an ISA has attracted foreign-owned firms to patent domestically. It is worth noting that both foreign-owned and domestic firms in the data belong to Canadian firms, and they are treated the same at CIPO for PCT applications.

Next, I investigate if CIPO has encouraged domestic firms to apply for patents abroad as an ISA. I start with a focus on the destinations of a PCT application filed at CIPO. In particular, I

[6]According to CIPO's annual reports for the period 2000-2008, among the top ten patent applicants each year, at least six firms were foreign-owned such as Proctor & Gamble Company, Honda Giken Kogyo Kabushiki Kaisha, and General Electric Company.

consider whether a PCT application at CIPO goes to the United States Patent and Trademark Office (USPTO), EPO, or CIPO. The results suggest that after CIPO became an ISA, Canadian firms, especially foreign-owned firms, increased only their filing of national phase PCT applications at EPO after filing PCT applications at CIPO. With data on Canadian firms' patenting at USPTO, I also find that as an ISA, CIPO has not affected Canadian firms' patenting in the U.S. Besides, CIPO's role as the ISA was not associated with significant changes in Canadian firms' investment abroad. The implication is that if the policy target is to encourage domestic firms to apply for patents or invest abroad, the domestic patent office may not achieve its goals by becoming an ISA.

Finally, I estimate several Logit regression models to investigate the effects of CIPO's role as an ISA on individual patent applications. The results first confirm that after CIPO became an ISA, the probability that an application was filed through PCT increased, relative to direct applications. Second, a PCT application was more likely to be granted a patent than a direct application at CIPO. In addition, Canadian evidence also suggests that a domestic firm's application was more likely to be granted a patent than a foreign-owned firm.

The rest of this paper is organized as follows. Section 3.2 reviews the literature. Section 3.3 presents the model and develops several hypotheses for the empirical analysis. The empirical framework is discussed in Section 3.4. Data and summary statistics are introduced in Section 3.5, and estimation results are reported in Section 3.6. Section 3.7 provides sensitivity tests and robustness checks. Section 3.8 investigates the effects of CIPO's role as an ISA on individual patents, and Section 3.9 concludes.

3.2 Literature Review

This paper contributes to the patent literature in four distinct ways. First, to the best of my knowledge, this is the first empirical study focusing on the role of ISA.[7] In this respect, this paper complements the literature that investigates how changes in patent systems or the harmonization of

[7] Eckert et al. (2019) briefly discuss CIPO's role as an ISA, but it is not the focus of the paper.

international Intellectual Property Rights (IPRs)[8] affect economic outcomes, including innovating and patenting activities.

The effects of changes in the patent system on firms' innovating behavior are ambiguous in the literature. Regarding who has the right to patent an innovation, in the first-to-invent system, a patent is granted to the applicant who files the patent application first, whereas in the first-to-invent system it is granted to the first inventor. Lo and Sutthiphisal (2009) find that CIPO's switch from the first-to-invent system to the first-to-file system in 1989 did not change R&D efforts by Canadian inventors. Chan (2010) finds that the standardization of patent laws across countries does not have a significant impact on firms' decisions to patent abroad. The establishment of the EPO in the 1970s unified examination and granting procedure, and reduced the difference in patentability standards across European countries (Deng, 2007). After that, European firms were encouraged to submit their patent applications directly to EPO rather than to individual patent offices (Eaton et al., 2004; Hall and Helmers, 2019).

Nevertheless, the efforts to harmonize international IPRs have shown some effects. For example, Maskus (2014) points out that countries adopting substantive improvement in patent standards have seen an expansion in trade growth, particularly in high-technology goods since the creation of TRIPS in 1995. Dinopoulos and Segerstrom (2010) also find that the adoption and implementation of international patent harmonization agreements such as TRIPS agreements increase the innovation rate in developing countries.

In addition, countries could be better off if they harmonize their IPRs standards, especially when developing countries follow IPRs standards in developed countries (Lai and Qiu, 2003). International harmonization could potentially generate large income transfers between countries, more likely from less innovative countries to innovative countries (McCalman, 2001), and increase patent applications worldwide (De Rassenfosse and van Pottelsberghe de la Potterie, 2009). Likewise, Branstetter et al. (2006) find that IPRs reforms in sixteen countries over the 1982-1999 period have significantly increased the R&D expenditure of U.S. multinational firms. My paper adds to

[8]The harmonization of international IPRs refers to the process of minimizing differences in the IPRs system across countries.

evidence that Canadian firms might respond to policy changes in the Canadian patent system.

Second, this paper is related to the studies on the relationship between the decision to patent abroad and the decision to do business abroad such as exporting, FDI, and outsourcing.[9] Firms' exports are associated with their international patenting (Dosi et al., 1990; Licht and Zoz, 2000). Maskus and Penubarti (1995) and Palangkaraya et al. (2017) find evidence that obtaining a patent in a foreign country has a significant impact on the decision to export to that country. Such positive relationships between exporting and the strength of IPRs protection in importing countries have been found in the case of Taiwan (Liu and Lin, 2005), China (Yew et al., 2011), the U.S. (Smith, 1999), and Spain (Caldera, 2010).

Furthermore, Bosworth (1984), Yang and Kuo (2008) and Nikzad (2012) find a strong and positive relationship between international patenting and FDI, whereas findings regarding the connection between patenting and foreign outsourcing are mixed. On the one hand, thanks to foreign outsourcing, firms can be more specialized in domestic innovations, leading to more innovations (Quinn, 2000; Chung and Yeaple, 2008; Venkatraman, 2004; Ethiraj et al., 2005). On the other hand, foreign outsourcing negatively affects firms' innovation due to less efficient information sharing (Teece et al., 1997; Lane and Lubatkin, 1998; Leiblein and Madsen, 2009), and replacement of firms' innovation activities in their home country (Hu and Jefferson, 2009). Miguelez (2016) further points out that cross-border inventive activities can take place through R&D outsourcing.

To protect innovations involved in exporting, FDI, and foreign outsourcing, firms need to apply for patents internationally. Picci (2010) shows that there exists an increasing trend in the level of internalization of inventive activities through the collaboration of innovators from different countries. In this respect, the harmonization of patent systems should help firms obtain patents in different countries with a simplified patenting procedure. Despite that, Rafiquzzaman (2002) finds that Canadian firms value property rights protection in their trading partners, and they are willing to export more to countries that have strong patent systems. Although firms may respond to changes in the host countries' patent system, I find no evidence that Canadian firms' FDI activities changed

[9]In the literature of international economics, 'foreign outsourcing' happens when a domestic firm contracts out some business activities to a foreign country (McCarthy and Anagnostou, 2004).

as a response to CIPO's role as an ISA. This finding might suggest that changes in the domestic patent system have no impact on firms' investing abroad. If the policy objective is to encourage domestic firms to invest abroad, it may not be achieved through patent policies at the domestic patent office.

Third, this paper directly contributes to the literature that studies Canadian firms' patenting behavior. In a 2018 report by the Council of Canadian Academies (CCA, 2018), Canada has shown a competitive inventive capacity, but its innovation outputs (e.g., patents) appear to fall behind its peer countries. The CCA report observes that Canadian innovators often sell their intellectual property abroad and seek growth opportunities elsewhere. Gallini and Hollis (2019) argue that it is important for Canada to understand how to generate innovative outputs more effectively from its innovative capacity. However, patents do not seem to be the most popular IPRs instrument used by innovators, including Canadian innovators (Trajtenberg, 2000; Nikzad, 2013; 2015;Pénin and Neicu, 2018), as patents are considered less important than other forms of IPRs protection (Baldwin et al., 1999).

Finally, this paper contributes to the debate regarding whether domestic and foreign applicants are treated equally at national patent offices. Webster et al. (2007; 2014) find that the country of origin has a significant impact on the application outcomes. Particularly, Webster et al. (2007) find that granting decisions at the Japanese Patent Office (JPO), and to a lesser extent at EPO, are associated with the applicant's origin. Furthermore, with more comprehensive data, incorporating more variables from extra data sources, Webster et al. (2014) confirm these findings and conclude that examiners at these two offices may favor domestic applicants over foreign applicants. In the case of Germany, Lehmann-Hasemeyer and Streb (2018) also find that foreign inventors may not be treated equally. In the extended analysis, I find that CIPO is more likely to grant a patent to an application from a domestic firm than a foreign-owned firm.

3.3 Conceptual Framework

3.3.1 Model Setup

I consider a two-stage patent filing model, in which a domestic firm endowed with an innovation decides to apply for patents in three countries: its home country and two foreign countries a and b.[10] There is one patent office in each country (patent office h, f_a and f_b respectively). The patentability of the innovation is unknown to the firm, but the firm has a prior belief about it: the innovation is patentable with probability $Pr(G) = \theta \in [0, 1]$ (hereafter, good innovation), and not patentable with probability $Pr(B) = (1 - \theta)$ (hereafter, bad innovation).[11] In my model, I do not model the decision-making process of examiners. Instead, the patent granting process is exogenous and fairly simple: a patent examiner (in the home or foreign patent offices) will grant a patent with a certain probability.

In the first stage of the model, the firm decides whether to file patent applications through PCT or directly. If an application is submitted to a national patent office directly, I call it a direct application, which requires an application fee C_{Ntl}. A direct application is examined by an examiner at the national patent office (hereafter, national examiner). National examiners carry out their search and examination to check if an innovation satisfies the patentability criteria and, importantly, make granting decisions.

For a direct application, a national examiner may grant a patent to a bad innovation in error with probability $\lambda_{direct} \in [0, 1]$. That is, a bad innovation may be rejected a patent with probability $1 - \lambda_{direct}$ through a direct application. For a direct application or a PCT application at the national phase, if a patent is rejected, the applicant can re-apply, and the application will be examined by

[10] As in the case of Canada, EPO was the ISA for Canadian applications before 2004, and CIPO became the ISA after 2004. Patent offices in other countries like the U.S. have never been the ISA for Canadian applications. As a result, considering the three countries is sufficient for the model.

[11] To be patentable, an innovation must be novel, non-obvious, and useful. Specifically, an innovation is novel if it the first of its kind in the world; an innovation is non-obvious if it would not have been obvious to someone working in the area of specialty; and an innovation is useful means that a valid patent cannot be obtained for something that does not work or that has no useful function. Note that in my model, being patentable is equivalent to being commercially valuable though they capture different dimensions of innovation. Distinguishing between patentable innovations and those that are commercially valuable is beyond the scope of this paper, and thus it is left for future research.

another examiner, so a good innovation is always granted a patent (Langinier and Marcoul, 2016).

If instead, an application is filed through PCT, I call it a PCT application. If the firm decides to file a PCT application, it pays a fixed fee C_{ISA}, and its PCT application goes through the examination and search process (called the international phase) by an ISA examiner. The ISA examiner writes a report, which can be positive (suggesting that the innovation is patentable) or negative (suggesting that the innovation is not patentable), but does not make granting decisions.

An ISA examiner may mistakenly write a positive report to a bad innovation with probability $Pr(+|B) = \lambda_{ISA} \in [0,1]$, but he always provides a positive report to a good innovation, i.e., $Pr(+|G) = 1$.[12] After receiving the ISA report, the firm updates its belief about the patentability according to Bayes' rule. The probability that an innovation is not patentable conditional on having a negative report is 1. If a positive report is received, the updated belief is

$$\tilde{\theta} = Pr(G|+) = \frac{Pr(+|G)Pr(G)}{Pr(+|G)Pr(G) + Pr(+|B)Pr(B)} = \frac{\theta}{\theta + (1-\theta)\lambda_{ISA}}. \quad (3.1)$$

As shown in Figure 3.1, in the first stage, through the direct application channel, the firm can decide to apply for patents in any of these three countries. In particular, the firm may only apply at the home patent office or apply at the home patent office and one of the two foreign patent offices, or apply only abroad, or apply at all patent offices. In contrast, a PCT application at this stage goes through the international phase and receives an ISA report.

[12] In the early stage of this paper, I explored the case where an ISA examiner may mistakenly provide a negative report to a good innovation. The results from such consideration are consistent with results with the current setting. Also, if an ISA examiner makes a wrong statement about a good innovation, the firm should have a chance to find it out when it reads the ISA report.

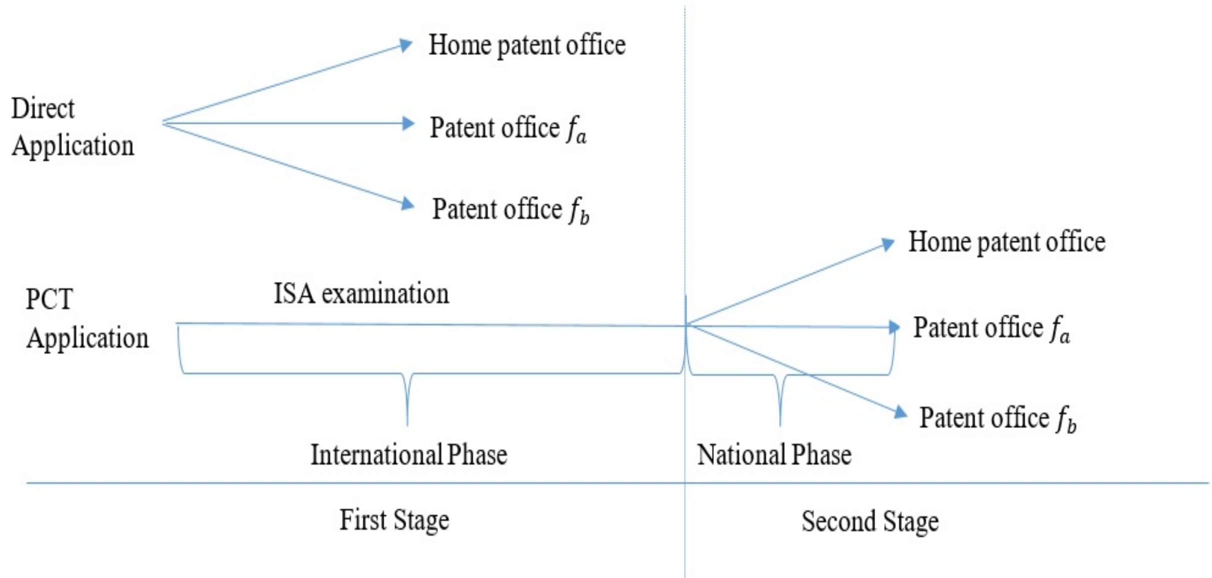


Figure 3.1: Two-stage Patent Filing

The second stage, which is only relevant if a PCT application has been filed in the first stage, is called the national phase of PCT applications. At this stage, the firm decides whether to apply for patents at national patent offices with the updated belief $\tilde{\theta}$. The national examiners have access to the ISA report. I consider two cases ($k = 1, 2$) regarding who is the ISA for the firm. In case 1 ($k = 1$), patent office f_b is the ISA, such that the ISA examiner is from patent office f_b. In this case, the firm will not encounter the same examiner during the international and national phases at the domestic patent office and patent office f_a. However, it may encounter the same examiner during the international and national phases at the patent office f_b. In case 2 ($k = 2$), the domestic patent office h is the ISA such that ISA examiners are from the domestic patent office. In this case, the firm may encounter the same examiner during the international and national phases at the domestic patent office. It will encounter different examiners during the international and national phases at patent offices f_a and f_b.

A national examiner makes granting decisions based on the ISA report and his examination. During the national phase of PCT applications, a national examiner may grant a patent to a bad innovation with probability $\lambda_{PCT,k} \in [0, 1]$, where $k = 1, 2$. Specifically, if the firm's application is processed by different examiners during the international and national phases, a national examiner grants a patent to a bad innovation with probability $\lambda_{PCT,1}$. In contrast, if the firm's application is processed by the same examiner during the international and national phases, the firm with a bad innovation will be granted a patent with probability $\lambda_{PCT,2}$, if it receives a positive ISA report, or be refused a patent if it receives a negative ISA report.

If the firm encounters the same examiner during the international and national phases, I assume that it will have a higher chance of obtaining a patent if its innovation is bad. That is during the national phase of PCT applications, $\lambda_{PCT,2} > \lambda_{PCT,1}$. The intuitive argument is that if the examiner has not found invalidating evidence during the international phase, he can hardly find invalidating evidence during the national phase, given that he will use similar search methods based on a similar database.

The firm can exploit its innovation by either producing directly in its home country or exploring business opportunities in foreign countries. In the latter case, the firm incurs a fixed cost of C_F. I assume that the home and foreign markets are identical. A good innovation is expected to bring a benefit g from each country to its owner if it is not granted a patent, and $G + \omega$ if granted a patent. In contrast, a bad innovation brings nothing to its owner if it is not granted a patent, but brings a benefit ω if it is granted a patent. The benefit ω refers to the value of a patent per se, whereas G is the incremental benefit from a good innovation. To simplify, I do not consider the effect of the time lag between a direct application and a PCT application on the payoff functions.

To summarize, patent office f_b is the ISA in case 1, and the domestic patent office is the ISA in case 2 for the firm. In either case, patent office f_a is not involved. Any change in the firm's patenting behavior from case 1 to case 2 will reflect the effect of the domestic patent office becoming an ISA. In the following subsections, I analyze how the firm's patenting behavior is affected when the domestic patent office becomes an ISA.

3.3.2 Direct v.s. PCT for Domestic Patenting

As studying patenting in multiple countries is complex, I start with the simple case in which the firm can only apply for patents in the home country. Even though PCT is designed for patenting abroad, the information generated from an ISA report is also valuable for patenting domestically. When considering whether to use PCT to apply for a patent at the domestic patent office or not, the firm compares the expected payoffs from a PCT application with a direct application, as well as the payoff without patenting. If the firm files a direct application, its expected payoff is[13]

$$\pi^h_{direct} = \theta(G + \omega) + (1 - \theta)\lambda_{direct}\omega - C_{Ntl}, \tag{3.2}$$

where the first part of (3.2) represents the expected payoff if the innovation is patentable with probability θ and is granted a patent. The second part is the expected payoff if the innovation is non-patentable with probability $(1 - \theta)$ and is granted a patent with probability λ_{direct}. The firm incurs an application cost C_{Ntl}. If the firm decides not to patent in the home country, its expected payoff from the domestic market is

$$\pi^h_{np} = \theta g. \tag{3.3}$$

The firm will directly apply for a patent rather than not applying if $\pi^h_{direct} \geq \pi^h_{np}$, or equivalently, if $\theta \geq \theta^h_{np}$, where

$$\theta^h_{np} = \frac{C_{Ntl} - \lambda_{direct}\omega}{G - g + (1 - \lambda_{direct})\omega}. \tag{3.4}$$

A PCT application goes through the international phase in the first stage, and the national phase in the second stage. Assuming that the firm decides to apply for a patent after receiving a positive report in the first stage, the *ex ante* expected payoff from filing a PCT application is

$$\pi^h_{PCT,k} = -C_{ISA} + [\theta + (1 - \theta)\lambda_{ISA}]\pi^h_{Ntl,k} \text{ where } k = 1, 2, \tag{3.5}$$

where $\pi^h_{Ntl,k}$ is the expected payoffs in the second stage, which is

$$\pi^h_{Ntl,k} = \tilde{\theta}(G + \omega) + (1 - \tilde{\theta})\lambda_{PCT,k}\omega - C_{Ntl} \text{ where } k = 1, 2. \tag{3.6}$$

[13]Note that these payoffs are independent of the commercial value of the patent if granted.

Substituting (3.6) into (3.5) results in

$$\pi^h_{PCT,k} = \theta(G+\omega) + (1-\theta)\lambda_{ISA}\lambda_{PCT,k}\omega - [\theta + (1-\theta)\lambda_{ISA}]C_{Ntl} - C_{ISA}. \tag{3.7}$$

Compared with a direct application, a PCT application has a cost disadvantage due to the ISA examination fee, as evidenced in (3.7). However, a PCT application also gives a cost advantage since a negative report will discourage the application to apply at national patent offices and then save costs during the national phase. In addition, if $\lambda_{ISA}\lambda_{PCT,k} < \lambda_{direct}$, PCT will give the applicant a lower chance to obtain a patent if the innovation is bad.

The firm will prefer to file a PCT application over not applying if $\pi^h_{PCT,k} \geq \pi^h_{np}$, or equivalently, if $\theta \geq \theta^h_{PCT,k}$, where

$$\theta^h_{PCT,k} = \frac{C_{ISA} + \lambda_{ISA}(C_{Ntl} - \lambda_{PCT,k}\omega)}{G - g + \omega - C_{Ntl} + \lambda_{ISA}(C_{Ntl} - \lambda_{PCT,k}\omega)}. \tag{3.8}$$

The firm will prefer to submit a direct application rather than a PCT application if $\theta^h_{direct} > \theta^h_{PCT,k}$, or equivalently, if $\theta \geq \theta^h_{PCT,k}$, where

$$\theta^h_{direct,k} = \frac{(1-\lambda_{ISA})C_{Ntl} - (\lambda_{direct} - \lambda_{ISA}\lambda_{PCT,k})\omega - C_{ISA}}{(1-\lambda_{ISA})C_{Ntl} - (\lambda_{direct} - \lambda_{ISA}\lambda_{PCT,k})\omega}. \tag{3.9}$$

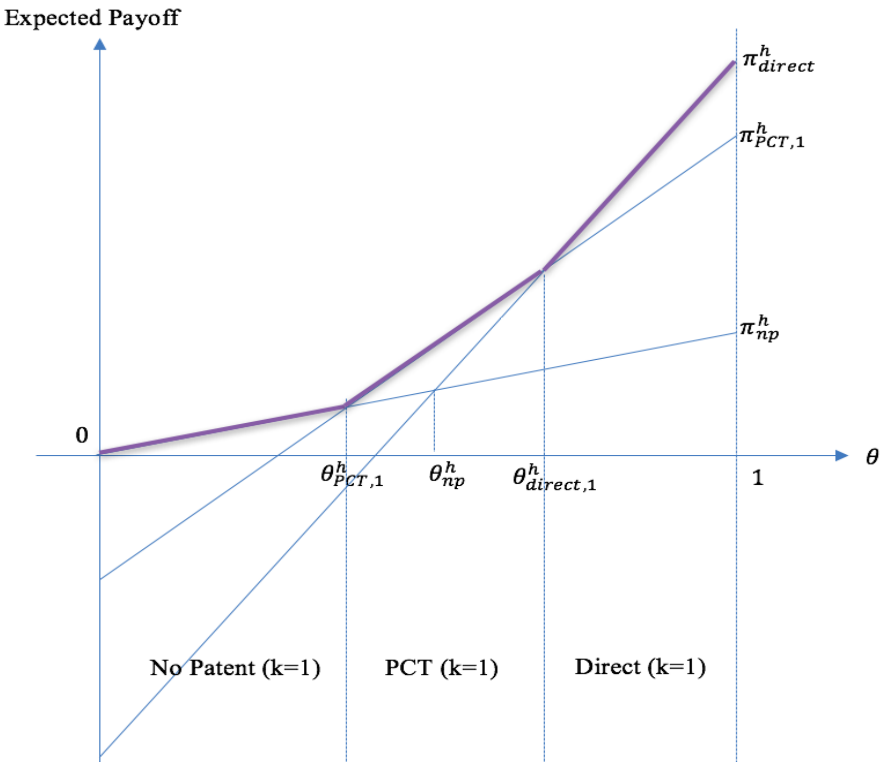


Figure 3.2: Expected Payoffs of Domestic Patenting with $k = 1$

Figure 3.2 represents the firm's expected payoff as a function of θ and illustrates the case where the patent system is the one described in Case 1 with $k = 1$. As shown in this figure, without the PCT, if $\theta < \theta^h_{np}$, the firm will prefer not to apply for a patent; if $\theta > \theta^h_{np}$, the firm will submit a direct application to the home patent office. In contrast, when the PCT exists, the firm will start to apply for a patent if $\theta > \theta^h_{PCT,1}$; the firm will apply for domestic patents through the PCT program if $\theta^h_{PCT,1} < \theta < \theta^h_{direct,1}$; the firm will file direct applications if $\theta > \theta^h_{direct,1}$. This is consistent with Guellec and van Pottelsberghe de la Potterie (2000), who argue that inventors of high-quality innovations apply directly. In contrast, inventors with innovations of unclear market potential are more likely to go through the PCT channel to obtain information on the patentability of their innovations. Overall, Figure 3.2 indicates that the PCT has a positive impact on the firm's propensity to patent and a negative effect on the firm's propensity to file direct applications.

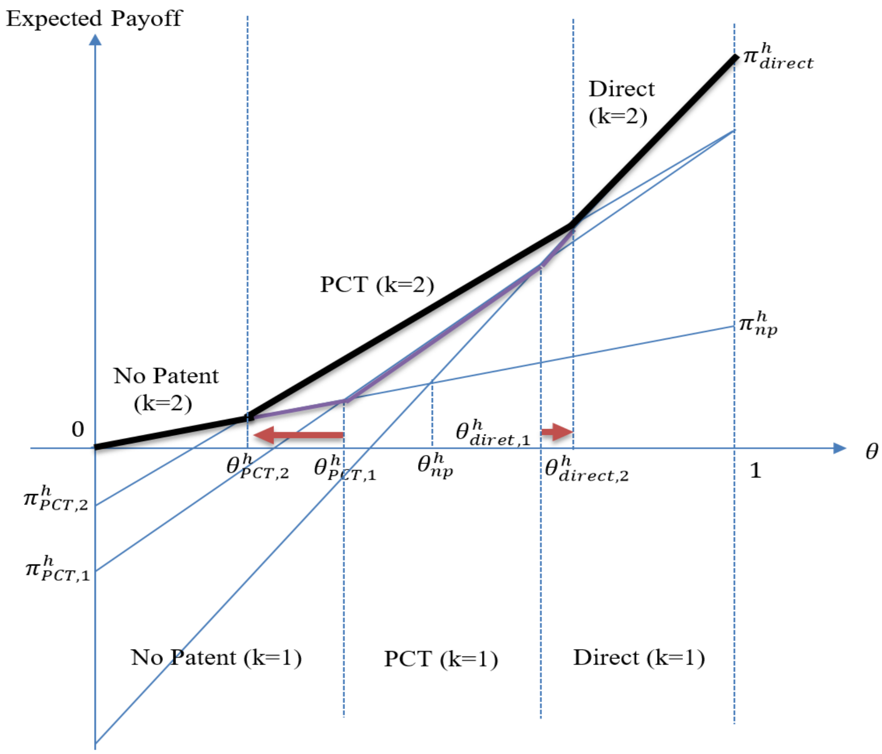


Figure 3.3: Expected Payoffs of Domestic Patenting with $k = 1$ and $k = 2$

Figure 3.3 represents not only the expected payoffs of the firm with $k = 1$ (where patent office f_b is the ISA) but also with $k = 2$ (where the domestic firm is the ISA). When the home patent office is an ISA, the firm will switch from a direct application to a PCT application if $\theta^h_{direct,1} < \theta < \theta^h_{direct,2}$. Furthermore, the firm will choose to apply for a patent even if $\theta < \theta^h_{PCT,1}$, but $\theta > \theta^h_{PCT,2}$. These results suggest that if the home patent office is the ISA, the effect of the PCT on the firm's patenting decision is further enhanced. It is worth noting that, in this case, while the expected quality of direct applications will increase, the expected quality of PCT applications may decrease.

If the value lies between $\theta < \theta^h_{PCT,2}$ and $\theta^h_{PCT,1}$, the firm may be granted a patent with a nonnegative probability. In addition, if the value lies between $\theta^h_{direct,1}$ and $\theta^h_{direct,2}$, the chance to obtain a patent is also higher because at the individual patent offices, a PCT application is more likely to be granted a patent than a direct application. As a result, when the domestic patent office is an ISA, not only the propensity to apply for patents will increase, but also the increased propensity to apply will result in more granted patents.

To summarize, in this subsection, I have considered the simple situation where the firm only considers patenting at the domestic patent office. The results show that PCT increases the firm's propensity to patent in the home country, which is further enhanced if the domestic patent office is the ISA. This case is not realistic as PCT is used for applying for patents in several countries. The firm makes patenting decisions in other countries following a similar procedure discussed in the following subsection.

3.3.3 Direct v.s. PCT for International Patenting

I now focus on the case where the firm considers patenting in the home country as well as in foreign countries. Without PCT, the firm applies for patents either at the home patent office or foreign patent offices directly. The firm's expected payoff from a direct application to a foreign patent office is

$$\pi^{f}_{direct} = \theta(G+\omega) + (1-\theta)\lambda_{direct}\omega - C_{Ntl} - C_F, \text{ where } f = f_a, f_b, \tag{3.10}$$

where the difference between the expected payoff function (3.10) and the expected payoff function (3.2) at the home country is the fixed cost C_F. Due to the fixed cost C_F which is in addition to patent application fees, the threshold to apply for a patent is higher in foreign countries than in the home country. As a result, the firm either patents in the home country or patents in all countries. In this case, the firm's expected payoff from direct applications in the three countries can be written as

$$\pi_{direct} = \begin{cases} \pi^{h}_{direct} \text{ if } \pi^{f}_{direct} < 0, \text{ where } f = f_a, f_b \\ \pi^{h}_{direct} + \pi^{f_a}_{direct} + \pi^{f_b}_{direct} \text{ if } \pi^{f}_{direct} \geq 0, \text{ where } f = f_a, f_b. \end{cases} \tag{3.11}$$

From the expected payoff (3.11), the firm considers patenting abroad if the second stage expected payoff in a foreign country is non-negative. When represented in graph where θ is on the horizontal axis, the expected payoff curves are piecewise.

If the firm decides not to apply for a patent in the foreign countries, its expected payoff from any foreign market is

$$\pi_{np}^{f} = \theta g - C_F \text{ where } f = f_a, f_b. \tag{3.12}$$

The firm considers exploring business opportunities abroad only if $\pi_{np}^{f} \geq 0$. Overall, if the firm does not consider to apply for a patent, it can either produce in the home country or establish businesses in the two foreign countries. The additional cost involved in exploring foreign markets increases the minimum θ required to apply for a patent abroad. In this case, the expected payoff in the three countries without patenting can be written as

$$\pi_{np} = \begin{cases} \pi_{np}^{h} \text{ if } \pi_{np}^{f} < 0 \text{ where } f = f_a, f_b, \\ \pi_{np}^{h} + 2\pi_{np}^{f} \text{ if } \pi_{np}^{f} \geq 0 \text{ where } f = f_a, f_b. \end{cases} \tag{3.13}$$

The firm considers expanding its business without patenting in a foreign market only if doing business in that country generates non-negative profits.

When filing a PCT application, the firm considers the expected payoff from all three markets. First, as patent office f_a does not act as an ISA for the domestic firm, the expected payoff of patenting at this office will not be affected by who is the ISA. The firm's expected payoff to submit an application to patent office f_a in the second stage is thus

$$\pi_{Ntl,k}^{f_a} = \tilde{\theta}(G + \omega) + (1 - \tilde{\theta})\lambda_{PCT,1}\omega - C_{Ntl} - C_F. \tag{3.14}$$

If the firm decides to patent in the patent office f_b, its expected payoff in the second stage is

$$\pi_{Ntl,k}^{f_b} = \tilde{\theta}(G + \omega) + (1 - \tilde{\theta})\lambda_{PCT,3-k}\omega - C_{Ntl} - C_F \text{ where } k = 1, 2. \tag{3.15}$$

Equation (3.15) suggests that the firm's patenting at the domestic patent office when $k = 1$ is the same as its patenting at patent office f_b when $k = 2$, vice versa.

If a PCT application has been filed after receiving the ISA report, the firm decides whether to apply for patents in one patent office, in two patent offices, or in all three patent offices. First, consider the case where the home patent office is not the ISA but patent office f_b is ($k = 1$). In this case, the expected payoff in the three countries is

$$\pi_{PCT,1} = \begin{cases} [\theta + (1-\theta)\lambda_{ISA}]\pi^h_{Ntl,1} - C_{ISA} \text{ if } \pi^{f_a}_{Ntl,1} < 0 \text{ and } \pi^{f_b}_{Ntl,1} < 0 \\ [\theta + (1-\theta)\lambda_{ISA}](\pi^h_{Ntl,1} + \pi^{f_b}_{Ntl,1}) - C_{ISA} \text{ if } \pi^{f_a}_{Ntl,1} < 0 \text{ and } \pi^{f_b}_{Ntl,1} \geq 0 \\ [\theta + (1-\theta)\lambda_{ISA}](\pi^h_{Ntl,1} + \pi^{f_a}_{Ntl,1} + \pi^{f_b}_{Ntl,1}) - C_{ISA} \text{ if } \pi^{f}_{Ntl,1} \geq 0 \text{ where } f = f_a, f_b. \end{cases} \tag{3.16}$$

If $\pi^{f_a}_{Ntl,1} < 0$ and $\pi^{f_b}_{Ntl,1} < 0$, the firm will only consider patenting at the home patent office; if $\pi^{f_a}_{Ntl,1} < 0$ and $\pi^{f_b}_{Ntl,1} \geq 0$, the firm will consider patenting at the home patent office and patent office f_b; if $\pi^{f_a}_{Ntl,1} \geq 0$ and $\pi^{f_b}_{Ntl,1} \geq 0$, the firm will consider patenting in all three countries.

Second, consider the case where the home patent office is the ISA ($k = 2$). In this case, the firm treats the two foreign countries as being the same and its expected payoff is thus

$$\pi_{PCT,2} = \begin{cases} [\theta + (1-\theta)\lambda_{ISA}]\pi^h_{Ntl,2} - C_{ISA} \text{ if } \pi^{f}_{Ntl,2} < 0 \text{ where } f = f_a, f_b, \\ [\theta + (1-\theta)\lambda_{ISA}](\pi^h_{Ntl,2} + 2\pi^{f}_{Ntl,2}) - C_{ISA} \text{ if } \pi^{f}_{Ntl,2} \geq 0 \text{ where } f = f_a, f_b. \end{cases} \tag{3.17}$$

If $\pi^{f_a}_{Ntl,1} < 0$ and $\pi^{f_b}_{Ntl,1} < 0$, the firm will only consider patenting at the home patent office; if $\pi^{f_a}_{Ntl,1} \geq 0$ and $\pi^{f_b}_{Ntl,1} \geq 0$, the firm will consider patenting in all three countries.

In Figures 3.2 and 3.3, I have implicitly made a few assumptions on the intercepts and slopes of the payoff functions. Now, I discuss these assumptions. First, if the firm knows that its innovation is good ($\theta = 1$), patenting through either channel is better than not patenting, i.e., $\pi_{PCT,k}(\theta = 1) = 3(G + \omega - C_{Ntl}) - C_{ISA} - 2C_F > \pi_{np}(\theta = 1) = 3g - 2C_F$ and $\pi_{direct}(\theta = 1) = 3(G + \omega - C_{Ntl}) > \pi_{np}(\theta = 1) = 3g - 2C_F$. When the first condition holds, the second automatically holds. This implies that if the firm knows that its innovation is good, patenting through either channel is a profitable choice, and the direct channel is preferred. This assumption is explicitly written as

$$\text{(A1)} \qquad \underbrace{3(G+\omega-g)}_{\text{Expected benefit of patenting a good innovation from PCT}} > \underbrace{C_{ISA}+3C_{Ntl}.}_{\text{Expected cost of patenting a good innovation from PCT}}$$

Second, if the firm knows that it has a bad innovation, it is not worth applying for a patent. This assumption will hold if $\pi_{PCT,1}(\theta = 0) < 0$, $\pi_{PCT,2}(\theta = 0) < 0$ and $\pi_{direct}(\theta = 0) < 0$, which can be written as

$$\text{(A2)} \qquad \underbrace{\lambda_{ISA}\lambda_{PCT,2}\omega}_{\text{Expected benefit of patenting a bad innovation from PCT}} < \underbrace{C_{ISA}+\lambda_{ISA}C_{Ntl}.}_{\text{Expected cost of patenting a bad innovation through PCT}}$$

Assumptions (A1) and (A2) exclude the two extreme cases in which the firm will apply for a patent or it will never apply for a patent. However, these two assumptions are not sufficient. I exclude another extreme case in which the firm never considers PCT. To make sure that both direct and PCT channels are used, the expected payoff function π_{direct} must intersect with the expected payoff function $\pi_{PCT,k}$ within $\theta \in [0, 1]$. Since $\pi_{direct}(\theta = 1) > \pi_{PCT,k}(\theta = 1)$, I only need to assume that when $\theta = 0$, the expected payoff is higher from a PCT application than a direct application, i.e. $\pi_{direct}(\theta = 0) < \pi_{PCT,k}(\theta = 0)$. This assumption is explicitly written as

$$\text{(A3)} \qquad \underbrace{C_{ISA}-\lambda_{ISA}\lambda_{PCT,2}\omega}_{\text{Expected cost of patenting a bad innovation from PCT}} < \underbrace{C_{Ntl}-\lambda_{direct}\omega.}_{\text{Expected cost of patenting a bad innovation directly}}$$

Figure 3.4 represents the firm's expected payoff as a function of θ. The key difference with Figure 3.3 is the payoff curves are piecewise. As shown in Figure 3.4, when $\theta > \theta_{direct,1}$, the firm prefers to explore foreign markets with patenting directly; when $\theta_{PCT,1} < \theta < \theta_{direct,1}$, the firm prefers to explore foreign markets with patenting through PCT; when $\theta < \theta_{PCT,1}$, the firm prefers to not patent. In contrast, when $\theta > \theta_{direct,2}$, the firm prefers to explore foreign markets with patenting directly; when $\theta_{PCT,2} < \theta < \theta_{direct,2}$, the firm prefers to explore foreign markets with patenting through PCT; when $\theta < \theta_{PCT,2}$, the firm prefers to not patent. When the domestic patent office is an ISA, the threshold to patent further decreases to $\theta_{PCT,2}$ from $\theta_{PCT,1}$, suggesting an increase in propensity to patent. Figure 3.4 suggests that neither PCT nor ISA has an impact on firms' decision to do business abroad. In addition, Figure 3.4 also shows that the increase in PCT applications is associated with a decrease in direct applications if the home patent office is the ISA. I summarize all the results in the following proposition.

Proposition 1 *Under assumptions (A1) to (A3), when the domestic patent office is an ISA, the propensity to*

i) apply for a patent at the domestic patent office increases;

ii) file PCT applications at the domestic patent office increases;

iii) apply for a patent at b (former ISA) decreases after filing PCT applications domestically;

iv) apply for a patent in country a does not change.

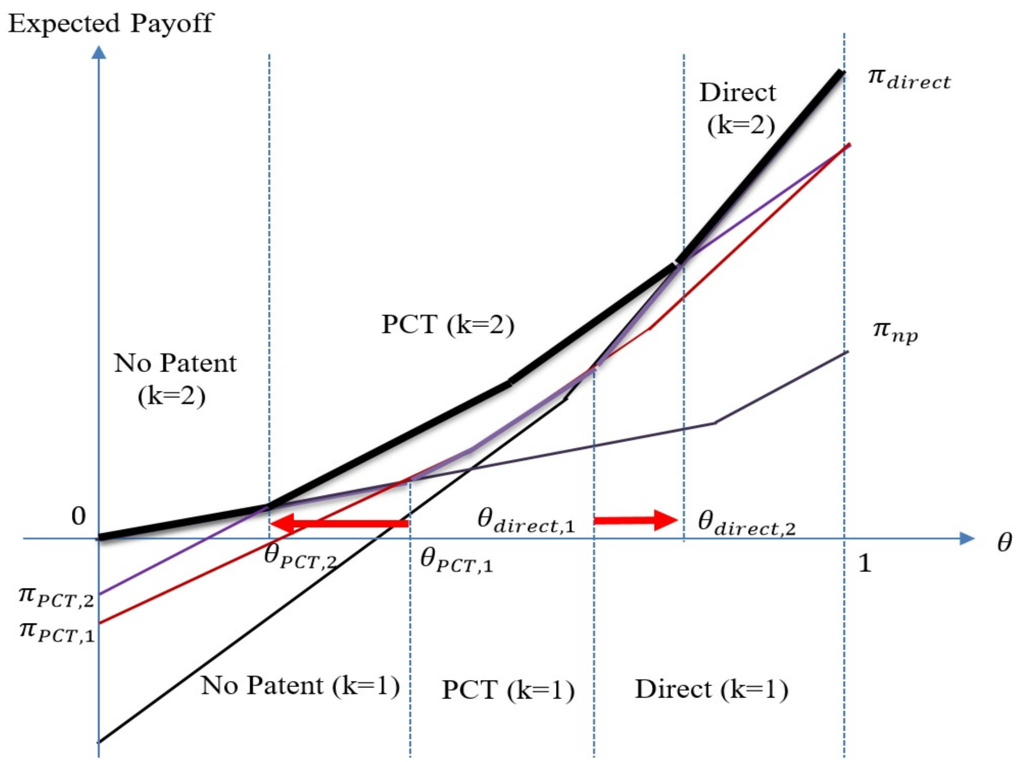


Figure 3.4: Expected Payoffs of International Patenting with $k = 1$ and $k = 2$

To summarize, this model helps understand how PCT and ISA may affect the firm's decision to apply for a patent, apply for a patent abroad, and use PCT. Proposition 1 addresses two issues. First, results i) and ii) predict that the domestic patent office's role as an ISA may encourage firms to patent domestically. Second, result iii) predicts that as an ISA, the domestic patent office may reduce domestic firms' patenting abroad in country b, who is the ISA for the domestic firm when the domestic patent office is not. Third, result iv) predicts that as an ISA, the domestic patent office does not affect domestic firms' patenting abroad in country a, who is never an ISA for the domestic firm. All parameters are provided in Table 3.1.

Insert **Table 3.1: Parameters and Brief Description**

The reality is more complex than the model; for example, I assume that all ISAs will follow the same standard for PCT examinations, but in reality, patent offices may have their search and examination rules. I also assume that all ISAs charge the same examination fee, but some patent offices charge a higher examination fee than others. For instance, CIPO charges a much lower ISA examination fee than EPO. In addition, my model has taken the viewpoint of a representative domestic firm. However, for example, a foreign firm may enjoy the benefits of CIPO becoming an ISA if a foreign firm can list a Canadian applicant in its applications, which is easy to operate for foreign-owned firms in Canada.

3.3.4 Implications and Hypotheses

CIPO started its service as an ISA in July 2004. In the context of Canada, the patent office in country a of the above model refers to any foreign patent office other than EPO (e.g., USPTO), and the patent office in country b refers to EPO. Also, the case where $k = 1$ refers to the situation where EPO was the ISA for Canadian firms before 2004, and the case where $k = 2$ refers to the situation where CIPO is the ISA for Canadian firms after 2004. Guided by the theoretical model, in this section, I develop the hypotheses for the empirical analysis.

First, CIPO's role as an ISA may increase the likelihood of obtaining patents and decrease the costs of obtaining these patents. Result i) of Proposition 1 suggests that Canadian firms were more likely to patent in Canada when CIPO was an ISA as stated in Hypothesis 1.

Hypothesis 1: *CIPO's role as an ISA increases Canadian firms' propensity to patent at CIPO.*

Second, ISA reports allow applicants to evaluate the patentability of their innovations before entering the national phase of PCT applications, during which granting decisions are made. This reduces the uncertainty during this phase and gives PCT applications an advantage over direct applications. Consequently, as predicted in result ii) of Proposition 1, I expect that Canadian firms would file more PCT applications and less direct applications as stated in Hypothesis 2.

Hypothesis 2: *When CIPO started its ISA services in 2004, Canadian firms increased (decreased) their PCT (direct) applications.*

Third, I investigate if CIPO' role as an ISA was associated with an increase in Canadian firms' patenting at foreign patent offices, in particular at the USPTO and EPO. Result iii) of Proposition 1 suggests that when CIPO became an ISA, Canadian firms may have decreased their patenting abroad through filing PCT applications at CIPO. In contrast, result iv) of Proposition 1 suggests Canadian firms' patenting in the U.S. will not be affected by CIPO's role as an ISA. This argument is summarized in the following hypothesis.

Hypothesis 3: *When CIPO became an ISA, Canadian firms filed less national phase PCT applications at EPO through filing international phase PCT applications at CIPO; their patenting in the U.S. will not be affected.*

Finally, a firm's propensity to explore business opportunities abroad through FDI or exporting is not explored in my model. However, the literature suggests that international patenting is positively related to firms' business activities abroad (Licht and Zoz, 2000; Yew et al., 2011; Palangkaraya et al., 2017). I will empirically test if Canadian firms' FDI experienced significant changes when CIPO became an ISA, which is stated in the following hypothesis.

Hypothesis 4: *CIPO's role as an ISA was associated with an increase in Canadian firms' FDI activities.*

3.4 Empirical Framework

Consistent with Proposition 1, the empirical investigations of hypotheses 1 through 4 answer two questions. The first question investigates whether CIPO's role as an ISA has any impact on Canadian firms' patenting at CIPO. The second question examines if CIPO's role as an ISA has encouraged domestic firms to apply for patents and invest abroad. The idea is to understand whether there is an increase in domestic patenting, or an increase in patenting abroad, or an increase in overseas business activities, etc.

The empirical estimation for the first question adopts a Difference-in-Differences (DID) approach. It is essential to separate the effect of CIPO's role as an ISA from other time trends. I mainly adopt two strategies to address this issue. First, I identify a control group for Canadian firms. Such a group of firms should have been exposed to similar economic conditions as Canadian firms but have not been affected by CIPO's role as an ISA. The U.S. and Canada share a border, speak a common language (English), and have close economic relationships. In this sense, the macroeconomic environments for Canadian and U.S. firms are similar, though not identical. U.S. firms thus are used as a control group. Second, I include specific trends in the regressions. In all the regressions, I control for country-specific trends and industry-specific trends, aiming to separate the effect of CIPO becoming an ISA from the effects of other country-specific and industry-specific factors over time.

A firm's patenting variable Pat_{isct} measures the logarithm of the number of patent applications that will be eventually granted in country c to firm i of country c in industry s in year t. If there is no patents during a year, Pat_{isct} is zero. The variable Pat_{isct} is expressed as

$$Pat_{isct} = \alpha_0 + \alpha_1 ISA_t + \alpha_2 CAN_{isct} + \alpha_3 ISA_t \times CAN_{isct} + \sigma X_{isct} + \delta_i + \varepsilon_{isct}, \qquad (3.18)$$

where ISA_t is a dummy variable that takes the value 1 for the period 2005-2008; CAN_{isct} is a dummy variable that takes the value 1 for firms in Canada; the coefficient of interest is α_3 which measures the effect of CIPO's role as an ISA on Canadian firms' patenting; X_{isct} represents the control variables, including firm-level characteristics $Size$, $Experience$, $R\&D$, and HHI,industry-level trends and fixed effects, and province-level trends and fixed effects which will be defined in the subsequent section 5.2; and ε_{isct} is the error term. In the subsequent robustness check section, the independent variables X_{isct} will be lagged by one or two years to check if my findings still hold if firm characteristics are assumed to have a delayed impact on firms' patenting.

To obtain unbiased and valid estimations for such a regression, I need to verify that Canadian and U.S. firms followed a similar trend in their domestic patenting before 2004. This verification is known as the common trend assumption in the DID literature. I perform a placebo test to examine if patenting patterns of Canadian and U.S. firms started to differ only shortly before CIPO became an ISA. The following model indicates whether there were systematic differences in the trend between the two groups of firms from 2000 to 2004,

$$Pat_{isct} = \beta_0 + \beta_1 Pseudo\_ISA_t + \beta_2 CAN_{isct} + \beta_3 Pseudo\_ISA_t \times CAN_{isct} + \sigma X_{isct} + \delta_i + \varepsilon_{isct}, \quad (3.19)$$

where $Pseudo\_ISA_t$ is a dummy variable and takes the value 1 for years shortly before 2004;[14] other terms follow the same definitions as in equation (3.18). If the estimate of β_3 is statistically significant, it would suggest that Canadian firms are different from U.S. firms in terms of patenting activities before CIPO became an ISA. A significant difference in the patenting patterns in the pre-treatment period could undermine the validity of the DID approach.

The second question explores Canadian firms' patenting and business activities in detail. CIPO's service as an ISA is only available to Canadian applicants, or foreign-owned firms if one applicant listed in the patent application is Canadian. However, foreign-owned firms would be more likely to use the ISA services in their own national patent offices as they are more familiar with their

[14] I look at 2002 and 2003 as explained later.

offices.[15] Indeed, they, or the lawyers or patent agents who work for them, probably understand better national laws and use the same language.[16] Baldwin et al. (2002) find that foreign-owned firms patent more at CIPO than domestic firms. A foreign-owned firm is often a subsidiary of a larger firm in a foreign country. Balasubramanian and Lee (2008) argue that patents are managed by the headquarter in the state of origin in a centralized manner.

Let $Activity_{ispt}$ represent a set of variables for a Canadian firm i in industry s of province p in year t, which can be expressed as

$$Activity_{ispt} = \gamma_0 + \gamma_1 ISA_t + \gamma_2 Domestic_{ispt} + \gamma_3 ISA_t \times Domestic_{ispt} + \sigma Z_{ispt} + \delta_i + \varepsilon_{ispt}, \quad (3.20)$$

where $Domestic_{ispt}$ is a dummy variable that takes the value 1 for a domestic firm i in industry s of province p; Z_{ispt} represents the control variables, including firm-level characteristics Age, $Size$, $Experience$, $R\&D$, and HHI, industry-level trends and fixed effects, and province-level trends and fixed effects; and ε_{ispt} is the error term. The coefficients of interest are γ_3, which captures the difference in the effect of CIPO's role as an ISA on domestic and foreign-owned firms, and γ_1 which captures the effect of post-treatment years 2005-2008.

3.5 Data and Descriptive Statistics

There exist no public linkage in Canada between data on firms' patenting and firm-level information due to confidentiality issues. In this paper, under an arrangement that maintains legal confidentiality requirements, patent data of Canadian firms from CIPO and USPTO are linked to the National Accounts Longitudinal Microdata File (NALMF) at Statistics Canada, which keeps track of firms' characteristics such as employment, R&D expenditure, and operation location. In addition, I was granted access to Canadian Direct Investment Abroad (CDIA), which includes data on Canadian firms' FDI by destination. CDIA records not only the capital a Canadian firm invested

[15] According to the NALMF, a firm is foreign-owned if the country of residence of its ultimate shareholder is not Canada.

[16] These arguments regarding where a foreign-owned firm would use ISA service were gathered from communication with CIPO's representatives.

abroad but also the capital the firm received from foreign investors in a year.

As discussed in the previous section, U.S. firms are used as the control group for Canadian firms. The patent datasets for U.S. firms constructed by Hall et al. (2001) can be linked to financial data of publicly-listed U.S. firms in Compustat. However, the data by Hall et al. (2001) were only updated to 2006. In this paper, I use the patent data compiled by Dorn et al. (2019), which covers U.S. firms' patenting up to early 2013. The patent data are merged with the Compustat database following the procedure documented in Hall et al. (2001).

The focus of this paper is the firms' patenting behavior. However, only a small fraction of Canadian firms in NALMF have patented (less than 1%). To focus on firms' patenting or innovating behavior, in all analyses, I first investigate *patenting firms* that have at least one patent during the study period, 2000-2008. Then, I further include firms that have invested in R&D over the period 2000-2008 (i.e., *innovating firms*). In this way, I exclude firms that have never done R&D or patented during the study period.

3.5.1 Measuring Firm Activities

In this subsection, I describe how the dependent variables are defined and the data sources for each dependent variable. I start with the definition of Pat_{isct} as specified in equations (3.18) and (3.19), then move to the definition of $Activity_{ispt}$ as specified in equation (3.20).

When USPTO receives a direct application or a PCT application in the national phase, it will automatically examine it and make granting decisions. In contrast, when CIPO receives a direct application or a PCT application in the national phase, it requires the applicant to request an examination within five years. When such a request is submitted, CIPO starts to examine the application and make granting decisions. In the study period 2000-2008, an applicant requested an examination after 2.4 years on average. The variable Pat_{isct} refers to the number of patent applications of U.S. firms that would be eventually granted by 2011 at USPTO or of Canadian firms that would be eventually granted by 2014 at CIPO. When Pat_{isct} refers to Canadian firms, patent data from CIPO and firm-level data from NALMF were used. When Pat_{isct} refers to U.S. firms, patent data from

Dorn et al. (2019) and firm-level data from Compustat were used. I exclude firms that exited the datasets before 2004 or firms that entered the datasets after 2004 to ensure that firms in my sample have been exposed to the changing role of CIPO as an ISA. The estimation results of Pat_{isct} will be discussed in Tables 5 and 6.

The outcome variable $Activity_{ispt}$ measures a set of Canadian firms' activities, aiming to compare domestic and foreign-owned firms.[17] First, information on whether a patent application at CIPO was filed through PCT or not allows me to create three variables: the total number of applications at CIPO ($Total_{CIPO}$), the number of PCT applications in the international phase at CIPO (PCT_{CIPO}), and the number of direct applications at CIPO ($Direct_{CIPO}$). For this set of analyses, my focus is on firms' first-stage patenting filing behavior, so the number of direct applications did not include PCT applications at the national phase. Thus, $Total_{CIPO}$ equals the sum of PCT_{CIPO} and $Direct_{CIPO}$. The estimation results of this set of outcome variables will be discussed in Table 3.7.

Second, patent data from CIPO track the national phase of a PCT application filed at CIPO during the international phase. I have information on whether a PCT application at CIPO ultimately went to USPTO or EPO or CIPO. In this case, $Activity_{ispt}$ refers to Canadian firms' PCT applications filed at CIPO. I create three variables to investigate the destination of a PCT application at CIPO. Specifically, I consider the number of PCT applications that ultimately went to USPTO ($USPTO_{PCT}$), the number of PCT applications that ultimately went to EPO (EPO_{PCT}), and the number of PCT applications that ultimately went to CIPO ($CIPO_{PCT}$). If a PCT application was filed at CIPO and did not go to any of these three patent offices at the national phase of PCT, it was excluded from the sample.[18] Table 3.8 will present the estimation results of this set of outcome variables.

Third, Canadian firms' patenting at USPTO should not be affected by either PCT applications

[17] As the ownership of a firm may change over time, and I exclude firms whose owners have changed in a year during the study period. Only a small fraction of observations were dropped.

[18] EPO, USPTO, and CIPO together receive the majority of patent applications by Canadian firms. It is beyond the scope of this paper, but it would be interesting to study why a firm decides not to apply for patents in a patent office after receiving the ISA report.

at CIPO or patent application through other channels as USPTO is never the ISA for them. Data on Canadian firms' patenting at USPTO allows me to investigate Canadian firms' patenting behavior at USPTO through international phase PCT at USPTO or directly. In this case, $Activity_{ispt}$ refers to Canadian firms' patent applications filed at USPTO. Similar to the CIPO data, I create three variables: total number of applications at USPTO $Total_{USPTO}$, the number of PCT applications at USPTO PCT_{USPTO}, and the number of direct applications at USPTO (not including PCT applications at the national phase), $Direct_{USPTO}$. Table 3.9 will report the estimation results of this set of outcome variables.

In my final specifications, $Activity_{ispt}$ refers to Canadian firms' FDI activities abroad. I first measure FDI activities by the total outflow of investment from a Canadian firm, which gives the *gross FDI*. When a Canadian firm invests abroad, it may also receive financing from a foreign firm. To account for the capital received by a firm, I subtract the investment that a Canadian firm receives from a foreign country from its gross FDI, which provides *net FDI*. The CDIA data show that in terms of net FDI, the U.S. and Europe account for 61.79% and 13.75% of total Canadian investment abroad, respectively; in terms of gross FDI, the ratio is 55.17% for the U.S. and 18.79% for Europe. As a result, I measure Canadian firms' FDI using three variables: FDI to the world, FDI to the U.S., and FDI to Europe. The estimation results of FDI variables will be reported in Table 3.10.

3.5.2 Control Variables

My econometric models include a set of firm-level control variables. First, as summarized in Cohen (2010), firms' innovation activities are associated with firm size. The variable $Size$ is measured by the logarithm of total assets (e.g., Helmers and Rogers, 2011). Second, I control for Age, as measured by the difference between the current year and the establishment year. Firm age and patenting have been shown to have a negative relationship (Smith-Doerr et al., 1999). Third, I control for past patenting $Experience$ using the total number of patent applications in the past five years (e.g., Yanadori and Cui, 2013; Eckert et al., 2019). Fourth, I include the variable $R\&D$

by taking the logarithm of R&D expenditures to control for the positive effect of a firm's R&D expenditure on its patenting (Lerner and Zhu, 2007).[19]

I also include a set of industry-level control variables. First, I control for industrial concentration using the Herfindahl-Hirschman Index (HHI), which is calculated at the first four digits of the North American Industry Classification System (NAICS) based on the annual revenue. Second, in all regressions, I also include industry dummies based on the first two digits of NAICS. Finally, I include a linear trend variable t and its interaction with industry dummies, province dummies, and country dummies to control for these specific trends. Table 3.2 collects brief definitions and data sources for all variables.

Insert **Table 3.2: Definition of Variables**

3.5.3 Summary Statistics

During the period 2000-2008,4,425 patenting firms filed patent applications at CIPO, among which approximately 90 foreign-owned firms. In total,17,431 patent applications were filed. Table 3.3 presents the summary statistics of the characteristics of different types of firms. As shown in the first two columns of Table 3.3, only a small proportion of firms in Canada have patented. Generally, patenting firms are younger and larger than non-patenting firms. Patenting firms invest more in R&D than non-patenting firms. Additionally, patenting firms are facing more competition than non-patenting firms. Domestic firms submit fewer patent applications than foreign-owned firms on average.

Insert **Table 3.3: Characteristics of Different Types of Firms**

Columns (3) and (4) compare the characteristics of domestic and foreign-owned patenting firms. In general, foreign-owned firms are older and larger, face more competition, and have more patenting experience than domestic firms. Columns (5) and (6) compare the characteristics

[19] Reporting R&D expenditure is not mandatory in the NALMF database. However, a representative from Statistics Canada confirms that if a firm has done R&D, it always reports the R&D expenditure.

of firms that invest abroad and firms that do not. The statistics show that firms that invest abroad are generally older and larger, face more competition, and invest more in R&D. Besides, firms investing abroad have more patenting experience than firms that do not invest abroad. The last two columns compare Canadian and U.S. patenting firms. The numbers indicate that U.S. firms in the sample are larger in terms of total assets, face more competition, have the more patenting experience, and invest more in R&D than Canadian firms. I will address this difference in firm size in the econometric analysis.

Figure 3.5 plots the total number of patent applications that are eventually granted to Canadian firms at CIPO and U.S. firms at USPTO. It is worth noting that these applications include both direct and PCT applications in the international phase and would be eventually granted. As shown in Figure 3.5, the number of patent applications of U.S. firms at USPTO is far larger than the number of patent applications of Canadian firms at CIPO. However, Figure 3.5 suggests that before 2004, patenting trends at these two patent offices were similar. Shortly after CIPO became the ISA, in 2005 and 2006, there was an apparent increase in patenting by Canadian firms at CIPO. The decline in late years is due to the delay in the granting process.

Insert **Figure 3.5: Total Patent Applications (eventually granted) by Canadian and U.S. Firms**

Table 3.4 reports the patenting statistics of domestic and foreign-owned firms in Canada. Among all patenting firms, about 100 are foreign-owned. The numbers suggest that foreign-owned firms have submitted more patent applications than domestic firms. For instance, for every application by a domestic firm, a foreign-owned firm submits 1.4 (0.48/0.34) patent applications on average. In terms of PCT applications, on average, a foreign-owned firm submits 1.7 times more applications than a domestic firm. It also illustrates that foreign-owned firms have filed more national phase PCT applications at EPO and USPTO than domestic firms after filing PCT applications at CIPO.

Insert **Table 3.4: Patenting Statistics at CIPO by Domestic and Foreign-owned Firms**

3.6 Results

In this section, I present the estimation results of the econometric models specified in Section 4. I start with the estimation of the falsification equation (3.19), examining whether the patenting patterns of Canadian firms at CIPO were systematically different from U.S. firms at USPTO before CIPO became an ISA. As the falsification tests indicate that the patenting patterns of Canadian and U.S. firms during the pre-treatment period, 2000-2004 in their home country did not differ, I then present the main results that CIPO's role as an ISA was associated with an increase in Canadian firms' patenting at CIPO. Next, I present the estimation results of equation (3.20), aiming to investigate if domestic and foreign-owned firms responded differently to CIPO becoming an ISA.

3.6.1 CIPO's Role as an ISA and Canadian Firms' Patenting at CIPO

To obtain unbiased and valid estimations from the DID approach, it requires that Canadian and U.S. firms follow a similar trend in their patenting patterns in the home patent office in the pre-treatment period 2000-2004. Figure 3.6 plots the average number of domestic patent applications (eventually granted) per year of Canadian firms at CIPO and U.S. firms at USPTO. Figure 3.6 shows that during 2000-2008, the average number of patent applications (eventually granted) by U.S. firms follows a smoothing trend. In contrast, the average number of patent applications (eventually granted) by Canadian firms at CIPO increased dramatically after 2004. Due to the truncation issue, the average number of granted patents in late years declined for firms in both countries.

Insert **Figure 3.6: Average Patent Applications (eventually granted) by Canadian and U.S. Firms**

Figure 3.6 suggests that the patenting patterns of Canadian and U.S. firms before 2004 were similar. Falsification tests can further examine if the patenting patterns of Canadian and U.S. firms started to differ only shortly before CIPO became an ISA. Table 3.5 contains the regression results of equation (3.19) for the period 2000-2004 with the assumption that CIPO started its ISA services at an earlier date. The first three columns report the regression results assuming that CIPO began its ISA service in 2003. In the last three columns, I repeat the analysis by considering that CIPO started its ISA service in 2002. The coefficients of the interaction term $Pseudo\_ISA \times CAN$ are insignificant, suggesting that Canadian and U.S. firms' patenting patterns were not systematically different during the pre-treatment period 2000-2004. This justifies the use of the DID approach.

Insert **Table 3.5: Patenting Patterns in the Pre-treatment Period, 2000-2004**

Figure 3.6 and results in Table 3.5 justify the validity of the DID approach as specified in equation (3.18). Table 3.6 presents the estimation results of equation (3.19). U.S. firms in Compustat are used as the control group for Canadian firms in NALMF. I focus on patenting and innovating firms in the first and second columns, respectively. The coefficients and signs of the control variables show that firms' patent applications are positively associated with R&D expenditure, age, size, patent experience, and industrial competitions. These results are consistent with the studies in the literature (Lerner and Zhu, 2007; Cohen, 2010; Helmers and Rogers, 2011; Eckert et al., 2019).

In both panels of Table 3.6, the coefficients of the interaction term $ISA \times CAN$ are significantly positive, suggesting an increase in Canadian firms' patenting at CIPO after CIPO started its role as an ISA in 2004. More specifically, the coefficients suggest that due to CIPO's role as an ISA, patent applications at CIPO increased by 3.99% for Canadian patenting firms, and by 2.74% for innovating firms. According to WIPO statistics, during the period 2000-2008, about 40000 patent applications were filed at CIPO annually. Using this number, I can infer that, on average, CIPO's role as an ISA could lead to approximately 1600 more patent applications at CIPO each year. Note that in Table 3.6, I consider only patent applications that were eventually granted. In this respect, I underestimate the effect of CIPO's role as an ISA on increasing patent applications at CIPO. Consequently, CIPO's role as an ISA must have led to more than a 4% increase in patent applications at CIPO, which also suggests that Canadian firms favor CIPO over EPO if they can choose who the ISA is.

Insert **Table 3.6: CIPO's Role as an ISA and Canadian Firms' Patenting at CIPO**

3.6.2 CIPO's Role as an ISA and International Patenting at CIPO

Results in the previous subsection suggest that there was an uptick in patenting activities in Canada relative to patenting in U.S. The primary function of PCT is to facilitate innovators' international patenting, which involves foreign innovators' patenting in the home country and domestic innovators' patenting abroad. In this subsection, I focus on Canadian firms and decompose their patenting as patenting by domestic firms and patenting by foreign-owned firm. The purpose is to investigate whether CIPO's role as an ISA has, first, attracted foreign innovators to patent more at CIPO, and second, encouraged domestic Canadian firms to patent more abroad.

Figure 3.7 plots the average number of PCT applications in the international phase by domestic and foreign-owned firms over time. The figure shows that the average number of PCT applications filed by domestic firms at CIPO increased slightly, whereas the average number of PCT applications by foreign-owned firms significantly increased after 2004. This suggests that CIPO's role as an ISA has encouraged foreign-owned firms to patent in Canada.

Insert **Figure 3.7: The Number of PCT Applications per Firm by Domestic and Foreign-owned Firms**

Figure 3.8 plots the average number of direct applications by domestic and foreign-owned firms over time. As shown in Figure 3.8, in comparison to PCT applications, the direct applications by domestic firms have continued to decline. While the number of direct applications by foreign-owned firms kept falling before 2004, it started to reverse after 2004.

Insert **Figure 3.8: The Number of Direct Applications per Firm by Domestic and Foreign-owned Firms**

Table 3.7 presents the regression results for equation (3.20), which investigates whether domestic and foreign-owned firms respond differently to CIPO's role as an ISA. I also consider patenting firms first, and then innovating firms as a robustness check. The coefficients of ISA are positive and significant, confirming the findings in Table 3.6 that CIPO's role as an ISA is associated with an increase in Canadian firms' patenting at CIPO. The more interesting result is the significantly negative coefficient of the interaction term $ISA \times Domestic$. Figure 3.7 suggests that patenting by domestic firms is relatively stable. The results indicate that foreign-owned patenting firms submitted 12% more PCT applications and 9% more direct patent applications at CIPO due to CIPO's role as an ISA than domestic patenting firms.

Insert **Table 3.7: CIPO's Role as an ISA and International Patenting at CIPO**

Foreign-owned firms are more likely to file PCT applications at their own national patent offices. As a result, domestic firms are expected to submit more patent applications at CIPO as a response to CIPO's role as an ISA than foreign-owned firms. However, the results suggest that foreign-owned firms were more responsive to CIPO's role as an ISA than domestic firms. It might be because it is more convenient for foreign-owned firms to obtain patents at CIPO after CIPO became the ISA. As well, lower ISA examination fees charged by CIPO might be another reason to explain the increased attractiveness of CIPO to foreign-owned firms.

Results in Table 3.7 suggest that CIPO's role as an ISA was associated with an increase in patent applications from foreign-owned firms. I also investigate whether CIPO's role as an ISA encouraged domestic firms' patenting abroad using two approaches. First, as presented in Table 3.8, I investigate the destinations of a PCT application filed at CIPO. In particular, I investigate PCT applications filed at CIPO in their national phase at USPTO, EPO, and CIPO. The coefficient of ISA and its interaction with $Domestic$ are only significant for subsequent applications at EPO through PCT. This suggests that Canadian firms, especially foreign-owned firms, took advantage of CIPO's ISA service to apply for more EPO patents through PCT. Canadian firms' patenting at USPTO through PCT did not have significant change after 2004. The results suggest that in comparison with domestic firms, CIPO's role as an ISA has encouraged foreign-owned firms to apply for patents at EPO through PCT filings at CIPO. In particular, the results show that foreign-owned patenting firms filed 11% more national phase PCT applications at EPO than domestic patenting firms after filing international PCT applications at CIPO.

Insert **Table 3.8: International Patenting after Filing a PCT Application at CIPO**

Second, as presented in Table 3.9, I take advantage of patent data on Canadian firms' patenting at USPTO. Specifically, I investigate how Canadian firms filed applications at USPTO through the direct and PCT channels. Panel A focuses on patenting firms, and Panel B focuses on innovating firms. In all the regressions, the coefficients of ISA and its interaction with $Domestic$ are insignificant, suggesting that Canadian firms did not change their patenting at USPTO after 2004. USPTO was not the ISA for Canadian applicants, so Canadian firms' patenting at USPTO should not be affected by CIPO's role as an ISA. This finding is consistent with the result (iv) of Proposition 1. In the data, only about 10% of all patent applications by Canadian firms at USPTO were filed through PCT. If a Canadian firm wanted to apply for patents at USPTO, it was more likely that this firm would file direct applications. This further explains why CIPO's role as an ISA was not associated with significant changes in Canadian firms' PCT applications for USPTO patents.

Insert **Table 3.9: CIPO's Role as an ISA and Canadian Firms' Patenting at USPTO**

3.6.3 CIPO's Roles as an ISA and Canadian FDI

In this subsection, I investigate if there were significant changes in Canadian firms' investment abroad after CIPO became an ISA. Regression results are reported in Table 3.10, where Panel A and B focuses on patenting and innovating firms, respectively. The dependent variables are *gross FDI* in the first three columns and *net FDI* in the last three columns.

Insert **Table 3.10: CIPO's Role as an ISA and Canadian Foreign Direct Investment**

After controlling for provincial and industrial specific trends, I do not find any significant changes in Canadian firms' FDI to the world and particularly to the U.S. and Europe after 2004. This finding is robust regardless of how FDI is measured (gross or net). Besides, this finding is also consistent for patenting and innovating firms. A firm's decision to invest in a foreign country may be related to its decision to patent there. However, the results suggest that Canadian firms may not consider patenting as the most important factor when they make decisions to explore business opportunities abroad. Firms' decision to do business in a foreign country may involve several factors, and patenting is only one of them.

Exploring foreign business opportunities can also be done through exports. Statistics Canada has data on Canadian firms' exports. Due to the confidentiality issue, results related to exports cannot be released. However, when I replaced FDI with exports and repeated the analysis, all these results remain insignificant. This confirms that Canadian firms' business activities abroad are not responsive to CIPO's role as an ISA.

3.7 Sensitivity Tests and Robustness Checks

A key finding in this paper is that CIPO's role as an ISA is associated with an increase in patenting at CIPO. In section 3.6.1, I have investigated the validity of the DID approach. However, in addition to the common trend assumption, the analyses are subject to other concerns. In this section, I consider three key concerns.

The first concern is that a patent application at CIPO is not examined until its applicant submits a request for examination. To account for this difference, in the previous analysis in Tables 5 and 6, I have considered the patents granted to Canadian firms at CIPO by 2014 and to U.S. firms at USPTO by 2011. As a robustness check, in columns (1) and (3) of Table 3.11, I consider the patents granted to Canadian firms at CIPO by 2013 and to U.S. firms at USPTO by 2011. I also construct another sample where I consider the patents granted to Canadian firms at CIPO by 2014 and to U.S. firms at USPTO by 2012. In all the regressions, CIPO's role as an ISA was associated with an increase in Canadian firms' patenting at CIPO.

Insert **Table 3.11: Robustness Check: Different Granting Years at CIPO and USPTO**

The second concern for the results in Table 3.6 is that the average size of U.S. firms in Compustat is larger than Canadian firms in NALMF. To investigate if this affects the results, Table 3.12 provides a robustness check by dropping small Canadian firms and leaving the sample of U.S. firms unchanged. Again, I consider both patenting and innovating firms. The bottom 10% of Canadian firms are dropped from the sample in columns (1) and (4), the bottom 25% in columns (2) and (5), and the bottom 50% in columns (3) and (6). Table 3.12 shows that the coefficients of the interaction terms are significantly positive, suggesting that the inclusion of small Canadian firms will not affect the key findings in Table 3.6.

Insert **Table 3.12: Robustness Check: The Size of Canadian Firms**

The third concern is that the effects of firm-level variables may be delayed. For example, after a firm has invested in R&D, it may take a few years before generating an innovation. As a robustness check to the estimations of equation (3.18), I consider using lagged firm-level variables as regressors. Table 3.13 reports the results based on lagged firm-level characteristics as regressors. As my study covers four years before and after 2004, I consider one and two years lag. Results in Table 3.13 further confirm that in contrast to U.S. firms' patenting at USPTO, there was a significant increase in Canadian firms' patenting at CIPO. Note that the magnitudes of coefficients of the interaction term $ISA \times CAN$ are larger in Table 3.13 than in Table 3.6. This suggests that the effect of CIPO's role as an ISA is larger on firms that have been operating continuously.

Insert **Table 3.13: Robustness Check: Lagged Firm Characteristics as Regressors**

3.8 Additional Analysis on Individual Patents

The previous discussions have focused on firm-level analysis. In this subsection, I investigate the effects of CIPO's role as an ISA on individual patents. In particular, I am wondering whether PCT applications have a higher chance of getting granted patents at CIPO; if so, whether this chance was enhanced when CIPO became an ISA. Also, I investigate if an application filed by a domestic firm was more likely to be granted a patent at CIPO. I estimate the following Logit model

$$\textit{Pr(Granted=1)} = F(\eta_1 PCT + \eta_2 ISA + \eta_3 ISA \times PCT + \eta_4 Domestic + \eta_0 + \sigma Y), \quad (3.21)$$

where $F(z) = \frac{1}{1+e^{-z}}$ is the cumulative logistic distribution; $Granted$ is a dummy variable that takes the value 1 if an application was granted a patent by 2014; PCT is a dummy variable that takes the value 1 if an application was filed through PCT; Y controls for firm characteristics including $R\&D$, $Size$, HHI, Age, and province and industry fixed effects. CIPO data have information on whether a patent application was filed by multiple applicants. I create a dummy variable *Joint Invention*, indicating whether a patent belongs to more than one firm to capture the effect of joint ownership. Other variables are defined as in the previous sections.

In addition, I investigate if individual patent applications were more likely to be filed through PCT after CIPO started its role as an ISA after 2004. The following Logit model is estimated,

$$Pr(PCT = 1) = F(\zeta_1 Domestic + \zeta_2 ISA + \zeta_3 ISA \times Domestic + \zeta_0 + \sigma Y), \tag{3.22}$$

where again $F(z) = \frac{1}{1+e^{-z}}$ is the cumulative logistic distribution. The coefficients of interest are ζ_2 and ζ_3. If firm-level analysis is consistent with patent-level analysis, ζ_2 will be significantly positive and ζ_3 will be significantly negative.

Table 3.14 presents the Logit regression results. The first two columns consider patent applications at CIPO that were filed during the period 2000-2008. In column 1, all patent applications are considered. In column 2, I exclude patent applications that have not been examined by 2014. The average gap between the date of filing an application and the date of receiving the granting decision in the data was roughly 5.3 years. It would be likely that for applications in late years, the granting decisions have not been made yet. As a result, the likelihood of being granted a patent for an application submitted later is underestimated.

Insert **Table 3.14: Impact of CIPO's Role as an ISA on Individual Patents**

The results in the first two columns are consistent. A few points are worth noticing. First, the coefficient of ISA is significantly negative, which, to a large extent, reflects the fact that many late applications have not yet received their granting decisions. Second, the coefficient of PCT is strongly positive, suggesting that PCT applications were more likely to be granted patents than direct applications. Third, domestic firms were more likely to be granted patents. Finally, the interaction of ISA and PCT is significantly negative, suggesting that a PCT application was less likely to be granted a patent when CIPO became an ISA. Since more patents were expected to be granted in late years, current results underestimate the effect of CIPO's role as an ISA on the probability that a PCT application is granted. This will be an interesting issue to investigate in the future when more data become available.

In column (3) of Table 3.14, I investigate if PCT applications were more likely to be filed at CIPO when CIPO became an ISA. The coefficient of ISA is significantly positive, suggesting an evident increase in PCT filing at CIPO after 2004. In addition, the coefficient of the interaction term $ISA \times Domestic$ is significantly negative. This is consistent with the previous finding that foreign-owned firms were more likely to apply for patents at CIPO when CIPO became an ISA.

3.9 Conclusion

This paper sheds light on the effects of CIPO's role as an ISA on Canadian firms' patenting and business activities. I first develop a two-stage model of filing patent applications internationally. While a firm can file patent applications in individual patent offices directly, it can also submit its patent applications through PCT, which goes through the international phase first and then head to the national phase. The model predicts that PCT can increase the propensity of the firm to apply for a patent at the home country and that the extent of such an increase is enhanced when the domestic patent office is the ISA. Whether the domestic patent office's role as an ISA affects the firm's patenting abroad in a foreign patent office depends on whether it is the ISA when the domestic patent office is not. This finding also implies that Canadian firms favor CIPO as the ISA for their PCT applications over EPO.

Empirical results suggest that CIPO's role as an ISA was associated with an increase in patent applications at CIPO by Canadian firms. In particular, after CIPO became an ISA, foreign-owned firms filed more patent applications at CIPO than domestic firms. As well, national phase applications at EPO by Canadian firms, especially foreign-owned firms, increased after filing international phase PCT applications at CIPO. These findings thus suggest that CIPO's role as an ISA has attracted foreign innovators to patent in Canada. However, I do not find evidence that CIPO's role as an ISA was related to significant changes in domestic firms' patenting and investing in the U.S. and Europe. This might suggest that CIPO's role as an ISA has not encouraged domestic firms to patent and invest abroad.

These findings should help CIPO or Canadian IP policymakers to assess and evaluate the effects of CIPO's role as an ISA on Canadian firms' patenting behavior. This study also contributes to the general understanding of how a patent office's involvement in international cooperation may affect the patenting and innovating behavior of domestic firms. Becoming an ISA requires a patent office to train staff and form a new examining team, which is costly. As a result, understanding the impact of becoming an ISA can also provide some insights on whether a non-ISA patent office should become one. The findings suggest that when a patent office becomes an ISA, it may attract more patent applications from foreign-owned firms. If this is the policy objective, the patent office may consider becoming an ISA.

To conclude, I note a few directions for future research. First, a more in-depth analysis of whether a patent office should become an ISA should be conducted. In this paper, the granting process within a patent office is assumed to be mechanical. However, it would be insightful to endogenize the decision process within patent offices. Future studies could focus on how examiners determine their efforts to process applications in different cases and on how patent offices make decisions on whether or not to become an ISA.

Second, in my model, I have assumed that a patent office is more likely to grant a patent to a PCT application than to a direct application without clear supporting evidence. In the additional analysis of individual patents, my finding confirms that a PCT application is more likely to be granted a patent than a direct application by CIPO. However, it is not clear why patent offices behave in this way. Future research may focus on both theoretical and empirical models.

Third, I have attempted to investigate if a PCT application is more likely to be granted a patent by the domestic patent office when it becomes an ISA. However, due to data limitations, I cannot give a conclusive answer to this issue. It would be insightful to carry out such an investigation with data for a more extended period.

Fourth, in Table 3.8, I investigate the destination of PCT applications in the international phase at CIPO. I consider three destinations: CIPO, EPO, and USPTO. Only a fraction of PCT applications have finally gone to these three patent offices. It would be interesting to investigate why some PCT applications have not finally gone to any of these patent offices.

Finally, I do not explore the effect of CIPO's role as an ISA on the quality of patents. However, the quality of patents has caught a lot of attention in the literature. It would be interesting to investigate both theoretically and empirically how the quality of patents will change when the domestic patent office become an ISA.

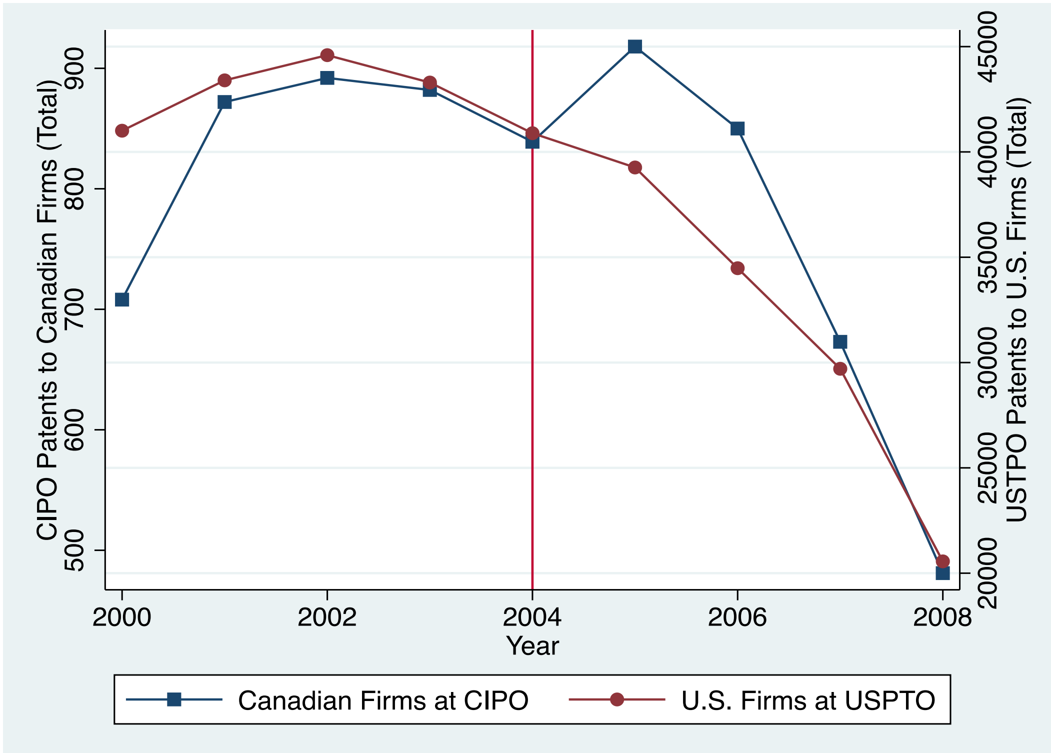


Figure 3.5: Total Patent Applications (eventually granted) by Canadian and U.S. Firms

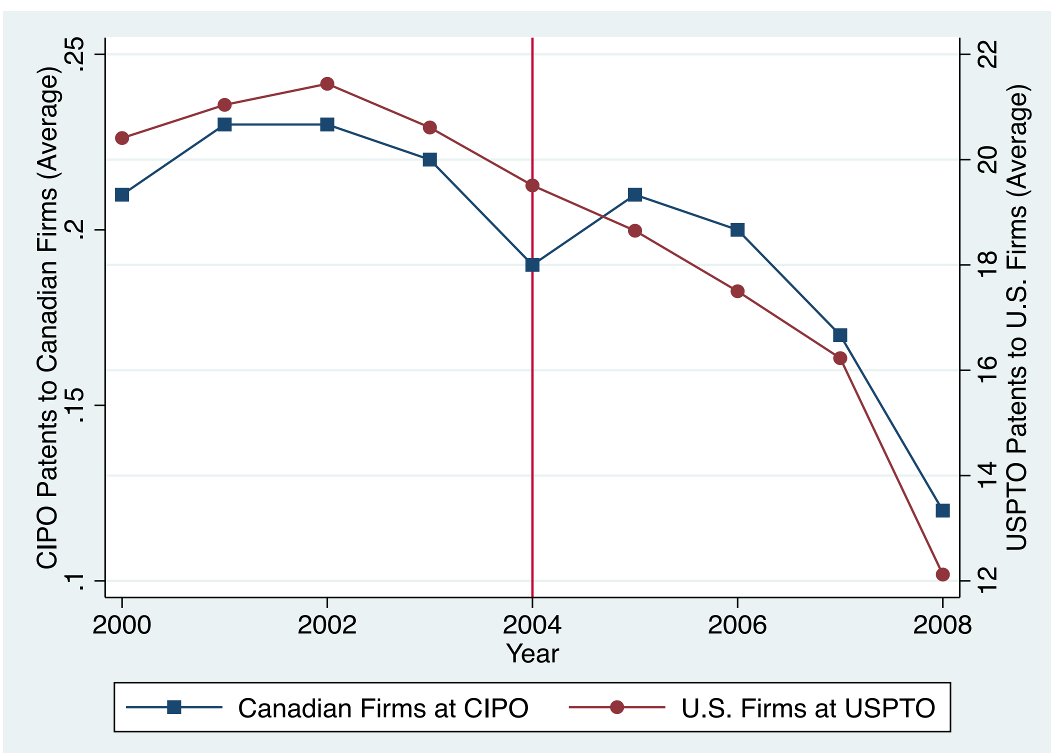


Figure 3.6: Average Patent Applications (eventually granted) by Canadian and U.S. Firms

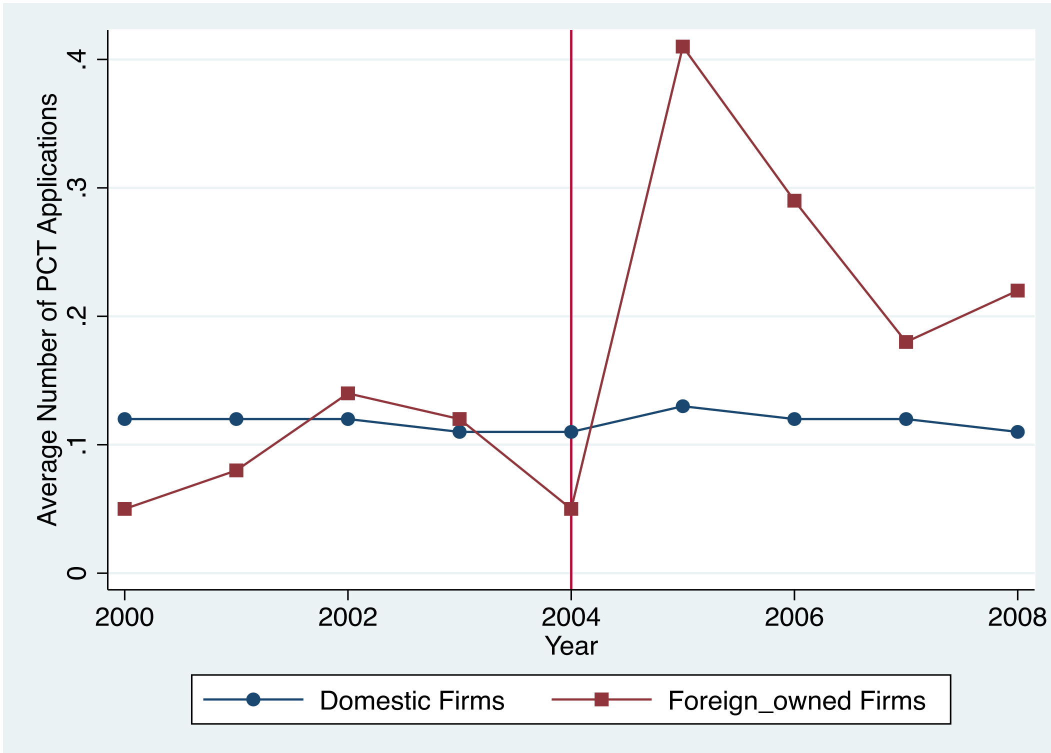


Figure 3.7: The Number of PCT Applications per Firm by Domestic and Foreign-owned Firms

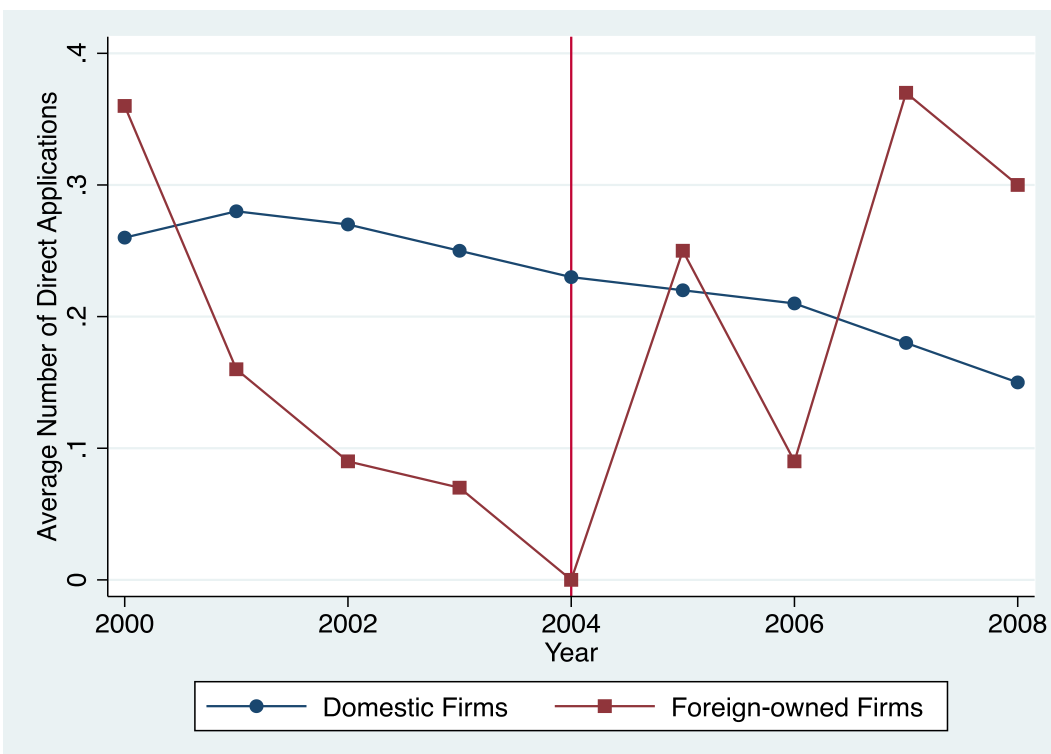


Figure 3.8: The Number of Direct Applications per Firm by Domestic and Foreign-owned Firms

Table 3.1: Parameters and Brief Description

Parameters	Description
θ	Probability that the firm's innovation is good
$\tilde{\theta}$	Bayesian updated probability after receiving a positive ISA report
G	Benefit from a patented good innovation
g	Benefit from a good innovation that is not patented
λ_{direct}	Probability that a bad innovation is granted a patent through the direct application channel
λ_{ISA}	Probability that a bad innovation receives a positive ISA report
$\lambda_{PCT,1}$	Probability that a bad innovation is granted a patent through the PCT channel if examiners in the international and national phases are from different patent offices
$\lambda_{PCT,2}$	Probability that a bad innovation is granted a patent through the PCT channel if examiners in the international and national phases are from the same patent office
C_{Ntl}	Application fees at the national patent office
C_F	Fixed costs of exploring business opportunities in a foreign country
C_{ISA}	ISA search and examination costs
ω	Value of holding a patent, "patent premium"
θ^h_{np}	Solution to $\pi^h_{direct} = \pi^h_{np}$
$\theta^h_{PCT,k}$	Solution to $\pi^h_{PCT,k} = \pi^h_{np}$, $k = 1, 2$
$\theta^h_{direct,k}$	Solution to $\pi^h_{direct,k} = \pi^h_{PCT,k}$, $k = 1, 2$
θ_{np}	Solution to $\pi_{direct} = \pi_{np}$
$\theta_{PCT,k}$	Solution to $\pi_{PCT,k} = \pi_{np}$, $k = 1, 2$
$\theta_{direct,k}$	Solution to $\pi_{direct,k} = \pi_{PCT,k}$, $k = 1, 2$

Table 3.2: Definition of Variables

Variables	Definition	Data Sources
Pat_{isct}	The logarithm of the number of patent applications that were eventually granted in country c to firm i in industry s of country c in year t	CIPO, Dorn et al. (2019)
$Activity_{ispt}$	A set of outcome variables for firm i in industry s of province p in year t	CIPO, USPTO, CDIA
ISA_t	A dummy variable that takes the value 1 for the period 2005-2008	Compustat, NALMF
CAN_{isct}	A dummy variable that takes the value 1 for Canadian firms in NALMF	Compustat, NALMF
$Pseudo\_ISA_t$	a dummy variable and takes the value 1 for the years 2003-2004; or alternatively for the years 2002-2004	Compustat, NALMF
$Domestic_{ispt}$	Dummy variable that indicates if firm i is domestic	NALMF
$Total_{CIPO}$	The logarithm of the number of total patent applications at CIPO	CIPO
PCT_{CIPO}	The logarithm of the number of PCT patent applications at CIPO	CIPO
$Direct_{CIPO}$	The logarithm of the number of direct patent applications at CIPO	CIPO
EPO_{PCT}	The logarithm of the number of PCT applications in the international phase at CIPO in a year that eventually go to EPO	CIPO
$USPTO_{PCT}$	The logarithm of the number of PCT applications in the international phase at CIPO in a year that eventually go to USPTO	CIPO
$CIPO_{PCT}$	The logarithm of the number of PCT applications in the international phase at CIPO in a year that eventually go to CIPO	CIPO
$Total_{USPTO}$	The logarithm of the number of total patent applications at USPTO	USPTO
PCT_{USPTO}	The logarithm of the number of PCT patent applications at USPTO	USPTO
$Direct_{USPTO}$	The logarithm of the number of direct patent applications at USPTO	USPTO
ISA	A dummy variable that takes the value 1 for the period 2005-2008	NALMF
$Size$	The logarithm of total assets	Compustat, NALMF
Age	The logarithm of the number of years since the firm was established	NALMF
$Experience$	The number of patents in the past 5 years	CIPO, USPTO, Dorn et al. (2019)
$R\&D$	The logarithm of R&D expenditure	Compustat, NALMF
HHI	Herfindahl-Hirschman Index: sum of squared market share of each firm in the same industry	Compustat, NALMF
Joint Invention	A dummy variable that takes the value 1 if a patent belongs to more than one firm	CIPO

Table 3.3: Characteristics of Different Types of Firms

	Panel A: Innovating Firms		Panel B: Patenting Firms					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Patenting	Non-patenting	Domestic	Foreign_owned	FDI	Non-FDI	Canada	U.S.
Age	1.94	2.07	1.93	2.45	2.50	1.90	-	-
	(0.83)	(0.79)	(0.83)	(0.67)	(0.62)	(0.83)	-	-
R&D	6.70	5.64	6.67	8.37	10.96	6.42	6.52	11.60
	(6.35)	(5.61)	(6.33)	(6.98)	(6.67)	(6.22)	(6.33)	(7.47)
HHI	0.06	0.04	0.06	0.08	0.10	0.05	0.06	0.16
	(0.10)	(0.08)	(0.10)	(0.12)	(0.12)	(0.09)	(0.10)	(0.15)
Size	14.43	13.65	14.37	17.09	19.31	14.11	14.24	19.69
	(3.04)	(2.29)	(3.01)	(3.07)	(2.42)	(2.79)	(3.20)	(1.93)
Domestic	0.98	0.99	-	-	0.89	0.98	-	-
	(0.14)	(0.11)	-	-	(0.32)	(0.12)	-	-
Experience	-	-	1.07	1.10	1.23	1.06	1.09	7.43
	-	-	(1.23)	(1.27)	(1.37)	(1.21)	(1.50)	(3.80)
Observations	34,373	273,547	33,644	729	2,135	32,238	35,912	17,950

The table presents the means and standard deviations (in parentheses) of firm-level variables. "Patenting" firms are those that have at least one patent during the study period, 2000-2008. "Non-Patenting" firms include firms that have invested in R&D but have no patents in the study period, 2000-2008. "FDI" and "Non-FDI" firms are those that have invested abroad and those that have not during the study period, 2000-2008. "Canada" and "U.S." refer to Canadian and U.S. firms.

Table 3.4: Patenting Statistics at CIPO by Domestic and Foreign-owned Firms

	Domestic	Foreign-owned
	Patenting at CIPO	
Total Applications	0.3443	0.4815
	(1.0795)	(1.4973)
PCT Applications	0.1191	0.1962
	(0.5295)	(0.7440)
Direct Applications	0.2154	0.2442
	(0.7537)	(0.9292)
	Patenting through PCT at CIPO	
National Phase at EPO	0.0889	0.1564
	(0.4370)	(0.6248)
National Phase at USPTO	0.0689	0.1084
	(0.3462)	(0.4576
National Phase at CIPO	0.0909	0.1605
	(0.4302)	(0.6270)
	Patenting at USPTO	
Total Applications	0.2566	0.2126
	(3.6931)	(1.1082)
PCT Applications	0.0264	0.0206
	(0.2727)	(0.2053)
Direct Applications	0.2302	0.1920
	(3.5612)	(1.0358)
Observations	33,644	729

This table reports the means and standard deviations (in parentheses) of patent applications of different categories by domestic and foreign-owned firms. The first three rows show the average number of total, PCT, and direct applications at CIPO. The next three rows show the average number of PCT applications at CIPO that ultimately go to EPO, USPTO, and CIPO. The last three rows show the average number of total, PCT, and direct applications at USPTO.

Table 3.5: Patenting Patterns in the Pre-treatment Period, 2000-2004

	CIPO Started its ISA Service in 2002		CIPO Started its ISA Service in 2003	
	(1)	(2)	(3)	(4)
Independent Variables	Patenting Firms	Innovating Firms	Patenting Firms	Innovating Firms
Pseudo_ISA	-0.0435	-0.0366	-0.0433	-0.0374
	(0.0329)	(0.0354)	(0.0421)	(0.0426)
CAN	-2.0856***	-1.8176***	-2.0884***	-1.8212***
	(0.4592)	(0.5624)	(0.4589)	(0.5627)
$Pseudo\_ISA \times CAN$	0.0640	0.0389	0.0542	0.0366
	(0.0418)	(0.0354)	(0.0391)	(0.0425)
R&D	0.0084***	0.0011***	0.0084***	0.0011***
	(0.0025)	(0.0004)	(0.0026)	(0.0004)
HHI	1.1884*	0.3851	1.1628	0.3781
	(0.6821)	(0.2473)	(0.7061)	(0.2524)
Size	0.0459***	0.0090***	0.0464***	0.0090***
	(0.0106)	(0.0014)	(0.0107)	(0.0014)
Experience	0.0644	0.1899***	0.0639	0.1895***
	(0.0430)	(0.0458)	(0.0422)	(0.0453)
Constant	3.7477***	3.2475***	3.7427***	3.2494***
	(0.2587)	(0.2333)	(0.2604)	(0.2327)
Observations	29,804	40,674	29,804	40,674
No of firms	6,512	183,846	6,512	183,846
R-squared	0.9864	0.9932	0.9864	0.9933

This table presents the estimation results of equation (3.19). The dependent variables are Pat_{isct}, which refers to the logarithm of the number of patent applications that are granted to U.S. firms by 2011 at USPTO and to Canadian firms by 2014 at CIPO. *Patenting Firms* refer to firms that have at least one patent during the period 2000-2008; and *Innovating Firms* refer to firms that either have at least one patent or have invested in R&D during 2000-2008. The first two columns report the estimation results assuming that CIPO started its ISA service in 2002 and in the last two columns, I repeat the analysis by assuming that CIPO started its ISA service in 2003. All regressions include country, industry, and firm fixed effects, as well as country and industry specific trends. Standard errors are clustered by industry. *** denotes 1%, ** 5%, and * 10% significance, respectively.

Table 3.6: CIPO's Role as an ISA and Canadian Firms' Patenting at CIPO

Independent Variables	(1) Panel A: Patenting Firms	(2) Panel B: Innovating Firms
ISA	-0.0399**	-0.0274*
	(0.0168)	(0.0151)
CAN	-0.6631**	-0.3908***
	(0.2564)	(0.1379)
$ISA \times CAN$	0.0356**	0.0271*
	(0.0164)	(0.0149)
R&D	0.0032***	0.0004***
	(0.0006)	(0.0001)
HHI	-0.0107	0.0125
	(0.0430)	(0.0107)
Size	0.0080***	0.0020***
	(0.0014)	(0.0003)
Experience	0.1332***	0.2012***
	(0.0136)	(0.0203)
Constant	0.6841***	0.3940***
	(0.1657)	(0.1295)
Observations	53,862	337,321
Number of Firms	6,550	40,814
R-squared	0.8919	0.9000

This table presents the estimation results of equation (3.18). The dependent variables are Pat_{isct}, which refers to the logarithm of the number of patent applications (both direct and PCT applications in the international phase) that are eventually granted to U.S. firms by 2011 at USPTO and to Canadian firms by 2014 at CIPO. *Patenting Firms* refer to firms that have at least one patent during the period 2000-2008; and *Innovating Firms* refer to firms that either have at least one patent or have invested in R&D during 2000-2008.All regressions include country, industry, and firm fixed effects, as well as country and industry specific trends. Standard errors are clustered by industry. *** denotes 1%, ** 5%, and * 10% significance, respectively.

Table 3.7: CIPO's Role as an ISA and International Patenting at CIPO

	Panel A: Patenting Firms			Panel B: Innovating Firms		
	(1)	(2)	(3)	(4)	(5)	(6)
Independent Variables	$Total_{CIPO}$	PCT_{CIPO}	$Direct_{CIPO}$	$Total_{CIPO}$	PCT_{CIPO}	$Direct_{CIPO}$
$ISA \times Domestic$	-0.2037***	-0.1162*	-0.0942**	-0.0363***	-0.0192	-0.0185**
	(0.0550)	(0.0646)	(0.0460)	(0.0117)	(0.0122)	(0.0076)
ISA	0.2113***	0.1250*	0.0916**	0.0371***	0.0202*	0.0182**
	(0.0564)	(0.0644)	(0.0460)	(0.0119)	(0.0122)	(0.0077)
Domestic	0.0336	-0.0028	0.0466	0.0075	-0.0007	0.0102
	(0.0514)	(0.0449)	(0.0393)	(0.0080)	(0.0069)	(0.0065)
R&D	0.0064***	0.0025***	0.0041***	0.0005***	0.0002***	0.0004***
	(0.0005)	(0.0004)	(0.0007)	(0.0001)	(0.0000)	(0.0000)
Experience	1.1699***	0.4885***	0.7330***	1.1824***	0.4952***	0.7396***
	(0.0199)	(0.0795)	(0.0719)	(0.0203)	(0.0800)	(0.0722)
Size	0.0086***	0.0051***	0.0043***	0.0012***	0.0008***	0.0006***
	(0.0013)	(0.0010)	(0.0011)	(0.0002)	(0.0002)	(0.0001)
HHI	-0.0066	-0.0033	0.0048	0.0018	0.0002	0.0034
	(0.0257)	(0.0199)	(0.0253)	(0.0055)	(0.0038)	(0.0047)
Age	-0.0217***	0.0011	-0.0216***	-0.0034***	0.0001	-0.0033***
	(0.0050)	(0.0039)	(0.0044)	(0.0007)	(0.0005)	(0.0006)
Constant	-0.1618**	-0.0754*	-0.1196*	-0.0288**	-0.0121*	-0.0222*
	(0.0785)	(0.0442)	(0.0722)	(0.0123)	(0.0064)	(0.0122)
Observations	34,373	34,373	34,373	307,920	307,920	307,920
Number of Firms	4425	4425	4425	38351	38351	38351
R-squared	0.6449	0.5969	0.5350	0.6860	0.6149	0.5722

This table presents the estimation results of equation (3.20). The dependent variables are $Activity_{ispt}$, which refers to patent applications of Canadian firms at CIPO regardless of whether applications are granted or not. Specifically, in columns (1) and (4), $Activity_{ispt}$ refers to the logarithm of the number of total patent applications at CIPO, $Total_{CIPO}$. In columns (2) and (5), $Activity_{ispt}$ refers to the logarithm of the number of PCT applications in the international phase at CIPO, PCT_{CIPO}. In columns (3) and (6), $Activity_{ispt}$ refers to the logarithm of the number of direct applications at CIPO (not include PCT applications at the national phase), $Direct_{CIPO}$. Panel A focuses on *Patenting Firms*, that have at least one patent during the period 2000-2008; Panel B focuses on *Innovating Firms*, that either have at least one patent or have invested in R&D during 2000-2008. All regressions include province, industry, and firm fixed effects, as well as province and industry specific trends. Standard errors are clustered by industry. *** denotes 1%, ** 5%, and * 10% significance, respectively.

Table 3.8: International Patenting after Filing a PCT Application at CIPO

	Panel A: Patenting Firms			Panel A: Innovating Firms		
	(1)	(2)	(3)	(4)	(5)	(6)
Independent Variables	$USPTO_{PCT}$	EPO_{PCT}	$CIPOO_{PCT}$	$USPTO_{PCT}$	EPO_{PCT}	$CIPOO_{PCT}$
$ISA \times Domestic$	-0.0508	-0.1148*	-0.0623	-0.0085	-0.0192*	-0.0108
	(0.0473)	(0.0612)	(0.0465)	(0.0079)	(0.0113)	(0.0081)
ISA	0.0549	0.1271**	0.0694	0.0089	0.0206*	0.0116
	(0.0467)	(0.0621)	(0.0462)	(0.0079)	(0.0115)	(0.0081)
Domestic	-0.0024	-0.0172	-0.0332	-0.0005	-0.0029	-0.0051
	(0.0324)	(0.0415)	(0.0390)	(0.0052)	(0.0063)	(0.0058)
R&D	0.0018***	0.0020***	0.0018***	0.0001***	0.0001***	0.0001***
	(0.0004)	(0.0003)	(0.0003)	(0.0000)	(0.0000)	(0.0000)
Experience	0.3293***	0.3686***	0.3782***	0.3348***	0.3737***	0.3830***
	(0.0685)	(0.0736)	(0.0532)	(0.0691)	(0.0740)	(0.0532)
Size	0.0034***	0.0042***	0.0037***	0.0005***	0.0006***	0.0005***
	(0.0007)	(0.0011)	(0.0008)	(0.0001)	(0.0002)	(0.0001)
HHI	0.0134	-0.0087	0.0110	0.0021	-0.0009	0.0029
	(0.0244)	(0.0171)	(0.0243)	(0.0044)	(0.0031)	(0.0050)
Age	-0.0017	0.0032	0.0021	-0.0002	0.0003	0.0002
	(0.0031)	(0.0031)	(0.0037)	(0.0004)	(0.0004)	(0.0005)
Constant	-0.0723**	-0.0254	-0.0240	-0.0105*	-0.0054	-0.0051
	(0.0340)	(0.0408)	(0.0419)	(0.0055)	(0.0059)	(0.0056)
Observations	34,373	34,373	34,373	307,920	307,920	307,920
Number of Firms	4425	4425	4425	38351	38351	38351
R-squared	0.5572	0.5849	0.5809	0.5702	0.5987	0.5962

This table presents the estimation results of equation (3.20). The dependent variables are $Activity_{ispt}$, which refers to the number of patent applications of Canadian firms at individual patent offices after filing a PCT application at CIPO. Specifically, in columns (1) and (4), $Activity_{ispt}$ refers to the logarithm of the number of PCT applications in the international phase at CIPO in a year that eventually go to USPTO ($USPTO_{PCT}$). In columns (2) and (5), $Activity_{ispt}$ refers to the logarithm of the number of PCT applications at CIPO that finally go to EPO (EPO_{PCT}). In columns (3) and (6), $Activity_{ispt}$ refers to the logarithm of the number of PCT applications at CIPO that finally go to CIPO ($CIPO_{PCT}$). Panel A focuses on *Patenting Firms*, that have at least one patent during the period 2000-2008; Panel B focuses on *Innovating Firms*, that either have at least one patent or have invested in R&D during 2000-2008. All regressions include province, industry, and firm fixed effects, as well as province and industry specific trends. Standard errors are clustered by industry. *** denotes 1%, ** 5%, and * 10% significance, respectively.

Table 3.9: CIPO's Role as an ISA and Canadian Firms' Patenting at USPTO

	Panel A: Patenting Firms			Panel A: Innovaing Firms		
	(1)	(2)	(3)	(4)	(5)	(6)
Independent Variables	$Total_{USPTO}$	PCT_{USPTO}	$Direct_{USPTO}$	$Total_{USPTO}$	PCT_{USPTO}	$Direct_{USPTO}$
$ISA \times Domestic$	0.0341	-0.0028	0.0185	0.0038	-0.0006	0.0014
	(0.0650)	(0.0223)	(0.0511)	(0.0102)	(0.0035)	(0.0081)
ISA	-0.0396	0.0008	-0.0233	-0.0045	0.0004	-0.0021
	(0.0657)	(0.0219)	(0.0514)	(0.0104)	(0.0034)	(0.0082)
Domestic	0.0375	0.0136	0.0254	0.0081	0.0022	0.0062
	(0.0374)	(0.0093)	(0.0368)	(0.0054)	(0.0016)	(0.0053)
R&D	0.0037***	0.0006***	0.0031***	0.0004***	0.0001***	0.0003***
	(0.0004)	(0.0002)	(0.0004)	(0.0001)	(0.0000)	(0.0001)
Experience	0.2148***	0.0326***	0.1918***	0.2200***	0.0333***	0.1965***
	(0.0160)	(0.0076)	(0.0172)	(0.0160)	(0.0077)	(0.0169)
Size	0.0022*	-0.0001	0.0022**	0.0002	-0.0000	0.0002
	(0.0012)	(0.0004)	(0.0010)	(0.0002)	(0.0001)	(0.0002)
HHI	0.0647*	0.0129	0.0603**	0.0168	0.0035	0.0152*
	(0.0337)	(0.0153)	(0.0294)	(0.0105)	(0.0042)	(0.0079)
Age	0.0036	0.0031	0.0025	-0.0002	0.0003	-0.0002
	(0.0051)	(0.0023)	(0.0044)	(0.0006)	(0.0003)	(0.0005)
Constant	0.0332	-0.0009	0.0336	-0.0031	-0.0012	-0.0023
	(0.0474)	(0.0136)	(0.0446)	(0.0066)	(0.0020)	(0.0062)
Observations	34,373	34,373	34,373	307,920	307,920	307,920
Number of Firms	4425	4425	4425	38351	38351	38351
R-squared	0.5204	0.3996	0.5116	0.5506	0.4047	0.5395

This table presents estimation results of equation (3.20). The dependent variables are $Activity_{ispt}$, which refers to granted patent applications of Canadian firms at USPTO by 2011. Specifically, in columns (1) and (4), $Activity_{ispt}$ refers to the logarithm of the number of total patent applications at USPTO, $Total_{USPTO}$. In columns (2) and (5), $Activity_{ispt}$ refers to the logarithm of the number of PCT applications at USPTO, PCT_{USPTO}. In columns (3) and (6), $Activity_{ispt}$ refers to the logarithm of the number of direct applications at USPTO (not include PCT applications at the national phase), $Direct_{USPTO}$. Panel A focuses on *Patenting Firms*, that have at least one patent during the period 2000-2008; Panel B focuses on *Innovating Firms*, that either have at least one patent or have invested in R&D during 2000-2008. All regressions include province, industry, and firm fixed effects, as well as province and industry specific trends. Standard errors are clustered by industry. *** denotes 1%, ** 5%, and * 10% significance, respectively.

Table 3.10: CIPO's Role as an ISA and Canadian Foreign Direct Investment

	Gross FDI			Net FDI		
	(1)	(2)	(3)	(4)	(5)	(6)
Independent Variables	World	Europe	USA	World	Europe	USA
	Panel A: Patenting Firms					
$ISA \times Domestic$	-6.7996	-3.9398	2.8175	-7.8881	-3.7841	3.6221
	(9.7706)	(2.7122)	(7.9139)	(9.3121)	(2.6637)	(7.8342)
ISA	5.4557	3.8006	-3.1419	6.8402	3.6474	-3.5495
	(10.0852)	(2.5674)	(8.1532)	(9.5979)	(2.5101)	(8.0231)
Domestic	5.7761	0.7867	4.1151	5.7997	0.8330	3.5346
	(12.1503)	(3.6335)	(7.0729)	(11.4406)	(3.6114)	(6.8375)
Observations	34,373	34,373	34,373	34,373	34,373	34,373
Number of Firms	4425	4425	4425	4425	4425	4425
R-squared	0.9014	0.8588	0.8806	0.8943	0.8584	0.8565
	Panel B: Innovating Firms					
$ISA \times Domestic$	-2.4132	-0.3405	-1.1610	-2.4812	-0.3185	-1.1128
	(2.8063)	(0.8474)	(1.5961)	(2.7822)	(0.8445)	(1.6153)
ISA	2.0168	0.2488	1.0304	2.1873	0.2363	1.0288
	(2.7945)	(0.8491)	(1.6381)	(2.7833)	(0.8473)	(1.6563)
Domestic	-0.5360	0.0461	-0.0382	-0.5919	0.0071	-0.1656
	(4.4225)	(0.8008)	(2.4359)	(4.0977)	(0.7912)	(2.3771)
Observations	307,920	307,920	307,920	307,920	307,920	307,920
Number of Firms	38351	38351	38351	38351	38351	38351
R-squared	0.9111	0.8745	0.8665	0.8989	0.8723	0.8440

This table presents estimation results of equation (3.20). The dependent variables are $Activity_{ispt}$, which refers to FDI by Canadian firms. Specifically, In columns (1) through (3), $Activity_{ispt}$ refers to the gross FDI to the entire world, to Europe, and to the U.S. In columns (4) through (6), $Activity_{ispt}$ refers to the net FDI to the entire world, to Europe, and to the U.S. Panel A focuses on *Patenting Firms*, that have at least one patent during the period 2000-2008; Panel B focuses on *Innovating Firms*, that either have at least one patent or have invested in R&D during 2000-2008. All regressions include province, industry, and firm fixed effects, as well as province and industry specific trends. Standard errors are clustered by industry. *** denotes 1%, ** 5%, and * 10% significance, respectively.

Table 3.11: Robustness Check: Different Granting Years at CIPO and USPTO

	Panel A: Patenting Firms		Panel B: Innovating Firms	
Independent Variables	(1) CIPO by 2013 USPTO by 2011	(2) CIPO by 2014 USPTO by 2012	(3) CIPO by 2013 USPTO by 2011	(4) CIPO by 2014 USPTO by 2012
ISA	-0.0400**	-0.0470***	-0.0276*	-0.0336**
	(0.0168)	(0.0171)	(0.0151)	(0.0153)
CAN	-0.6684***	-0.6041**	-0.3940***	-0.3363**
	(0.2573)	(0.2589)	(0.1386)	(0.1382)
$ISA \times CAN$	0.0341**	0.0426**	0.0271*	0.0333**
	(0.0164)	(0.0168)	(0.0149)	(0.0151)
R&D	0.0032***	0.0032***	0.0004***	0.0004***
	(0.0006)	(0.0006)	(0.0001)	(0.0001)
HHI	-0.0088	-0.0120	0.0125	0.0123
	(0.0427)	(0.0422)	(0.0107)	(0.0105)
Size	0.0078***	0.0085***	0.0019***	0.0020***
	(0.0014)	(0.0015)	(0.0003)	(0.0003)
Experience	0.1310***	0.1384***	0.1978***	0.2069***
	(0.0134)	(0.0135)	(0.0200)	(0.0198)
Constant	0.6919***	0.6280***	0.3982***	0.3407***
	(0.1661)	(0.1675)	(0.1301)	(0.1296)
Observations	53,862	53,862	337,321	337,321
Number of Firms	6,550	6,550	40,814	40,814
R-squared	0.8922	0.8952	0.9002	0.9038

This table presents estimation results of equation (3.18) when different granting years at CIPO and USPTO are used to construct the dependent variables are Pat_{isct}. Panel A focuses on *Patenting Firms*, that have at least one patent during the period 2000-2008; Panel B focuses on *Innovating Firms*, that either have at least one patent or have invested in R&D during 2000-2008. Specifically, in columns (1) and (3), Pat_{isct} refers to patent applications that are eventually granted by 2011 at USPTO and by 2013 at CIPO; and in columns (2) and (4), Pat_{isct} refers to patent applications that are eventually granted by 2012 at USPTO and by 2014 at CIPO. All regressions include country, industry, and firm fixed effects, as well as country and industry specific trends. Standard errors are clustered by industry. *** denotes 1%, ** 5%, and * 10% significance, respectively.

Table 3.12: Robustness Check: The Size of Canadian Firms

	Panel A: Patenting Firms			Panel B: Innovating Firms		
	(1)	(2)	(3)	(4)	(5)	(6)
Independent Variables	10%	25%	50 %	10%	25%	50 %
ISA	-0.0421**	-0.0439***	-0.0467***	-0.0281*	-0.0292*	-0.0311**
	(0.0168)	(0.0167)	(0.0168)	(0.0151)	(0.0150)	(0.0151)
CAN	-0.6091**	-0.5936**	-0.5709**	-0.3835***	-0.3831***	-0.3898***
	(0.2503)	(0.2500)	(0.2476)	(0.1381)	(0.1400)	(0.1425)
$ISA \times CAN$	0.0377**	0.0426***	0.0498***	0.0277*	0.0290*	0.0316**
	(0.0163)	(0.0164)	(0.0166)	(0.0149)	(0.0149)	(0.0150)
R&D	0.0030***	0.0033***	0.0040***	0.0004***	0.0004***	0.0006***
	(0.0007)	(0.0008)	(0.0010)	(0.0001)	(0.0001)	(0.0001)
HHI	-0.0124	-0.0228	-0.0377	0.0084	0.0052	-0.0024
	(0.0450)	(0.0476)	(0.0589)	(0.0111)	(0.0124)	(0.0159)
Size	0.0260***	0.0348***	0.0509***	0.0057***	0.0083***	0.0131***
	(0.0046)	(0.0066)	(0.0100)	(0.0008)	(0.0011)	(0.0018)
Experience	0.1290***	0.1232***	0.1149***	0.1969***	0.1883***	0.1682***
	(0.0135)	(0.0135)	(0.0140)	(0.0200)	(0.0200)	(0.0200)
Constant	0.3691**	0.2169	-0.0751	0.3371***	0.3019**	0.2466**
	(0.1547)	(0.1522)	(0.1669)	(0.1288)	(0.1296)	(0.1228)
Observations	50,601	45,285	36,199	306,965	259,736	180,154
Number of Firms	6,393	5,931	4,962	39,710	35,695	26,781
R-squared	0.8919	0.8919	0.8912	0.9009	0.9021	0.9043

This table presents estimation results of equation (3.18) when the bottom percentiles of Canadian firms are dropped from the samples used in Table 3.6. The dependent variables are Pat_{isct}. Panel A focuses on *Patenting Firms*, that have at least one patent during the period 2000-2008; Panel B focuses on *Innovating Firms*, that either have at least one patent or have invested in R&D during 2000-2008. Specifically, in columns (1) and (4), the bottom 10% of Canadian firms are dropped; in columns (2) and (5), the bottom 25%; and in columns (3) and (6), the bottom 50%. All regressions include country, industry, and firm fixed effects, as well as country and industry specific trends. Standard errors are clustered by industry. *** denotes 1%, ** 5%, and * 10% significance, respectively.

Table 3.13: Robustness Check: Using Lagged Firm-level Variables

	Panel A: Patenting Firms		Panel B: Innovating Firms	
	(1)	(2)	(3)	(4)
Independent Variables	One year lagged	Two years lagged	One year lagged	Two years lagged
ISA	-0.1018***	-0.0696***	-0.1832***	-0.1690***
	(0.0193)	(0.0206)	(0.0138)	(0.0135)
CAN	-0.8730***	-1.0280**	-0.4470***	-0.4688**
	(0.3198)	(0.4488)	(0.1705)	(0.1920)
$ISA \times CAN$	0.1013***	0.0795***	0.1830***	0.1700***
	(0.0193)	(0.0207)	(0.0138)	(0.0134)
R&D	0.0037***	0.0016**	0.0004***	0.0003***
	(0.0007)	(0.0007)	(0.0001)	(0.0001)
HHI	0.0106	0.0278	0.0260**	0.0317***
	(0.0505)	(0.0467)	(0.0106)	(0.0098)
Size	0.0069***	0.0036***	0.0025***	0.0023***
	(0.0018)	(0.0013)	(0.0004)	(0.0004)
Experience	-0.0483***	-0.1001***	0.0614***	0.0258
	(0.0105)	(0.0121)	(0.0188)	(0.0219)
Constant	0.8575***	1.0404***	0.4296***	0.4491**
	(0.2121)	(0.3036)	(0.1602)	(0.1816)
Observations	47,157	40,573	296,037	255,149
Number of Firms	6,543	6,515	40,796	40,677
R-squared	0.8970	0.9063	0.9007	0.9076

This table presents estimation results of equation (3.18) when the firm-level control variables are lagged by one or two years. The dependent variables are Pat_{isct}. Panel A focuses on *Patenting Firms*, that have at least one patent during the period 2000-2008; Panel B focuses on *Innovating Firms*, that either have at least one patent or have invested in R&D during 2000-2008.All regressions include country, industry, and firm fixed effects, as well as country and industry specific trends. Standard errors are clustered by industry. *** denotes 1%, ** 5%, and * 10% significance, respectively.

Table 3.14: Impact of CIPO's Role as an ISA on Individual Patents

Independent Variables	Granted=1		PCT=1
	(1)	(2)	(3)
	All	Examined	All
PCT	0.5726***	0.2080***	
	(0.0454)	(0.0536)	
$ISA \times PCT$	-0.9417***	-0.8483***	
	(0.0635)	(0.0713)	
$ISA \times Domestic$			-0.9090**
			(0.3777)
ISA	-0.0879**	-0.4014***	1.1844***
	(0.0379)	(0.0450)	(0.3764)
Domestic	0.9011***	0.8553***	0.3525
	(0.0810)	(0.0857)	(0.3699)
R&D	-0.0127***	-0.0153***	0.0334***
	(0.0031)	(0.0037)	(0.0033)
Size	0.0656***	0.0390***	0.0532***
	(0.0062)	(0.0070)	(0.0063)
HHI	-1.0826***	-1.8401***	-0.2551*
	(0.1501)	(0.1766)	(0.1489)
Age	-0.0271	-0.0891***	-0.0453*
	(0.0227)	(0.0266)	(0.0234)
Joint Invention	0.2819**	0.3640***	-0.4629***
	(0.1134)	(0.1406)	(0.1320)
Constant	-2.4819***	-1.0629***	-2.2137***
	(0.1775)	(0.2019)	(0.4012)
Observations	20,469	15,163	20,469

This table presents Logit regression results based on data on individual patents. The dependent variable in columns (1) through (2) is a dummy variable $Granted$, which takes a value of 1 if an application is granted a patent at CIPO by 2014. The dependent variable in column (3) is a dummy variable PCT, which takes a value of 1 if an application is filed through PCT. In columns (1) and (3), I consider all patent applications and in column (3) I exclude patent applications that have not been examined by 2014.*** denotes 1%, ** 5%, and * 10% significance, respectively. All regressions include industry and province fixed effects.

CHAPTER 4

LOCATIONAL PATENTING: SEQUENTIAL AND SIMULTANEOUS APPLICATIONS

4.1 Introduction

When an innovation is discovered, an innovator can protect it by applying for patents. The innovator considers not only whether to apply for a patent in the home country, but also in foreign countries. According to World Intellectual Property Organization (WIPO) statistics, the number of applications for foreign patents doubled worldwide between 2000 and 2018. Understanding locational patenting decisions is important for policymakers aiming to attract foreign innovation worldwide (Eckert et al., 2019). However, the literature lacks both empirical and theoretical evidence on this issue. In this paper, I provide a theoretical framework to analyze innovators' decisions on where to apply for patents.

Patenting decisions have been associated with innovation quality (Hanel, 2005; Fernández-Ribas, 2010; Jaffe and Lerner, 2011), patent systems with application fees (Rassenfosse and van Pottelsberghe de la Potterie, 2012), and examination intensities (Picard and van Pottelsberghe de la Potterie, 2013; Gimeno-Fabra and van Pottelsberghe de la Potterie, 2017). In addition, an innovator's decision to patent in another country is associated with international business opportunities such investment opportunities (Bosworth, 1984; Yang and Kuo, 2008; Nikzad, 2012), trade flows (Dosi et al., 1990; Licht and Zoz, 2000; Yang and Kuo, 2008), and outsourcing opportunities (Leiblein and Madsen, 2009; Hu and Jefferson, 2009; Miguelez, 2016). Although these studies show what factors may affect an innovator's decision on where to patent, it is not clear how. The aim is to build up a theoretical framework that take into account these factors to better understand how locational patenting decisions are formed with a focus on the role of application sequence and information availability.

National laws define patent rights, so a domestic patent cannot protect the innovation in a foreign country. International patenting involves patenting decisions at several patent offices. When an innovator decides to patent internationally, he can either submit his applications to the selected countries simultaneously or start an application in one country and then decide whether to proceed to other countries upon receiving some feedback from the first filing office. In a simultaneous application system, an innovator considers his expected payoff of patenting at each patent office separately. As long as the expected payoff of applying at one office is non-negative, he will submit an application at that patent office. In contrast, when the innovator files an application at the first patent office in a sequential application system, he has to consider the impact of his conduct on subsequent applications and the impact of outcomes of subsequent applications on his current applications.

In the model, an innovator has an innovation, whose quality is uncertain. He has a prior belief about whether his innovation is patentable. Based on his belief, his expected patenting payoff is a function of innovation quality, application fees, examination intensity, and perceived quality of patents (which determines the patenting benefit). The innovator will apply for a patent only if his expected patenting payoff is non-negative. Meanwhile, the perceived quality of patents is the third parties' expected probability that a granted innovation is patentable. The results suggest that the innovator would patent in a country where the application fee is low, or the examination intensity is tough. Business opportunities embodied in the innovation is a key determinant of the innovator's decision to patent.

I show that under a simultaneous application system, an increase in application fees at one office reduces the number of applications received. In contrast, such increased fees also increase the quality of patents. Likewise, tougher examination at one office has an ambiguous impact on the number of applications at this office. On the one hand, a tough examination reduces the probability of being granted, discouraging some applicants. On the other hand, a tough examination increases the average quality of granted patents, encouraging some applicants to apply for patents. Besides, with a simultaneous application system, more innovators apply for patents in countries with greater business opportunities even though the patent quality is perceived lower.

In contrast, in a sequential application system, the application outcomes at the first-filing office allow an innovator to update the probability that his innovation is good.[1] This updating process rules out applicants with bad quality innovation to further apply at the second patent office. Moreover, in a sequential application system, applicants may avoid application costs at the second patent office when receiving application outcomes at the first filing patent office. When an applicant makes a patenting decision at the first patent office, he takes the potential outcomes from the second patent office into account. More applications will be filed at the first patent office.

My study is different from much of the existing theoretical contributions on international patenting behavior. Theories on patenting behavior in the literature mostly focus on interactions between innovators and competitors (Horstmann et al., 1985; Langinier, 2005; Hellmann, 2007; Bessen and Maskin, 2009), but no studies focus on application sequence. In addition, my model is intentionally designed to incorporate innovation quality, patent systems, and business opportunities in a unified framework to understand locational patenting decisions.

The rest of this paper is organized as follows. Section 4.2 reviews relevant studies in the literature. Section 4.3 presents the model framework. While Section 4.4 focuses on application sequence and information availability, Section 4.5 compares the simultaneous and sequential application systems. Section 4.6 concludes.

4.2 Related Literature

Seeking patent protection in several countries is expensive. Therefore, to patent internationally, innovators should consider a variety of factors. Although international treaties such as the Patent Cooperation Treaty (PCT) facilitate firms to apply for patents in multiple countries, how to determine the geographical coverage of patent protection remains an issue (Schmidt, 2013). This section reviews contributions to international patenting behavior and discusses how this paper is related to these studies.

Firms' decisions to patent are associated with several factors such as application fees (e.g.,

[1]Note that, in reality, the outcomes at the first patent office typically take a long time and will not be available before the patentee applies to other patent offices. In this model, I do not consider the time issue to simplify the model.

De Rassenfosse and Jaffe, 2018), the quality of innovations (Atal and Bar, 2014), and the examination toughness at the patent offices (Gimeno-Fabra and van Pottelsberghe de la Potterie, 2017). In particular, Rassenfosse and van Pottelsberghe de la Potterie (2012) find that the decrease in application fees at the European Patent Office (EPO) has contributed significantly to the increase in the propensity to patent. Innovations are different in their quality (Jaffe and Lerner, 2011) and innovation quality is an important consideration when firms make patenting decisions (e.g., Atal and Bar, 2014). Regarding examination intensity, Gimeno-Fabra and van Pottelsberghe de la Potterie (2017) suggest that the propensity to patent in the U.S. is higher than that in Europe because the examination at EPO is tougher than at the United States Patent and Trademark Office (USPTO).

In addition to studies on patenting decisions, my study is particularly related to the literature of locational patenting. The decision on where to patent an invention is largely determined by where the innovation is expected to be used (Inkmann et al., 1998; Lo and Sutthiphisal, 2009). A firm considers to patent in another country only if the incremental revenue from patenting is sufficiently large (Chan, 2010). International patenting is associated with international business opportunities (e.g., trade, Foreign Direct Investment (FDI) and outsourcing). For example, a firm's decision to trade with a foreign country is significantly affected by whether it can obtain patents in that country (Maskus and Penubarti, 1995; Palangkaraya et al., 2017). Studies also find a strong connection between international patenting and FDI (Bosworth, 1984; Yang and Kuo, 2008; Nikzad, 2012), between cross-country patenting and trade flows (Dosi et al., 1990; Licht and Zoz, 2000; Yang and Kuo, 2008), and between international patenting and outsourcing (Leiblein and Madsen, 2009; Hu and Jefferson, 2009; Miguelez, 2016). In addition, business opportunities can also refer to the technology gap between the domestic country and foreign countries (Xu and Chiang, 2005; Archontakis and Varsakelis, 2011).[2]

While business opportunities may be the first consideration for international patenting, once firms decide to patent in a country, they also have to consider the quality of the patent system in

[2]Xu and Chiang (2005) find that the technology gap across countries affects firms' international patenting decisions. In the case of the U.S., a smaller technology gap between the U.S. and a destination country will increase the incentive to patent abroad because narrow technology gap increases imitation risk (Archontakis and Varsakelis, 2011).

that country. When firms consider patent applications abroad, the ability to defend a patent's claims and rights in the target country is assessed before filing these applications (Lemley and Shapiro, 2005). Countries with strong patent protection receive more foreign applications, and the quality of patent protection (e.g., enforcement of the law) at the receiving country has a significant impact on international patenting (Park, 1999; Yang and Kuo, 2008; Chan, 2010; Jaffe and Lerner, 2011).

Finally, my study is related to studies on the quality of patents. Since the seminal work by Farrell and Shapiro (2008), the literature has paid attention to the incidence of so-called "bad patents" (patents granted to innovations that do not satisfy patentability criteria). While application fees may be effective in weeding out low-quality patents (De Rassenfosse and Jaffe, 2018), various proposals have been raised to mitigate the bad patent problem. For instance, Encaoua et al. (2006) suggest that a feasible way to fix the bad patent problem is to carry out a more stringent examination. In contrast, Atal and Bar (2014) propose to allow applicants to apply for a "gold-plated" rather than a "regular" patent by paying higher fees and going through a tighter examination.

4.3 Model Framework

I adopt the framework used in Atal and Bar (2014) to evaluate an innovator's decision to apply for patents. However, my model departs from Atal and Bar (2014) in several ways. First, while Atal and Bar (2014) investigate an innovator's choice between two examination processes, I analyze an innovator's patenting choices between two patent offices. Second, my model addresses the role of application sequence and information availability, which is not discussed in their work.

In the model, I consider two patent offices a and b, located in two countries, and many innovators, each endowed with one innovation. At the outset, patent offices and innovators do not know the patentability of innovations. However, before filing for a patent application, an innovator has a prior belief about whether his innovation is good (his innovation satisfies the patentability requirements, e.g., novel, non-obvious and useful). The innovator has an *ex-ante* belief $\theta \in [0, 1]$ that his innovation is good, which is also referred to as the quality of the innovation and the innovator type. The belief θ is independently drawn, and follows a distribution with a cumulative distribution function $F(\theta)$, and a density function $f(\theta)$.

An innovator must decide whether to patent his innovation; once a patenting decision has been made, he decides whether to apply for patents in country a, country b or in both countries. To obtain a patent at patent office $i \in (a, b)$, an innovator files for a patent application, along with paying the required fees C_i. An examiner at the receiving patent office i examines the validity of the claims stated in the application. Upon making a final decision, examiners may make two types of errors: either wrongly reject a patent to a good innovation (Type I error), or incorrectly grant a patent to a bad innovation (Type II error). Type II errors are more common and also might be more damaging since type I errors can be potentially eliminated through a re-application (Langinier and Marcoul, 2016). In this paper, I focus only on Type II errors, and I assume that an examiner always grants a patent to a good innovation.

In particular, if an innovation is bad, an examiner rejects the application with probability π_i and grants a patent with probability $(1 - \pi_i)$ at patent office i. This implies that the innovation with θ can be granted a patent with probability $\theta + (1 - \theta)(1 - \pi_i) = 1 - \pi_i(1 - \theta)$ at patent office i. Moreover, for any innovator that applies for patents at both offices, the probability that an innovation is granted patents by both patent offices is $\theta + (1 - \theta)(1 - \pi_a)(1 - \pi_b) = [1 - \hat{\pi}(1 - \theta)]$ where $\hat{\pi} = \pi_a + \pi_b - \pi_a\pi_b$. By definition, $\hat{\pi}$ is the probability that a bad innovation is found by at least one patent office.[3]

Due to the incidence of Type II errors, when a patent is granted, it does not necessarily indicate that the patented innovation is good. However, for a granted innovation, third parties (e.g., competitors and potential investors) can form an expectation about the probability that a granted innovation is good. As in Atal and Bar (2014), the value of patents depends on the third parties' expectation. At the equilibrium, third parties' expectation correctly reflects the value of patents. Third parties' perceived quality of patents at patent office i is denoted as q_i, which is the probability that an innovation is good if it is granted a patent by patent office i. If an innovation is granted patents in multiple patent offices, the perceived quality of patents is the probability that

[3]The examination intensity π_i is assumed to be exogenous and is not influenced by the timing. However, how patent offices decide the examination intensity is an insightful topic of future research.

an innovation is good if its granted patents by these patent offices, which will be developed in the subsequent sections.

The value of patents is a function of the quality of innovations and the perceived quality of patents. If an innovation is good and patented at office i, it will bring its owner a benefit, Ω_i, which is fixed. Note that even without a patent, some benefits may exist for a good innovation. For simplicity, I assume that without a patent, the benefit from a good innovation will vanish due to competition. Besides, the benefit of a bad innovation without a patent is assumed to be zero. In other words, the profitability of an innovation depends on whether it is good and patented. Once an innovator is granted a patent, it obtains an extra benefit, $\omega(q_i)$, which is a function of q_i. I assume that $\omega(0) = 0$ and $\omega'(q_i) > 0$. Moreover, $\Omega_i > C_i > (1 - \pi_i)\omega(1)$, which means that application cost at patent office i is neither too high to discourage innovators with good innovation nor too low to encourage innovators with bad innovation even if third parties think it is good. In line with Hall (2009), Ω_i measures the value of a good innovation when it is granted a patent (e.g., business opportunities for a good innovation, which is not affected by third parties' perception), and $\omega(q_i)$ measures the value of patent rights. The sum of Ω_i and $\omega(q_i)$ is the incremental value of patenting a good innovation.

4.4 Application Sequence and Information Availability

I consider two types of application systems, which differ in the application sequence. In a *simultaneous application system*, an innovator can submit his applications simultaneously to both patent offices. In such a system, the innovator's decision to patent at one patent office depends on the expected payoff from applying at that patent office. In a *sequential application system*, an innovator can submit his patent applications sequentially. In this paper, I assume that an innovator first submits its application at patent office a and then decide whether to continue his application at patent office b upon receiving application outcomes from the first office a.[4] A key feature of the application sequence is that it allows an applicant to update his belief in the innovation quality.

[4] It is beyond the scope of this paper, but endogenizing where an innovator submits its applications first is an interesting area for future research.

Notice that in this paper, the simultaneous application system and the sequential application system do not exist at the same time. Neither innovators nor patent offices decide which system to choose.

The application sequence has two effects. In a sequential system, when an applicant receives the application outcomes at the first patent office a, he can update the probability that his innovation is good before entering the second patent office b. If the innovator is granted a patent at patent office a, he will update his belief θ using Bayes' rule, which is denoted as $\tilde{\theta}$, which is the probability that an innovation is good if it is granted a patent at patent office a and can be expressed as:

$$\tilde{\theta} = \frac{\theta}{1 - \pi_a(1 - \theta)}. \tag{4.1}$$

Note that under a sequential application system, if an application is granted, $\tilde{\theta} > \theta$. Intuitively, being granted a patent in the first patent office will strengthen the innovator's confidence in the quality of his innovation, which also encourages the applicant to patent at the second patent office. In contrast, if his application is rejected in the first office, his decision to apply in the second office may be affected as he becomes more pessimistic. As I assume that examiners will not wrongly reject a good innovation, a rejected application must be a bad innovation, and the applicant will not apply for a patent at the second patent office. Table 4.1 summarize all the parameters and their interpretations for reference.

The second effect is that third parties will have a chance to re-evaluate the quality of granted innovations. In a sequential application system without information availability, third parties cannot observe the same innovation's application outcomes at these two patent offices. Therefore, the application sequence will only have the first effect. In contrast, if the information is available, third parties can revise their perception of the patents' quality at both patent offices.

Table 4.1: Parameters and a Brief Description

Parameters	Description
θ	*ex-ante* probability that an innovation is good
$\tilde{\theta}$	Updated probability that an innovation is good if granted by the first office
$F(\theta)$	Cumulative distribution of θ
$f(\theta)$	Density function of θ
i	$i \in (a, b)$
C_i	Application fees at patent office i
π_i	Examination intensity at patent office i
Ω_i	The value of a good innovation when it is granted a patent at the patent office i
q_i	Third parties' perceived quality of patents issued by patent office i
$\omega(q_i)$	The value of a patent per se based on third parties' expectations

To focus on the role of information, I further consider an isolated information system and a connected information patent system. An *isolated information system* refers to a system in which these two patent offices are isolated and there is no information availability, and third parties cannot observe the outcome of applications for the same innovation in different patent offices. In contrast, in a *connected information system*, third parties can identify patent applications for the same innovation in different patent offices. A key feature of information availability is that it allows third parties to track the same innovation in different patent offices. Note that this distinction can matter even in a simultaneous system.

The reality is more complex than what I am modeling. To focus on the role of information availability and application sequence, I will consider four cases, whose key features are summarized in Table 4.2. In section 4.1, I focus on the case where patent applications are submitted simultaneously, and there is no information availability, whereas, in section 4.2, there is information availability. In contrast, section 4.3 focuses on sequential applications without information availability, and section 4.4 focuses on the sequential application system with information availability.

Table 4.2: Preview of Four Cases

	Isolated-information	Connected-information
Simultaneous	Applicants *cannot* update belief Third parties *cannot* track applications	Applicants *cannot* update belief Third parties *can* track applications
Sequential	Applicants *can* update belief Third parties *cannot* track applications	Applicants *can* update belief Third parties *can* track applications

4.4.1 Simultaneous Applications with Isolated Information

In this subsection, I focus on the case that applications are submitted simultaneously, and third parties cannot keep track of applications of the same innovation at different patent offices. It is worth noting that I essentially view the analysis of Atal and Bar (2014) from a new perspective and interpret some of their results in the context of locational patenting. In this case, an innovator makes its patenting decision at each patent office independently. This is also the benchmark case for the other three cases that I will discuss. The expected payoff of an innovator of type θ from applying at office i is

$$V_{sim\_iso,i}(\theta, q_i) = \theta[\Omega_i + \omega(q_i)] + (1-\theta)(1-\pi_i)\omega(q_i) - C_i, \tag{4.2}$$

where $[\Omega_i + \omega(q_i)]$ is the payoff from a good innovation (with probability θ) that is granted a patent, and $\omega(q_i)$ is the payoff if the innovation is bad with probability $(1-\theta)$ and is granted a patent with probability $(1-\pi_i)$.

An innovator will submit an application at patent office i if and only if $V_{sim\_iso,i}(\theta, q_i)$ is non-negative. As discussed in Atal and Bar (2014), if the application fees are extremely high, no innovator will apply for patents. In contrast, if the application fees are extremely low, all innovators will apply for patents. I rule out these two extreme cases by assuming that the application fees are neither too high to discourage all innovators not to patent nor too low to encourage all innovators to patent. Consequently, there exists a threshold θ_i such that an innovator with $\theta \geq \theta_i$ will submit an application in country i, where

$$\theta_{sim\_iso,i} = \frac{C_i - (1-\pi_i)\omega(q_{sim\_iso,i})}{\Omega_i + \pi_i\omega(q_{sim\_iso,i})}, \tag{4.3}$$

and such that $\theta_{sim\_iso,i}$ is a decreasing function of $q_{sim\_iso,i}$. While an increase in C_i or π_i will increase $\theta_{sim\_iso,i}$, an increase in Ω_i will decrease $\theta_{sim\_iso,i}$.

Adopting the methodology in Atal and Bar (2014), at the equilibrium, using Bayes' rule the perceived quality of patents issued by patent office i can be expressed as

$$q_{sim\_iso,i} = \Pr(Good|Granted_i) = \frac{\int_{\theta_{sim\_iso,i}}^{1} \theta f(\theta)d\theta}{\int_{\theta_{sim\_iso,i}}^{1}[1-\pi_i(1-\theta)]f(\theta)d\theta}, \tag{4.4}$$

where $q_{sim\_iso,i}$ is an increasing function of $\theta_{sim\_iso,i}$. An increase in $\pi_{sim\_iso,i}$ is associated with an increase in $q_{sim\_iso,i}$ as well a change in Ω_i and C_i has no effect on $q_{sim\_iso,i}$.

Third parties can evaluate the quality of patented innovations by estimating the probability that a patented innovation is good. If a patent is perceived to be of high quality, the value of a patent to its holder is high. The equilibrium is defined similarly to Atal and Bar (2014) as follows.

Definition 1 *An equilibrium is characterized with a pair ($q^*_{sim\_iso,i}, \theta^*_{sim\_iso,i}$), such that*

$$\theta^*_{sim\_iso,i} = \theta_{sim\_iso,i}(q^*_{sim\_iso,i}) \text{ and } q^*_{sim\_iso,i} = q_{sim\_iso,i}(\theta^*_{sim\_iso,i}).$$

Atal and Bar (2014) have shown that there exists a unique pair ($q^*_{sim\_iso,i}, \theta^*_i$) that satisfies the above definition. At the equilibrium, the perceived quality $q^*_{sim\_iso,i}$ and the threshold belief $\theta^*_{sim\_iso,i}$ are affected by the application fees C_i, the intensity π_i, and business opportunities of innovations Ω_i. If the perceived quality is higher, more innovators would apply for patents, which would reduce the perceived quality. Meanwhile, if the perceived quality is low, some innovators would not apply for patents, which would increase the perceived quality.

Regarding a firm's decision to apply for a patent, Atal and Bar (2014) have shown that in equilibrium, changes in application fees and examination intensity result in differences in patent quality and the volume of patent applications. Referring to firms' locational patenting, it suggests that differences in the patent application fees or the examination intensity result in a difference in firms' decision on which patent office to apply for patents. Proposition 1 summarizes the effect of the difference in application fees and examination intensity on the threshold to patent $\theta_{sim\_iso,i}$ and the perceived quality $q_{sim\_iso,i}$.

Proposition 1 *In a simultaneous application system with isolated information,*
(i) if $C_a > C_b$, $\theta^*_{sim\_iso,a} > \theta^*_{sim\_iso,b}$ *and* $q^*_{sim\_iso,a} > q^*_{sim\_iso,b}$*;*
(ii) if $\pi_a > \pi_b$, $q^*_{sim\_iso,a} > q^*_{sim\_iso,b}$ *and the sign of* $(\theta^*_{sim\_iso,a} - \theta^*_{sim\_iso,b})$ *is ambiguous;*
(iii) if $\Omega_a > \Omega_b$, $\theta^*_{sim\_iso,a} < \theta^*_{sim\_iso,b}$ *and* $q^*_{sim\_iso,a} < q^*_{sim\_iso,b}$*.*

Figure 4.1 illustrates Proposition 1, when application fees at patent office a are higher than at patent office b, $C_a > C_b$. The perceived quality function defined in equation (4.4) is represented by the curve $q_{sim\_iso,i}(\theta_{sim\_iso,i})$. As both offices are similar except for their application fees, the perceived quality curves are identical for these two patent offices. Likewise, the curves $\theta_{sim\_iso,a}(q_{sim\_iso,a})$ and $\theta_{sim\_iso,b}(q_{sim\_iso,b})$ represent the threshold function defined in (4.3) for patent office a and b. Since the perceived quality function is upward sloping and the threshold functions are downward sloping, the equilibrium for each office is unique, which is determined by $(\theta^*_{sim\_iso,i}, q^*_{sim\_iso,i})$ for $i = 1, 2$.

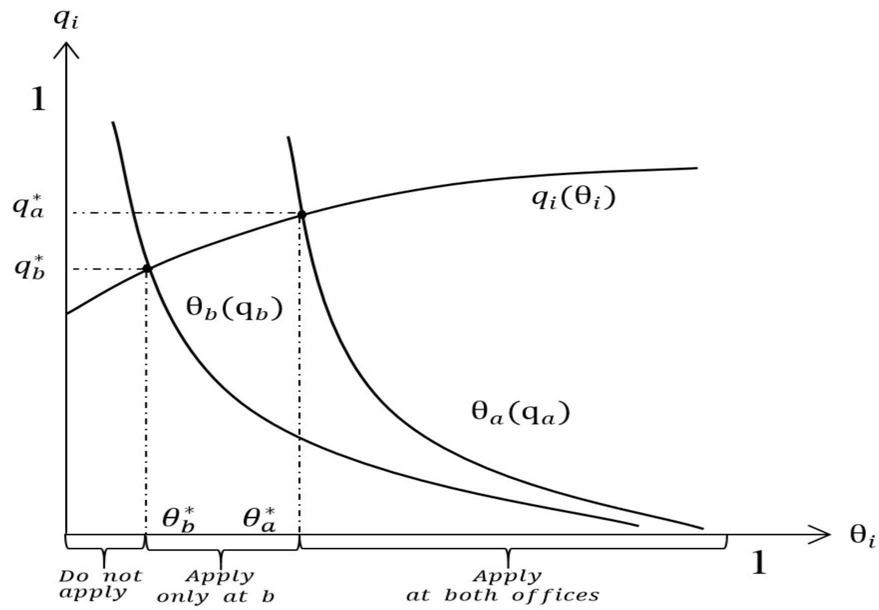


Figure 4.1: Equilibrium (q^*, θ^*) for Different Application Fees

As shown in Figure 4.1, innovators with θ lower than $\theta^*_{sim\_iso,b}$ will not apply anywhere, whereas innovators with θ above $\theta^*_{sim\_iso,a}$ will apply at both offices and innovators with $\theta \in [\theta^*_{sim\_iso,b}, \theta^*_{sim\_iso,a}]$ will apply only in patent office b. These results also indicate that, *ceteris paribus*, higher application fees would reduce the volume of applications and increase the patent quality. The intuition is that higher application fees would discourage marginal applicants to apply with a low probability of having a good innovation. As the quality of the pool of applications improves, the perceived patent quality increases.

Figure 4.2 illustrates the case where the examination intensity at patent office a is larger than that at patent office b, $\pi_a > \pi_b$. Both the perceived quality function and the threshold function increase in the examination intensity. Consequently, as shown in Figure 4.2, function $\theta_{sim\_iso,a}(q_{sim\_iso,a})$ is above function $\theta_{sim\_iso,b}(q_{sim\_iso,b})$ and also function $q_{sim\_iso,a}(\theta_{sim\_iso,a})$ is above function $q_{sim\_iso,b}(\theta_{sim\_iso,b})$. As a result, the perceived quality of applications is higher at patent office a than at patent office b. Intuitively, a higher examination intensity will decrease the probability of granting patents to bad innovations and discourage innovators with low θ to apply. These two effects will increase the perceived quality.

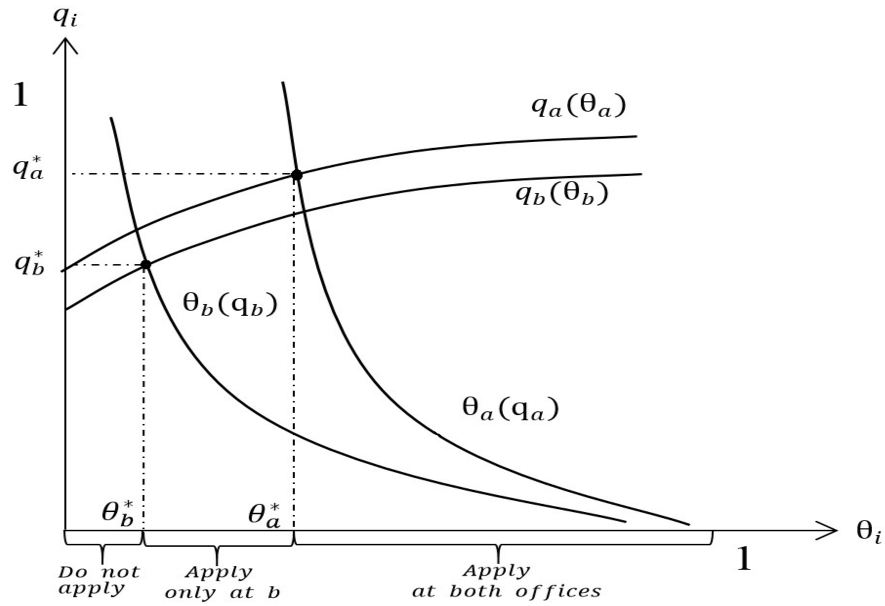


Figure 4.2: Equilibrium (q^*, θ^*) for Different Examination Intensities

However, in a simultaneous application system with isolated information, if the examination intensity is the only difference in the two patent offices, the comparison between the threshold $\theta^*_{sim\_iso,a}$ and $\theta^*_{sim\_iso,b}$ is ambiguous. On the one hand, a higher examination intensity will discourage marginal applicants because it means that if the innovation is bad, the probability of obtaining a patent becomes smaller. On the other hand, a higher examination intensity increases the value of holding a patent and encourages more applications.

In addition to the application fee and examination intensity, I now investigate the case where these two countries differ only in business opportunities Ω_i for $i = a, b$. Intuitively, a country with more opportunities should be more profitable for an innovator to exploit his innovation. Figure 4.3 illustrates the case where patent office a has more business opportunities than patent office b, $\Omega_a \geq \Omega_b$. In such a case, innovators with θ lower than $\theta^*_{sim\_iso,a}$ will not apply anywhere, whereas innovators with θ above $\theta^*_{sim\_iso,b}$ will apply at both offices and innovators with $\theta \in [\theta^*_{sim\_iso,a}, \theta^*_{sim\_iso,b}]$ apply only in patent office a.

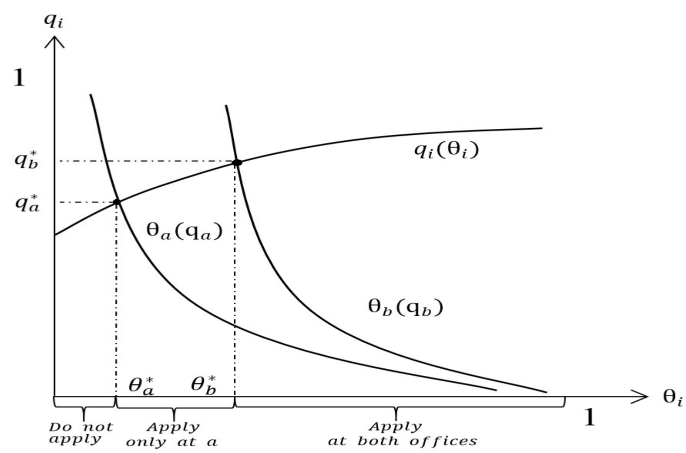


Figure 4.3: Equilibrium (q^*, θ^*) for Different Business Opportunities

4.4.2 Simultaneous Application with Connected Information

The previous subsection has shown how innovators decide where to apply for patents in a simultaneous application with isolated information. In the subsequent discussion, I assume that these two patent offices (countries) are identical to focus on the effect of information availability and application sequence.

I now consider the case with the simultaneous application system where third parties can observe the application outcomes for the same innovation in both countries. Three situations may occur. First, an innovator applies in both patent offices but is rejected by at least one patent office, suggesting that the innovation is bad. Second, an innovator applies in both offices and gets granted by both offices. Third, an innovator applies in one office but not the other and gets granted a patent. However, an equilibrium in the third situation does not exist with identical patent offices, which is verified in the Appendix. Consequently, I focus on the situation that an innovator either applies nowhere or at both patent offices.

If an innovator applies for patents in both offices, if third parties know the application outcome at each office, a patent has value to its holder only if the patent holder receives patents at both offices. If only one patent office rejects to grant a patent to an applicant, his innovation will be treated as bad even he receives a patent from the other patent office. This is because, by assumption, an examiner will never reject a patent to a good innovation. For any innovator that applies for patents at both offices which are identical, the probability that an innovation is granted patents by both patent offices is $[1 - \hat{\pi}(1 - \theta)]$ where $\hat{\pi} = 2\pi - \pi^2$. Again, $\hat{\pi}$ is the probability that a bad innovation is found by either patent office a or b.

In this case, the expected payoff from applying at either patent office is the same. For convenience, the expected payoff at patent office a is written as

$$V_{sim\_con,a}(\theta, q_a) = \theta[\Omega + \omega(q_a)] + (1 - \theta)(1 - \hat{\pi})\omega(q_a) - C,$$

where $[\Omega + \omega(q_a)]$ is the payoff from a good innovation (with probability θ) that is granted a patent at patent office a, and $\omega(q_a)$ is the payoff if the innovation is bad with probability $(1 - \theta)$ and is granted a patent with probability that the innovation is granted patents by both patent offices $(1 - \hat{\pi})$. The above expected payoff function leads to the threshold to apply in patent office a in this case,

$$\theta_{sim\_con,a} = \frac{C - (1 - \hat{\pi})\omega(q_{sim\_con,a})}{\Omega + \hat{\pi}\omega(q_{sim\_con,a})}. \tag{4.5}$$

If an innovation has patents in both countries, the perceived quality of patents is

$$q_{sim\_con,a} = \frac{\int_{\theta_{sim\_con,a}}^{1} \theta f(\theta) d\theta}{\int_{\theta_{sim\_con,a}}^{1} [1 - \hat{\pi}(1 - \theta)] f(\theta) d\theta}, \tag{4.6}$$

Equations (4.5) and (4.6) jointly determine the equilibrium in this case. Compared with an equilibrium in a simultaneous application system with isolated information as defined by equations (4.3) and (4.4), the only difference is the examination intensity changes from π to $\hat{\pi}$. This difference leads to the following proposition.

Proposition 2. *At the equilibrium in a simultaneous application system with isolated information,the sign of* $(\theta^*_{sim\_iso,a} - \theta^*_{sim\_con,a})$ *is ambiguous, and* $q^*_{sim\_iso,a} < q^*_{sim\_con,a}$.

Proposition 2 suggests that information availability in a simultaneous application system is equivalent to an increase in the examination intensity. Intuitively, when information availability is available to third parties, they can evaluate the quality of an innovation more accurately. To be treated as a good innovation, the innovation has to be granted patents by both patent offices, which is harder than to obtain a patent at a single office. Referring to Figure 4.2, once an innovation is granted patents at both offices, the perceived quality is higher than that without information availability as $\hat{\pi} > \pi$. Despite increased perceived quality induces more applications, it discourages some applications as being granted by both patent offices is not easy. As a result, the number of applications may increase or decrease.

4.4.3 Sequential Application with Isolated Information

Without information availability under a sequential application system, third parties can only observe an application at individual patent offices. Recall that in a sequential application system, the first filing office is patent office a, and the second filing office is patent office b. As examiners will never reject a good innovation, if rejected at patent office a, an innovator will not apply for a patent at patent office b.

Third parties know that applications are submitted in sequence, but they cannot keep track of applications of the same innovation with isolated information. As a result, if an innovation is granted a patent in patent office a but rejected a patent in patent office b, the patent holder can still enjoy the value of patents at patent office a. As well, when third parties see an application at the second patent office b, they know that the same innovation has obtained a patent at office a.

At the second patent office b, the innovator can patent or not. If the innovator applies at b, the expected payoff is

$$\tilde{\theta}[\Omega + \omega(q_a) + \Omega + \omega(q_b)] + (1 - \tilde{\theta})[\omega(q_a) + (1 - \pi)\omega(q_b)] - C.$$

Note that if the innovation is bad, it will not affect the benefit from the first office $\omega(q_a)$ but to get the benefit from the second patent office, the innovation has to be granted with probability $(1-\pi)$. In contrast, if the innovator decide not to patent at b, his expected payoff is

$$\tilde{\theta}[\Omega + \omega(q_a)] + (1-\tilde{\theta})\omega(q_a).$$

The innovator forms the added expected payoff function based on the difference of the above two payoff functions,which can be written as

$$\tilde{V}_{seq\_iso,b}(\tilde{\theta}, q_b) = \tilde{\theta}[\Omega + \omega(q_b)] + (1-\tilde{\theta})(1-\pi)\omega(q_b) - C,$$

where $[\Omega + \omega(q_b)]$ is the payoff from a good innovation (with probability $\tilde{\theta}$, which is defined in equation (4.1)) that is granted a patent, and $\omega(q_b)$ is the payoff if the innovation is bad with probability $(1-\hat{\theta})$ and is granted a patent with probability $(1-\pi)$. Consequently, referring to the original distribution of θ, the threshold of applying at the second office is

$$\theta_{seq\_iso,b} = \frac{C - (1-\hat{\pi})\omega(q_{seq\_iso,b}) - \pi C}{\Omega + \hat{\pi}\omega(q_{seq\_iso,b}) - \pi C}, \tag{4.7}$$

where $\hat{\pi} = 2\pi - \pi^2$. Although third parties cannot observe applications of the same innovation at both patent offices, they know that any application at the second office b has been granted a patent at the first office a. As a result, the perceived quality at the second patent office is

$$q_{seq\_iso,b} = \frac{\int_{\theta_{seq\_iso,b}}^{1} \theta f(\theta) d\theta}{\int_{\theta_{seq\_iso,b}}^{1} [1 - \hat{\pi}(1-\theta)] f(\theta) d\theta}. \tag{4.8}$$

The above equation suggests that third parties can update their perception of the quality of patents at the second patent offices despite isolated information.

Under the sequential application system, when an innovator decides to patent at the first office, he must consider the potential outcomes at the second office. Thus, the expected payoff of applying at the first office is:

$$V_{seq\_iso,a}(\theta, q_a, q_b) = \underbrace{[\theta(\Omega + \omega(q_a)) + (1-\theta)(1-\pi)\omega(q_a) - C]}_{\text{Expected payoff from applying at the first patent office}} + [\theta + (1-\theta)(1-\pi)]\tilde{V}_{seq\_iso,b}(\tilde{\theta}, q_b),$$

where the first part is the expected payoff from patenting at the patent office a, and the second part is the expected payoff from patenting at patent office b if a patent is granted at patent office a with probability $[\theta + (1-\theta)(1-\pi)]$. In a sequential application system, the application sequence may give the applicant a chance to not apply at the second patent office. As a result, the applicant may save money by not applying at the second patent office. In this case, the threshold at the first office in this case is:

$$\theta_{seq\_iso,a} = \frac{C - (1-\pi)\omega(q_{seq\_iso,a}) + C - (1-\hat{\pi})\omega(q_{seq\_iso,b}) - \pi C}{\Omega + \pi\omega(q_{seq\_iso,a}) + \Omega + \hat{\pi}\omega(q_{seq\_iso,b}) - \pi C}. \tag{4.9}$$

In a sequential application system with isolated information, third parties know that any application at the second patent office b has been granted a patent at the first patent office a. However, third parties do not have information about whether an innovation is granted at the second patent office b when they see an innovation is granted a patent by the first patent office a. Thus, the perceived quality at the first patent office is

$$q_{seq\_iso,a} = \frac{\int_{\theta_{seq\_iso,a}}^{1} \theta f(\theta) d\theta}{\int_{\theta_{seq\_iso,a}}^{1} [1 - \pi(1-\theta)] f(\theta) d\theta}. \tag{4.10}$$

Equations (4.7) through (4.10) jointly determine the equilibrium for a sequential application system with isolated-information. I have shown that application sequence matters for firms' locational patenting. In a sequential application system, an applicant can always update his belief about his innovation quality. However, without information availability, third parties have no more information than in the case of a simultaneous application system. The difference at equilibrium in contrast to a simultaneous application system is summarized in Proposition 3.

Proposition 3. *With isolated information, at the equilibrium,*

$\theta^*_{seq\_iso,b} < \theta^*_{sim\_iso,b}$ *and the sign of* $(q^*_{seq\_iso,b} - q^*_{sim\_iso,b})$ *is ambiguous;*

the signs of $(\theta^*_{seq\_iso,a} - \theta^*_{sim\_iso,a})$ *and* $(q^*_{seq\_iso,a} - q^*_{sim\_iso,a})$ *are ambiguous.*

Proposition 3 states that in an information-isolated system, the application sequence decreases the application thresholds at patent office b. Intuitively, at the second patent office b, the increased belief in innovation quality ($\tilde{\theta} > \theta$) will encourage innovators to apply for patents, which reduces the threshold to apply and in turn reduces perceived quality of patents. However, as the application sequence is equivalent to an increase in the examination intensity at the second patent office, the perceived quality of patent increases. Overall, whether the perceived quality of patents increases or decreases is not clear.

At the first patent office a, the effect of the application sequence on the threshold is not clear. The potential cost-saving (if an application is rejected a patent at a, the innovator will not apply at b) will encourage innovators to patent. However, the increased examination at the second patent office reduces the incentive to patent. As a result, whether the threshold increase or decrease is ambiguous, which further leads the ambiguous change in the perceived quality of patents at patent office a.

4.4.4 Sequential Application with Connected Information

Under a sequential application system with connected information, third parties can observe applications for the same innovation at all individual patent offices. If an innovation is rejected a patent by the first office, the innovator will not apply at the second patent office. However, it is possible that a patent is granted at the first office but rejected at the second patent office. With information availability, patents have value only if an innovation is granted by both offices or an innovation is granted a patent in the first patent office without going to the second office.

In such a sequential application system, applicants can always update their belief and form their payoff function based on the updated information. In addition, when the applicants consider patenting at the second office, they have to consider the risk that if they are rejected by the second office, a patent granted by the first office will lose its value. At the second patent office b, the innovator can patent or not. If the innovator applies at b, the expected payoff is

$$\tilde{\theta}[\Omega + \omega(q_a) + \Omega + \omega(q_b)] + (1 - \tilde{\theta})(1 - \pi)[\omega(q_a) + \omega(q_b] - C.$$

Note that in this case, only if the innovation get a patent from b with probability $(1 - \pi)$ can the innovator has the benefit from patent office a. In contrast, if the innovator decide not to patent at b, his payoff is

$$\tilde{\theta}[\Omega + \omega(q_a)] + (1 - \tilde{\theta})\omega(q_a).$$

The added expected payoff function for patenting at the second patent office is defined as the difference of the above two payoff functions, which can be written as

$$\tilde{V}_{seq\_con,b}(\tilde{\theta}, q_b) = \tilde{\theta}[\Omega + \omega(q_b)] + (1 - \tilde{\theta})(1 - \pi)\omega(q_b) - (1 - \tilde{\theta})\pi\omega(q_a) - C,$$

where $[\Omega + \omega(q_b)]$ is the payoff from a good innovation with probability $\tilde{\theta}$, which is defined in equation (4.1), and granted a patent, and $\omega(q_b)$ is the payoff if the innovation is bad with probability $(1 - \tilde{\theta})$ and is granted a patent with probability $(1 - \pi)$, and $\omega(q_a)$ is the payoff if the innovation is bad with probability $(1 - \tilde{\theta})$ and rejected a patent with probability π. The threshold at the second office is

$$\theta_{seq\_con,b} = \frac{C - (1 - \hat{\pi})\omega(q_{seq\_con,b}) - \pi C + (1 - \pi)\pi\omega(q_{seq\_con,a})}{\Omega + \hat{\pi}\omega(q_{seq\_con,b}) - \pi C + (1 - \pi)\pi\omega(q_{seq\_con,a})}. \tag{4.11}$$

When innovators make their decisions to patent at the first office, they also have to consider the fact that a patent issued by the first patent office may lose its value if it is not granted by the second office. As a result, the expected payoff to apply at the first patent office is

$$V_{seq\_con,a}(\theta, q_a, q_b) = \underbrace{[\theta(\Omega + \omega(q_a)) + (1 - \theta)(1 - \pi)\omega(q_a) - C]}_{\text{Expected payoff from applying at the first patent office}} + [\theta + (1 - \theta)(1 - \pi)]\tilde{V}_{seq\_con,b}(\tilde{\theta}, q_b),$$

where the first part is the expected payoff from patenting at the patent office a, and the second part is the expected payoff from patenting at patent office b if a patent is granted at patent office a with probability $[\theta + (1-\theta)(1-\pi)]$. The threshold to patent at patent office a is

$$\theta_{seq\_con,a} = \frac{C - (1-\hat{\pi})\omega(q_{seq\_con,a}) + C - (1-\hat{\pi})\omega(q_{seq\_con,b}) - \pi C}{\Omega + \hat{\pi}\omega(q_{seq\_con,a}) + \Omega + \hat{\pi}\omega(q_{seq\_con,b}) - \pi C}. \tag{4.12}$$

Third parties know that all applications at the second patent office have been granted at the first patent office as they are able to keep track of the same innovation in both patent offices given the information availability. As a result, at the equilibrium, the perceived quality of the same innovation in both patent office will be the same. In such a case, the perceived quality can be written as

$$q_{seq\_con,a} = q_{seq\_con,b} = \frac{\int_{\theta_{seq\_con,a}}^{1} \theta f(\theta) d\theta}{\int_{\theta_{seq\_con,a}}^{1} [1 - \hat{\pi}(1-\theta)] f(\theta) d\theta}. \tag{4.13}$$

In a sequential application system with information availability, the equilibrium is characterized by equations (4.11) through (4.13). In contrast to the sequential application system without information availability, the key difference is that when referring to the first patent office, the examination intensity changes from π to $\hat{\pi}$. This leads to the following proposition.

Proposition 4 *In a sequential application system, at the equilibrium,*
$q^*_{seq\_iso,b} < q^*_{seq\_con,b}$ *and* $\theta^*_{seq\_iso,b} < \theta^*_{seq\_con,b}$;
$q^*_{seq\_iso,a} < q^*_{seq\_con,a}$ *and the sign of* $(\theta^*_{seq\_iso,a} - \theta^*_{seq\_con,a})$ *is ambiguous.*

Proposition 4 states that in a sequential application system, information availability is equivalent to an increase in the examination intensity at both patent offices. As discussed, an increase in the examination intensity will increase the perceived quality of patents issued by both patent offices. However, whether it increases the number of patent applications at both patent offices is ambiguous.

In Proposition 3, I have investigated the effect of the application sequence on innovators' patenting decisions without information availability. Proposition 5 summarizes the effect of the application sequence when information is connected.

Proposition 5 *With connected information, at the equilibrium,*
$q^*_{sim\_con,b} < q^*_{seq\_con,b}$ *and* $\theta^*_{sim\_con,b} < \theta^*_{seq\_con,b}$*;*
the signs of $(q^*_{seq\_con,a} - q^*_{sim\_con,a})$ *and* $(\theta^*_{seq\_con,a} - \theta^*_{sim\_con,a})$ *are ambiguous.*

Proposition 5 suggests that when information is available, the application sequence will discourage firms' patenting at the second patent office, which increases the perceived quality of patents. However, despite the increase in the perceived quality of patents, information availability makes it harder to obtain patents at both patent offices. As a result, at the first patent office a, neither the threshold to apply nor the perceived quality of patents in a sequential application system cannot compare with those in a simultaneous application system. I will discuss further regarding a comparison between these two application systems in the next section.

4.5 Sequential or Simultaneous

In the previous discussion, I have assumed that simultaneous and sequential application systems do not exist at the same time. In this section, I assume that innovators are allowed to choose either the application system. Although third parties may behave differently when innovators can choose patent systems, I will not explore that in this paper. For simplicity, I assume that third parties will not change their expectations when different application systems are available. If information is not available, an innovator would compare the expected payoffs of simultaneous and sequential applications, which can be written as

$$\Delta_{iso} = 2V_{sim\_iso,i} - V_{seq\_iso,a}$$

The first part is the total expected payoff of simultaneous applications, and the second part is the total expected payoff of sequential applications. The definition can be further simplified as

$$\Delta_{iso} = 2[1-\pi(1-\theta)][\omega(q_{sim\_iso,a}) - \frac{\omega(q_{seq\_iso,a}) + \omega(q_{seq\_iso,b})}{2}] - \pi(1-\theta)[C-(1-\pi)\omega(q_{_{seq\_iso,b}})]. \quad (4.14)$$

When Δ_{iso} is positive, it would suggest that a simultaneous application is preferred; when Δ_{iso} is negative, it would suggest that a sequential application is preferred. Since $[C-(1-\pi)\omega(q_{seq\_iso,b})] > 0$, the sign of Δ_{iso} depends on the sign of $[\omega(q_{sim\_iso,a}) - \frac{\omega(q_{seq\_iso,a})+\omega(q_{seq\_iso,b})}{2}]$: if it is negative, then Δ_{iso} is negative; if it is positive, then its magnitude also matters.

If information is available, the difference in the total expected payoff in the case that innovators apply for patents at both offices is

$$\Delta_{con} = 2V_{sim\_con,a} - V_{seq\_con,a}$$

which can be simplified as

$$\Delta_{con} = 2[(1-\hat{\pi}(1-\theta)][\omega(q_{sim\_con,a}) - \omega(q_{seq\_con,a})] - \pi(1-\theta)C. \quad (4.15)$$

The sign of Δ_{con} also depends on the sign of $[\omega(q_{sim\_con,a}) - \omega(q_{seq\_con,a})]$. When information is available, the perceived quality of patents at both patent offices would be the same at the equilibrium. This suggests that if the perceived quality of patents under a simultaneous application system is lower than that under a sequential application system, then a simultaneous application system is always preferred.

4.6 Discussion and Conclusions

Cross-border patenting has been studied in the literature. However, there is no theoretical model to analyze the effect of application sequence and information availability on locational patenting decisions. This paper attempts to fill this theoretical gap. I firstly build a benefit-cost framework to analyze a firm's decision on whether to patent in a country. My model connects the quality of innovations per se, the perceived quality of patents, patent examination intensity, and business opportunities in a country. The model shows that firms with high-quality innovations are more likely to patent and patent in multiple countries. While a high examination intensity in a patent office may reduce a firm's propensity to patent, due to the increased perceived quality of patents, it is also possible that firms may be discouraged due to the lower possibility of obtaining patents. The quality of innovations, the perceived quality of patents play a role once a firm has decided to patent in a country. However, business opportunities across countries can dominantly determine locational patenting.

I then extend the model by considering the impact of the application sequence. When patent applications for the same innovations are submitted in a sequence, an innovator will update his belief on the probability that his innovation is good. This updating allows an innovator to revise his decision to patent at the second filing office. Although the application sequence grants the applicants a chance to improve his decision to patent at the second patent office, the model shows that application sequence may induce more applications of bad innovations, which in turn reduce the quality of patents.

I also consider the role of information availability. Increased information availability is equivalent to an increase in examination intensity in both the simultaneous and sequential application system. As a result, information availability among patent offices increases the perceived quality of patents, which may encourage applications of bad innovations. However, in a sequential application system, information availability mainly affects third parties.

The model provides some new insights to understand the cross-border patenting behavior of firms as well as the impacts of cooperation among patent offices. However, I do not consider the timing effect of the application sequence. For instance, with information availability, the second office may save examination and search time, and applicants can also receive the granting decision more quickly. This would be an interesting future research topic. Theoretical contributions may also extend to analyze how patent offices would interact with each other in terms of information availability. In addition, there is an extreme lack of empirical evidence on the effect of the application sequence.

For instance, the Patent Prosecution Highway (PPH) allows examiners in participating countries to reuse search and examination results (information availability). This falls into my cases where patent offices cooperate, and application sequence plays a role. While PPH is intentionally designed to speed up the application process, my model suggests that PPH can also increase the quality of patents at the second patent office through a self-selected procedure. Since the examination outcome at the first filing office will be informed to the second filing office, some applicants with lower quality innovation will withdraw from the second filing office. However, if patent offices are vastly different, it is also possible that the outcome at the first office can lead to a larger application volume in the second office.

4.7 Appendix

Proof of Proposition 1

Consider the general case where $\Omega_i + \omega(q_i) \geq C_i \geq (1 - \pi_i)\omega(q_i)$. Recall equation (4.3) and write it as

$$\Omega_i \theta_i - C_i + [1 - \pi_i + \pi_i \theta_i]\omega(q_i) = 0. \tag{A1}$$

By differentiating equation (A1) with respect to the application fees C_i, I obtain

$$[\Omega_i + \pi_i \omega(q_i)]\frac{\partial \theta_i}{\partial C_i} + [1 - \pi_i + \pi_i \theta_i]\frac{\partial \omega(q_i)}{\partial q_i}\frac{\partial q_i}{\partial C_i} - 1 = 0. \tag{A2}$$

Equation (A2) is simplified as

$$A\frac{\partial \theta_i}{\partial C_i} + B\frac{\partial q_i}{\partial C_i} = 1, \tag{A3}$$

where $A = [\Omega_i + \pi_i \omega(q_i)] > 0$, and $B = [1 - \pi_i + \pi_i \theta_i]\frac{\partial \omega(q_i)}{\partial q_i} > 0$.

On the other hand, recall equation (4.4) and write it as

$$\int_{\theta_i}^{1} \{q_i[1-\pi_i+\pi_i\theta]-\theta\} f(\theta) d\theta = 0. \tag{A4}$$

By differentiating equation (A4) with respect to the application fees C_i, I obtain

$$\int_{\theta_i}^{1} [1-\pi_i+\pi_i\theta] f(\theta) d\theta \frac{\partial q_i}{\partial C_i} - \{q_i[1-\pi_i+\pi_i\theta_i]-\theta_i\} f(\theta_i) \frac{\partial \theta_i}{\partial C_i} = 0. \tag{A5}$$

That can be simplified as

$$D\frac{\partial q_i}{\partial C_i} - F\frac{\partial \theta_i}{\partial C_i} = 0, \tag{A6}$$

where $D = \int_{\theta_i}^{1}[1-\pi_i+\pi_i\theta]f(\theta)d\theta > 0$, and $F = \{q_i[1-\pi_i+\pi_i\theta_i]-\theta_i\}f(\theta_i) > 0$.

From equations (A5) and (A6), I obtain

$$\frac{\partial q_i}{\partial C_i} = \frac{F}{BF+AD} > 0,$$

and

$$\frac{\partial \theta_i}{\partial C_i} = \frac{D}{BF+AD} > 0.$$

Ceteris paribus, if $C_a > C_b$, at the equilibrium $\theta^*_{sim\_iso,a} > \theta^*_{sim\_iso,b}$ and $q^*_{sim\_iso,a} > q^*_{sim\_iso,b}$.

Regarding the case where the only difference is the examination intensity, I consider the general case where $\Omega_i + \omega(q_i) \geq C_i \geq (1-\pi_i)\omega(q_i)$. By differentiating equation (A1) with respect to the examination intensity π_i, I obtain

$$[\Omega_i + \pi_i\omega(q_i)]\frac{\partial \theta_i}{\partial \pi_i} + [1-\pi_i+\pi_i\theta_i]\frac{\partial \omega(q_i)}{\partial q_i}\frac{\partial q_i}{\partial \pi_i} = (1-\theta_i)\omega(q_i), \tag{A7}$$

which can be simplified to

$$A\frac{\partial \theta_i}{\partial \pi_i} + B\frac{\partial q_i}{\partial \pi_i} = (1-\theta_i)\omega(q_i). \tag{A8}$$

By differentiating equation (A4) with respect to the examination intensity π_i, I obtain

$$-\int_{\theta_i}^{1} q_i(1-\theta)f(\theta)d\theta+\int_{\theta_i}^{1}[1-\pi_i+\pi_i\theta_i]f(\theta)d\theta\frac{\partial q_i}{\partial \pi_i}-\{q_i[1-\pi_i+\pi_i\theta_i]-\theta_i\}f(\theta_i)\frac{\partial \theta_i}{\partial \pi_i}=0, \quad \text{(A9)}$$

which can be simplified as

$$D\frac{\partial q_i}{\partial \pi_i}-F\frac{\partial \theta_i}{\partial \pi_i}=\int_{\theta_i}^{1} q_i(1-\theta)f(\theta)d\theta. \quad \text{(A10)}$$

Equations (A8) and (A10) gives

$$\frac{\partial q_i}{\partial \pi_i}=\frac{A}{AD+BF}\int_{\theta_i}^{1} q_i(1-\theta)f(\theta)d\theta+\frac{F}{AD+BF}(1-\theta_i)\omega(q_i)>0,$$

and

$$\frac{\partial \theta_i}{\partial \pi_i}=\frac{D}{AD+BF}(1-\theta_i)\omega(q_i)-\frac{B}{AD+BF}\int_{\theta_i}^{1} q_i(1-\theta)f(\theta)d\theta,$$

since $\frac{D}{AD+BF}(1-\theta_i)\omega(q_i)$ and $\frac{B}{AD+BF}\int_{\theta_i}^{1} q_i(1-\theta)f(\theta)d\theta$ are both positive, the sign of $\frac{\partial \theta_i}{\partial \pi_i}$ is ambiguous. To summarize, ceteris paribus, at the equilibrium, if $\pi_a>\pi_b$, $q^*_{sim\_iso,a}>q^*_{sim\_iso,b}$ and the sign of $(\theta^*_{sim\_iso,a}-\theta^*_{sim\_iso,b})$ is ambiguous;

Similarly, the following conditions can be obtained,

$$\frac{\partial q_i}{\partial \Omega_i}=-\frac{F}{AD+BF}\theta_i<0,$$

and

$$\frac{\partial \theta_i}{\partial \Omega_i}=-\frac{D}{AD+BF}\theta_i<0.$$

Ceteris paribus, at the equilibrium, if $\Omega_a>\Omega_b$, $\theta^*_{sim\_iso,a}<\theta^*_{sim\_iso,b}$ and $q^*_{sim\_iso,a}<q^*_{sim\_iso,b}$.

□

Verifying that an equilibrium does not exist such that firms with low θ don't apply anywhere,

firms with high θ apply in both countries, and firms with intermediate θ apply in only one. In the case that an innovator only applies for patents in one office, following the expected payoff function (4.3), the threshold to apply is

$$\underline{\theta}_i = \frac{C - (1-\pi)\omega(\underline{q}_i)}{\Omega + \pi\omega(\underline{q}_i)} = \frac{X}{Y} < 1. \tag{A11}$$

If an innovation has patents in both countries, the perceived quality of patents is

$$\overline{q}_i = \frac{\int_{\overline{\theta}_i}^{1} \theta f(\theta) d\theta}{\int_{\overline{\theta}_i}^{1} [1 - \hat{\pi}(1-\theta)] f(\theta) d\theta}, \tag{A12}$$

where $\hat{\pi} = \pi_a + \pi_b - \pi_a\pi_b = 2\pi - \pi^2$ and $\overline{\theta}_i$ is the solution to the following equation,

$$\underbrace{\theta(\Omega + \omega(\underline{q}_i)) + (1-\theta)(1-\pi)\omega(\underline{q}_i) - C}_{\text{Expected payoff from applying at one office}} = 2\underbrace{\left[\theta(\Omega + \omega(\overline{q}_i)) + (1-\theta)(1-\hat{\pi})\omega(\overline{q}_i) - C\right]}_{\text{Expected payoff from applying at two office}}.$$

The above equation leads to the threshold to apply in both patent office,

$$\overline{\theta}_i = \frac{C + (1-\pi)\omega(\underline{q}_i) - 2(1-\hat{\pi})\omega(\overline{q}_i)}{\Omega + 2\hat{\pi}\omega(\overline{q}_i) - \pi\omega(\underline{q}_i)} = \frac{C - (1-\pi)\omega(\underline{q}_i) + 2[(1-\pi)\omega(\underline{q}_i) - (1-\hat{\pi})\omega(\overline{q}_i)]}{\Omega + \pi\omega(\underline{q}_i) + 2[\hat{\pi}\omega(\overline{q}_i) - \pi\omega(\underline{q}_i)]}$$

which can be further written as

$$\overline{\theta}_i = \frac{X + 2[(1-\pi)\omega(\underline{q}_i) - (1-\hat{\pi})\omega(\overline{q}_i)]}{Y + 2[\hat{\pi}\omega(\overline{q}_i) - \pi\omega(\underline{q}_i)]}. \tag{A13}$$

such that if $\theta \geq \overline{\theta}_i$, an innovator will apply for patents at both patent offices. Eventually, the perceived quality of patents with an application only at one office is

$$\underline{q}_i = \frac{\int_{\underline{\theta}_i}^{\overline{\theta}_i} \theta f(\theta) d\theta}{\int_{\underline{\theta}_i}^{\overline{\theta}_i} [1 - \pi(1-\theta)] f(\theta) d\theta} \tag{A14}$$

If an equilibrium characterised by equations (A11), (A12), (A13), and (A14) exist, the following condition holds

$$\underline{\theta}_i < \overline{\theta}_i \tag{A15}$$

If such an equilibrium exists, it is evident that $\underline{q}_i < \overline{q}_i$. Hence, $\omega(\underline{q}_i) < \omega(\overline{q}_i)$. Let $\underline{\theta}_i > \overline{\theta}_i$, then

$$\underline{\theta}_i - \overline{\theta}_i = 2\frac{X[\hat{\pi}\omega(\overline{q}_i) - \pi\omega(\underline{q}_i)] - Y[(1-\pi)\omega(\underline{q}_i) - (1-\hat{\pi})\omega(\overline{q}_i)]}{Y\{Y + 2[\hat{\pi}\omega(\overline{q}_i) - \pi\omega(\underline{q}_i)]\}} > 0$$

The denominator is positive, so numerator must be negative

$$X[\hat{\pi}\omega(\overline{q}_i) - \pi\omega(\underline{q}_i)] - Y[(1-\pi)\omega(\underline{q}_i) - (1-\hat{\pi})\omega(\overline{q}_i)] > 0$$

which can be simplified as

$$\frac{C - \Omega - \omega(\underline{q_i})}{\Omega + \pi\omega(\underline{q_i})} > \frac{\omega(\underline{q}_i) - \omega(\overline{q}_i)}{\hat{\pi}\omega(\overline{q}_i) - \pi\omega(\underline{q}_i)} > \frac{\omega(\underline{q}_i) - \omega(\overline{q}_i)}{\pi\omega(\overline{q}_i) - \pi\omega(\underline{q}_i)} = -\frac{1}{\pi}.$$

Then

$$\frac{C - \Omega - \omega(\underline{q_i})}{\Omega + \pi\omega(\underline{q_i})} > -\frac{1}{\pi},$$

which can be simplified as

$$(1-\pi)\Omega + \pi C > 0.$$

As $(1-\pi)\Omega$ is positive and πC is negative, the above inequality always holds. Thus,

$$\underline{\theta}_i > \overline{\theta}_i \tag{A16}$$

As inequalities (A15) and (A16) contradicts, there is no such an equilibrium that if $\theta \in [0, \underline{\theta}_i]$, an innovator will not apply anywhere; if $\theta \in [\underline{\theta}_i, \overline{\theta}_i]$, an innovator will only apply at one patent office;if $\theta \in [\overline{\theta}_i, 1]$, an innovator will apply at both patent offices.

□

Proof of Proposition 2. It can be shown that $\hat{\pi} - \pi = \pi - \pi^2 = \pi(1-\pi) > 0$. This means that $\hat{\pi} > \pi$. As shown in the proof of proposition 1, in the equilibrium, the sign $\frac{\partial \theta_i}{\partial \pi}$ is positive and the sign of $\frac{\partial \theta_i}{\partial \pi}$ is ambiguous. Comparing the simultaneous application with isolated information with the simultaneous application with with connected information, the only change is the examination intensity changes from π to $\hat{\pi}$. As a result, information availability is equivalent to an increase in examination intensity, which means that at the equilibrium, $q^*_{sim\_iso,a} < q^*_{sim\_con,a}$ and the sign of $(\theta^*_{sim\_iso,a} - \theta^*_{sim\_con,a})$ is ambiguous.

□

Proof of Proposition 3. At the second office, we compare the two cases with and without application sequence

$$\begin{aligned} \theta_{seq\_iso,b} - \theta_{sim\_iso,b} &= \frac{C - (1-\hat{\pi})\omega(q_b) - \pi C}{\Omega + \hat{\pi}\omega(q_b) - \pi C} - \frac{C - (1-\pi)\omega(q_b)}{\Omega + \pi\omega(q_b)} \\ &= -\frac{\pi[C - (1-\pi)\omega(q_b)][\Omega + \omega(q_b) - C]}{[\Omega + \hat{\pi}\omega(q_b) - \pi C][\Omega + \pi\omega(q_b)]} < 0. \end{aligned} \tag{A17}$$

The above inequality suggests that without information availability, the threshold function in a sequential system is always below the threshold function in a simultaneous system. On the other hand, as $\hat{\pi} > \pi$, $q_{seq\_iso,b} > q_{sim\_iso,b}$. Thus at the equilibrium, $\theta^*_{seq\_iso,b} < \theta^*_{sim\_iso,b}$ and the sign $(q^*_{seq\_iso,b} - q^*_{sim\_iso,b})$ is not clear.

Similarly, at the first office, we compare the two cases with and without application sequence. Note that $[C - (1-\hat{\pi})\omega(q_b) - \pi C] - [\Omega + \hat{\pi}\omega(q_b) - \pi C] = -[\Omega + \omega(q_b) - C] < 0$.

$$
\begin{aligned}
\theta_{sim\_iso,a} - \theta_{seq\_iso,a} &= \frac{C-(1-\pi)\omega(q_a)}{\Omega+\pi\omega(q_a)} - \frac{C-(1-\pi)\omega(q_a)+C-(1-\hat{\pi})\omega(q_b)-\pi C}{\Omega+\pi\omega(q_a)+\Omega+\hat{\pi}\omega(q_b)-\pi C} \\
&> \frac{C-(1-\pi)\omega(q_a)}{\Omega+\pi\omega(q_a)} - \frac{C-(1-\pi)\omega(q_a)+[\Omega+\hat{\pi}\omega(q_b)-\pi C]}{\Omega+\pi\omega(q_a)+\Omega+\hat{\pi}\omega(q_b)-\pi C} \\
&= -\frac{[\Omega+\hat{\pi}\omega(q_b)-\pi C][\Omega+\omega(q_a)-C]}{[\Omega+\pi\omega(q_a)][\Omega+\hat{\pi}\omega(q_a)+\Omega+\hat{\pi}\omega(q_b)-\pi C]} = X \qquad \text{(A18)}
\end{aligned}
$$

The inequality (A18) suggests that $(\theta_{sim\_iso,a} - \theta_{seq\_iso,a}) \in (X, +\infty)$,where $X < 0$. In this case, the threshold function in a simultaneous system can be below or above the threshold function in a sequential application system. Given that the functions of the perceived quality of patents at patent office a as defined in equations (4.4) and (4.10) have the same function structure, at the equilibrium, the signs of $(\theta^*_{seq\_iso,a} - \theta^*_{sim\_iso,a})$ and $(q^*_{seq\_iso,a} - q^*_{sim\_iso,a})$ are not clear.

□

Proof of Proposition 4. At the second office, we compare the two cases with and without information availability

$$
\begin{aligned}
\theta_{seq\_iso,b} - \theta_{seq\_con,b} &= \frac{C-(1-\hat{\pi})\omega(q_b)-\pi C}{\Omega+\hat{\pi}\omega(q_b)-\pi C} - \frac{C-(1-\hat{\pi})\omega(q_b)-\pi C+(1-\pi)\pi\omega(q_a)}{\Omega+\hat{\pi}\omega(q_b)-\pi C+(1-\pi)\pi\omega(q_a)} \\
&= -\frac{(1-\pi)\pi\omega(q_a)[\Omega+\omega(q_b)-C]}{[\Omega+\hat{\pi}\omega(q_b)-\pi C][\Omega+\hat{\pi}\omega(q_b)-\pi C+(1-\pi)\pi\omega(q_a)]} < 0. \qquad \text{(A19)}
\end{aligned}
$$

The above inequality suggests that without information availability, the threshold function in a sequential system is always below the threshold function in a sequential application system. On the other hand, the functions of the perceived quality of patents at patent office b as defined in equations (4.8) and (4.13) have the same function structure. Thus, at the equilibrium, $q^*_{seq\_iso,b} < q^*_{seq\_con,b}$ and $\theta^*_{seq\_iso,b} < \theta^*_{seq\_con,b}$.

At the first patent office a, we compare the two cases with and without information availability

$$\begin{aligned}
\theta_{seq_iso,a} - \theta_{seq_con,a} &= \frac{C-(1-\pi)\omega(q_a)+C-(1-\hat{\pi})\omega(q_a)-\pi C}{\Omega+\pi\omega(q_a)+\Omega+\hat{\pi}\omega(q_a)-\pi C} \\
&- \frac{C-(1-\hat{\pi})\omega(q_a)+C-(1-\hat{\pi})\omega(q_b)-\pi C}{\Omega+\hat{\pi}\omega(q_a)+\Omega+\hat{\pi}\omega(q_b)-\pi C} \\
&= -\frac{2\pi(1-\pi)\omega(q_a)[\Omega+\omega(q_b)-C]}{[\Omega+\pi\omega(q_a)+\Omega+\hat{\pi}\omega(q_a)-\pi C][\Omega+\hat{\pi}\omega(q_a)+\Omega+\hat{\pi}\omega(q_b)-\pi C]} \\
&< 0. \qquad \text{(A20)}
\end{aligned}$$

As $\hat{\pi} > \pi$, the function of $q_{seq\_iso,a}$ as defined in (4.10) is below the function of $q_{seq\_con,a}$ as defined in (4.13). Therefore, at the equilibrium, $q^*_{seq\_iso,a} < q^*_{sim\_iso,a}$ and the sign $\theta^*_{seq\_iso,a} - \theta^*_{seq\_iso,a}$ is not clear. □

Proof of Proposition 5. At the second office, we compare the two cases with and without application sequence

$$\begin{aligned}
\theta_{sim_con,b} - \theta_{seq_con,b} &= \frac{C-(1-\hat{\pi})\omega(q_b)}{\Omega+\hat{\pi}\omega(q_b)} - \frac{C-(1-\hat{\pi})\omega(q_b)-\pi C+(1-\pi)\pi\omega(q_a)}{\Omega+\hat{\pi}\omega(q_b)-\pi C+(1-\pi)\pi\omega(q_a)} \\
&= \frac{\pi[C-(1-\pi)\omega](q_a)[\Omega+\omega(q_b)-C]}{[\Omega+\hat{\pi}\omega(q_b)][\Omega+\hat{\pi}\omega(q_b)-\pi C+(1-\pi)\pi\omega(q_a)]} > 0. \qquad \text{(A21)}
\end{aligned}$$

The above inequality suggests that when information is connected, the threshold function in a simultaneous system is always below the threshold function in a sequential application system. On the other hand, the functions of the perceived quality of patents at patent office b as defined in equations (4.6) and (4.13) have the same function structure. Thus, at the equilibrium, $q^*_{sim\_con,b} < q^*_{seq\_con,b}$ and $\theta^*_{sim\_con,b} < \theta^*_{seq\_con,b}$.

Similarly, at the first patent office a, we compare the two cases with and without application sequence. Note that $[C-(1-\hat{\pi})\omega(q_b)-\pi C]-[\Omega+\hat{\pi}\omega(q_b)-\pi C]=-[\Omega+\omega(q_b)-C]<0$.

$$\begin{aligned}\theta_{sim\_con,a}-\theta_{seq\_con,a} &= \frac{C-(1-\hat{\pi})\omega(q_a)}{\Omega+\hat{\pi}\omega(q_a)}-\frac{C-(1-\hat{\pi})\omega(q_a)+C-(1-\hat{\pi})\omega(q_b)-\pi C}{\Omega+\hat{\pi}\omega(q_a)+\Omega+\hat{\pi}\omega(q_b)-\pi C}\\ &> \frac{C-(1-\hat{\pi})\omega(q_a)}{\Omega+\hat{\pi}\omega(q_a)}-\frac{C-(1-\hat{\pi})\omega(q_a)+\Omega+\hat{\pi}\omega(q_b)-\pi C}{\Omega+\hat{\pi}\omega(q_a)+\Omega+\hat{\pi}\omega(q_b)-\pi C}\\ &= -\frac{[\Omega+\hat{\pi}\omega(q_b)-\pi C][\Omega+\omega(q_b)-C]}{[\Omega+\hat{\pi}\omega(q_a)][\Omega+\hat{\pi}\omega(q_a)+\Omega+\hat{\pi}\omega(q_b)-\pi C]}=Y \end{aligned} \tag{A22}$$

The inequality (A22) suggests that $(\theta_{sim\_con,a}-\theta_{seq\_con,a})\in(Y,+\infty)$,where $Y<0$. In this case, the threshold function in a simultaneous system can be below or above the threshold function in a sequential application system. Given that the functions of the perceived quality of patents at patent office a as defined in equations (4.6) and (4.13) have the same function structure, at the equilibrium, the signs of $(q^*_{seq\_con,a}-q^*_{sim\_con,a})$ and $(\theta^*_{seq\_con,a}-\theta^*_{seq\_con,a})$ are not clear. □

CONCLUDING REMARKS

The focus of this dissertation is to investigate how firms make locational patenting decisions. I start this thesis with a literature review of innovators' decisions regarding whether to patent and where to patent. Using a unique dataset, I empirically analyze what factors affect Canadian firms' locational patenting behavior and study the effect of CIPO's role as an ISA on Canadian firms' patenting behavior. I then develop a theoretical framework to investigate how the significant factors in the empirical findings affect firms' decisions on where to apply for patents.

Chapter One reviews related patent literature. The review suggests that innovators may apply for patents to win reputation, block competitors, gain bargaining power, avoid lawsuits, and mislead rivals. They may also choose not to patent because of fees involved, or the fear that competitors will invent around their patents, and the disclosure of too much information. Regarding locational patenting decisions, the review suggests that entry to a foreign market acts as the primary motivation for firms to patent abroad. However, the selection of a particular patent office can be complicated. Firms usually consider at least three factors: the patent system in the foreign country, the quality of the innovation, and business opportunities in the destination country.

In Chapter Two, I use data on Canadian firms' patenting activities to analyze what factors affect Canadian firms' locational patenting decisions in Canada and the U.S. Several findings are worth noting. First, Canadian firms are more likely to apply for patents at the office with which they have experience. Second, as a firm accumulates more patents from CIPO and USPTO, it will probably patent at both USPTO and CIPO. Third, patent scope plays an important role in firms' decisions of where to patent. Canadian firms with innovations of broader patent scope are more likely to patent in both countries. Fourth, older firms are more likely to patent in both countries. Fifth, an increase in R&D expenditure is associated with an increase in firms' decisions to apply for patents at USPTO only. Finally, large firms are reluctant to apply for patents at USPTO only but tend to apply for patents at CIPO only.

Results in Chapter Two suggest that CIPO's role as an ISA affects Canadian firms' patenting through PCT. However, how firms' patenting behavior is affected by CIPO's role as an ISA remains unanswered. In Chapter Three, I develop a model to investigate the role of the ISA and provide empirical evidence from Canadian firms. In the model, I show that under certain conditions, the PCT increases firms' patenting, which may be magnified when the domestic patent office is an ISA. The empirical analysis evaluates how Canada's participation in international cooperation as an ISA may affect Canadian firms. The general implication of the empirical results is that if the policy target is to encourage firms to patent in their home country, the domestic patent office should consider becoming an ISA. Alternatively, if the policy target is to encourage domestic firms to patent or invest abroad, becoming an ISA may not help.

In general, the empirical results in Chapters Two and Three suggest that firms' locational patenting behavior can be affected by firm-level, industry-level factors, and policy design in the patent system. When policymakers design policies to encourage innovation, they should understand what factors play a dominant role in their countries. For instance, Canada should focus more on policy design to improve business opportunities to attract more Canadian firms to apply for patents in Canada. The decision to apply for a patent should be a function of both the intrinsic patentability of the innovation and its potential commercial importance. That is, the decision to apply does not reflect only "quality" but also opportunity.

In Chapters Two and Three, empirical evidence suggests that innovators' locational patenting decisions are affected by various factors. However, it is not clear how these factors affect innovators' patenting behavior. In Chapter Four, I develop a theoretical framework to analyze the processes by which such factors affect firms' decisions on where to patent. I consider the role of innovation quality, application fees, the intensity of examinations, and the economic opportunities. The model indicates that high-quality innovations are more likely to be patented in multiple countries. I also show that cooperation among patent offices regarding information availability and application sequence can make a difference to firms' locational patenting decisions.

This thesis contributes to the patent literature in three aspects. Firstly, this thesis complements the patent literature by providing evidence on firms' decisions on where to patent (Hanel, 2005). In Chapter Two, I empirically investigate what factors affect firms' patenting decisions by directly linking patent data and firm-level characteristics. In contrast, existing studies either use surveys to ask firms directly why they patent or theoretically discuss motivations behind firms' patenting decisions (e.g., Cohen, 2010; Eckert and Langinier, 2014).

Second, to my knowledge, Chapter Three is the first study focusing on how a country's participation in PCT as an ISA can affect firms' decisions to patent, and decisions on where to patent. I develop a two-stage model of filing patent applications across countries and provide empirical evidence on the theoretical predictions using a unique dataset.

Third, there is no theoretical model to analyze the effect of application sequence and information availability on locational patenting decisions. In Chapter Four, I attempt to fill this theoretical gap. I develop a benefit-cost framework to analyze a firm's decision on whether to patent in a country. The model incorporates the quality of innovations, the perceived quality of patents, the patent examination intensity, and business opportunities in a country. I then extend the model by investigating the role of application sequence and information availability.

The empirical findings have a few policy implications. If the policy target is to encourage firms to apply for patents in their home country, the domestic patent office may set preferential policies towards young and small firms. Besides, the domestic patent office may be worth participating more in international patent cooperation, like becoming an ISA. However, if the policy target is to encourage firms to apply for patents abroad, the policy direction is to reduce the barriers for firms to do business in foreign markets and to enhance trade and investment cooperation with other countries. In this respect, encouraging patenting abroad may not be achieved when the domestic patent office becomes an ISA.

The empirical analyses help us understand how the locational patenting decisions are related to firm-level, industry-level characteristics, and CIPO's role as an ISA. However, it has several limitations due to data availability, which also leaves us some future research areas.

Future studies can first investigate where a firm would patent first if it considers various patenting locations. Where to start might be important since the application outcome at the first filing patent office will have a significant impact on subsequent patenting decisions. When the home patent office is the ISA, examiners for PCT applications during the international and national phases are likely to be the same. If an examiner gives a positive report during the international phase, he will likely grant a patent to the same applicant. When the domestic patent office becomes an ISA, it is interesting to investigate whether a PCT application is more likely to be granted a patent. In Canada's case, this issue could be addressed with data on a more extended period, such that all patent applications submitted before 2008 have received their granting decisions.

Next, researchers can conduct a more in-depth analysis of whether a patent office should become an ISA. In this paper, I assume that the granting process within a patent office is mechanical. However, it would be insightful to endogenize the decision process within patent offices. Future studies could focus on how examiners determine their efforts to process applications in different cases and on how patent offices make decisions on whether or not to become an ISA.

Then, I do not explore the effect of CIPO's role as an ISA on the quality of patents, which has caught a lot of attention in the literature. It would be interesting to investigate theoretically and empirically how the quality of patents will change when the domestic patent office becomes an ISA or generally gets more involved in international patent cooperation.

In recent years, the Patent Prosecution Highway (PPH) has become popular among innovators seeking patent protection in several countries. Like PCT, PPH is an international cooperation program designed to speed up the application process by sharing information among patent offices. Since 2014, CIPO has signed PPH agreements with 29 patent offices. Up to June 2019, CIPO has received 18,342 PPH requests compared to 60,336 at USPTO.[5] An investigation of the potential effects of joining the PPH will further enhance our understanding of how international patent cooperation can affect firms' locational patenting decisions.

The model in Chapter Four provides some new insights to understand the cross-border patenting behavior of firms and the impacts of cooperation among patent offices. However, I do not

[5]The numbers are extracted from the Patent Prosecution Highway Portal Site.

consider the timing effect of the application sequence. For instance, with information availability, the second office may save examination and search time, and applicants can also receive the granting decision faster. Theoretical contributions may also be extended to analyze how one patent office would interact with another in terms of information availability. There is also a lack of empirical evidence on the effect of the application sequence.

Finally, at different stages of a country's development, firms' patenting decisions can be different. Studying the relationship between firms' locational patenting decisions with a country's development would be interesting. Firms in a developing country can be weak in their innovative capacity. However, does it mean that these firms will not consider patenting abroad? When the country develops, these firms' inventive capacity will increase. Does it mean that these firms will consider patenting abroad? We need more investigations to answer such questions.

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