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Old Wine in New Bottles: Patenting Propensity

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Abstract

Although patenting propensity has been an old topic, our understanding of it is still fragmentary due to the complexity in the decision-making and the data limitations in empirical research. This paper first provides a conceptual framework showing that firm characteristics, business opportunities, and the patent system jointly determine firms' patenting decisions. Using a unique dataset merging patent data from multiple patent offices with firm-level data during 2000–2008 for Canadian firms, we then study patenting propensity empirically. We find that firms' propensity to patent is associated with firm age, size, expenditure on research and development, and profitability, as well as business opportunities measured by industry-level exports. Further, Canada's participation in the Patent Cooperation Treaty as an International Search Authority has encouraged more firms to patent. Theoretical and empirical investigations support the idea that a useful framework of studying firms' patenting propensity should simultaneously consider firms' internal and external factors within and outside the patent system.

Keywords Firm-level · United framework · Patent system · Patenting propensity

JEL Classification O30 · O34 · O38

1 Introduction

Firms apply for patents to avoid lawsuits, increase negotiation position, prevent imitation, obtain licensing revenue, avoid expensive imitation costs, distort rival firms' decisions in research and development (R&D) activities, reduce the risk of being held up by external patent owners, and increase the value of innovation (e.g., Cohen et al. 2000; Hall and Ziedonis 2001; Sichelman and Graham 2008; Graham et al. 2009; Palangkaraya et al. 2008;

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Arora et al. 2008). Existing studies have made significant contributions to explain patenting decisions from various perspectives, but our understanding of patenting propensity is still fragmentary.[1] Any single factor is insufficient to determine the patenting decision. A firm's patenting propensity is usually influenced by many considerations (Eckert and Langinier 2014). To decide whether to apply for patents, a firm needs to evaluate benefits and costs, as well as prospects and risks. The evaluation often incorporates multi-level factors related to the firm, the industry, and the macro institution.

This paper aims to build up a unified framework to model firms' patenting decisions basing on benefit-cost analysis. Integrating key factors discussed in the literature, the unified framework provides an effective instrument to analyze firms' patenting propensity. Theoretically, the framework incorporates three levels of factors. First, we examine firm characteristics that affect a firm's innovating ability, which is the cornerstone in the firm's decision to patent or not. Innovating ability indicates the extent of benefits that innovation may bring to the company. Without protection, it will be a loss for the company when the intellectual property is infringed. The difference in patenting benefits and costs determines whether innovation is worth patenting. For instance, young firms have a stronger incentive to gain market power through patenting, whereas older firms have more resources to conduct quality research and development (Peeters 2006). Hence, we propose to consider firm characteristics, such as age, size, R&D intensity, profitability and debt ratio (Coad 2018; Cohen 2010; Lerner and Zhu 2007; Tian and Wang 2011). Second, the business opportunity is also an important condition when innovators make patenting decisions. The business opportunity of the industry indicates the potential value of the application of a patent. For example, industry-level export intensity and FDI demonstrate the existing opportunity in foreign markets, and competition intensity also induces propensity to apply for patents. Finally, the design of the patent system at the institutional level is another factor (Hall and Helmers 2019). It determines the costs and convenience of applying for patents and therefore affects the probability of obtaining patents.

Using a unique dataset merging from multiple patent offices, we apply the theoretical framework to examine firms' patenting propensity empirically. In the past, empirical studies have been limited by data availability. Legal obligations and confidentiality issues have prevented researchers from merging patent data with firm-level information. This is even challenging to link firm-level data with patent data across countries. As a result, firms' patenting propensity has been investigated, either focusing on surveys of selected firms or focusing only on patenting at a location in existing studies (see examples in Cohen 2010; Eckert and Langinier 2014). However, without including patenting behavior at home and abroad, findings can be biased. For example, during 1990–2010, Canadian patent applications accounted for about 13–15% of all patent applications in Canada, whereas the USA was the destination of 50% of Canadian applications (Nikzad 2011, 2013). In this paper, we were granted access to information on Canadian firms' patenting in Canada and the USA and these firms' tax filing information by Statistics Canada. Our analysis of patenting propensity is based on the sample of all Canadian firms and considers their patenting activities in both Canada and the USA during 2000–2008.

Overall, the empirical findings from Canadian firms are consistent with our theoretical discussions. First, firm characteristics such as firm size, age, profitability, R&D expenditures

[1] Patenting propensity or propensity to patent in this paper primarily refers to innovators' inclination to apply for patents when they have patentable innovation. In our empirical analyses, in a narrow sense, it refers to Canadian firms' inclination to apply for patents that are eventually granted when patenting in the USA is involved because data on patenting in the USA only include patents that are granted.

have shown significant effects on patenting propensity. Second, industry-level business opportunities influence firms' patenting propensity. Specifically, firms in export-intensive industries have shown a stronger patenting propensity than those in other industries; and industry-level competition induces manufacturing firms to apply for patents. Finally, the institutional-level patent system design has a significant impact. After the Canadian Intellectual Property Office (CIPO) started its services as an International Search Authority (ISA) under the Patent Cooperation Treaty (PCT), more Canadian firms were encouraged to apply for patents. These findings are robust to patenting propensity at home and abroad.

Despite patenting propensity being an old topic, some issues are still unclear and worth more study due to the complexity of firm decisions. This paper contributes to the literature in several ways. First, we build a unified framework to provide a comprehensive understanding of firms' patenting propensity. Firm-level characters, industry-level business opportunities, and institutional-level patent system design are considered.

Second, this paper contributes to empirical research by focusing the whole sample of Canadian firms and their patenting worldwide and thus may avoid potential biases due to limited sampling in the existing literature. Unlike survey data and separated data, the data used in this study are merged from multiple patent offices; and we link firm-level data with patent data across countries. This unique dataset allows us to investigate firms' patenting propensity at home and abroad. In particular, this paper complements (Eckert et al. 2020), who focus on a sample of Canadian firms that have applied for patents and investigate these firms' decisions on where to apply for patents.

The structure of this paper is organized as follows. Section 2 reviews the related literature. In Section 3, we investigate a firm's patenting decisions in a conceptual framework. Section 4 focuses on the econometric framework, whereas Section 5 describes the data sources, defines explanatory variables, and presents summary statistics. Section 6 presents the empirical findings. Section 7 concludes.

2 Literature review

In theory, innovating firms have private information about the profitability and improvability of their innovation (Horstmann et al. 1985; Langinier 2005). These firms can influence the behavior of their competitors strategically through random patenting. As patent examiners have the authorities to grant patents, they can also affect innovators' incentives to patent (see Lemley et al. 2005; Lichtman and Lemley 2007; Atal and Bar 2010,). Other theoretical studies also consider imitation cost (Gallini 1992) and breadth of patents (Gilbert and Shapiro 1990).

The theoretical investigations suggest that information asymmetry between innovators and other parties, including examiners and competitors, allows innovators to patent strategically. However, patenting decisions can be affected by more factors than theories can model. Empirical investigations also provide important insights. For instance, survey-based studies suggest that firms apply for patents to avoid lawsuits, increase negotiation position, prevent imitation, and obtain licensing revenue etc. (Levin et al. 1987; Cohen et al. 2000; Hall and Ziedonis 2001; Sichelman and Graham 2008; Graham et al. 2009). These surveys also suggest that firms may also choose not to patent to avoid disclosing too much information because of fees involved or because of the fear that competitors will invent around their patents. Hence, firms' patenting decision is a complex issue, and it is still worth studying.

Asking firms why they apply for patents is the most straightforward way to know about their incentives to patent. The main value of patents is the temporary monopoly power that allows patent holders to exclude their competitors from using the same technology. The purpose that firms apply for patents is to maintain their monopolistic position (Gilbert and Newbery 1982). However, survey-based studies suffer from a few shortcomings. First, incentives reported in surveys may depend on the respondents' expertise, experience, and understanding, leading to subjective answers. Second, reported incentives are hardly connected to other factors to understand the firm's patenting behavior fully. As a result, many studies directly link patent data to firm-level characteristics. Factors explored in empirical studies can be divided into firm-level factors, business opportunities, and patent system design.

Many studies have focused on firms' characteristics. Firm age is one factor that has been related to firms' patenting decisions (Balasubramanian and Lee 2008; Kotha et al. 2011; Coad 2018). Peeters (2006) argue that while young firms may be motivated to apply for patents for higher market power, older firms are more capable of supporting their patenting activities. Firm size is another important factor. Large firms are more likely to create inventions and apply for patents (Cohen 2010). Besides, a firm's patenting decision might depend on whether it is owned by a foreign entity (Baldwin 1997). As well, a positive relationship is found between firms' patenting and their R&D expenditure (Lerner and Zhu 2007), between a firm's profitability and the number of its patents (Tian and Wang 2011), and a negative relationship between the propensity to patent and financial constraints (Cohen 2010).

In addition to firm-level factors, whether an innovation has business opportunities is an important consideration when the innovator makes patenting decisions. Thus, the propensity to patent also differs from industry to industry (Scherer 1965, 1967). For instance, Mansfield (1986) claims that patents are used more frequently in pharmaceutical and chemical industries than other industries. Moreover, manufacturing firms can explore business opportunities across countries. Consequently, firms' cross-border patenting decisions are associated with their decisions to export (Dosi et al. 1990; Licht and Zoz 2000; Maskus and Penubarti 1995; Palangkaraya et al. 2017) and their decision to invest abroad in the form of foreign direct investment (Bosworth 1984; Yang and Kuo 2008; Nikzad 2012).

In particular, investigating patenting propensity is related to the choice of patenting and secrecy for innovation protection. In a theoretical model, Kultti et al. (2007) show that although keeping the innovation secret in many cases provides more protection than patents, patents can be more protective under certain conditions. Further, Kultti et al. (2006) believe that a weak patent system makes the society better off than without a patent system. Panagopoulos and Park (2018) also theoretically show that narrow patent rights can stimulate more innovations than trade secrecy. Empirical evidence is also provided in the literature. For example, Arundel (2001) finds that secrecy was rated higher than patents by R&D-performing firms in Europe in 1993. Hussinger (2006) studies German manufacturing firms in 2000 and concludes that secrecy is important for uncommercialized inventions, but patents are generally more effective for intellectual property protection. In the case of the USA, Cohen et al. (2000) document that secrecy is more heavily emphasized than patents by manufacturing firms.

Finally, firms' decisions to patent are related to factors in the patent system design. In the 1970s, the European Patent Office (EPO) was established to unify examination and granting procedures and reduce the difference in patentability standards across European countries (Deng 2007). Eaton et al. (2004) and Hall and Helmers (2019) have studied this change and found that European firms were encouraged to apply for patents. On the other hand, Lo and Sutthiphisal (2009) conclude that Canadian firms did not react to CIPO's switch from the first-to-invent system to the first-to-file system in 1989. Also, Chan (2010) finds that the standardization of patent laws across countries does not change firms' propensity to patent.

3 Conceptual Framework

The conceptual model aims to link firms' patenting decisions and key determinants intuitively. We assume that each firm has an innovation, and this innovation is good with probability θ, and bad with probability $(1-\theta)$. The value of θ lies between zero and one and it is determined by the firm. For example, if a firm has accumulated rich experience in R&D, we would expect a higher θ for that firm.

We further assume that a bad innovation brings nothing to its owner if it is not patented and a benefit of B if it is patented. As per our setting, B refers to the value of patents per se. In contrast, a good innovation can bring its owner a benefit of $(G+B)$ if it is patented and a benefit of g if it is not patented. G is the monopoly benefit from a patented innovation, and g is the benefit if competitors exist due to the lack of patents. Therefore, it must be the case, $G \geq g$. To some extent, $(G-g)$ measures the competition and business opportunities in the market. If $(G-g)$ is very large, this will imply that being a monopoly in this market would be profitable. On the contrary, if $(G-g)$ is very small, it would mean that this market has no huge potential for monopoly operation. In addition, $(G-g)$ can also be affected by which technology and industry an innovation belongs to. For example, an innovation in the pharmaceutical industry can have a much larger value than an innovation in the agricultural industry."

As per Atal and Bar (2014), B can be understood as the generally perceived value of patents People cannot evaluate the quality of innovation by simply checking if it is patented or not. We assume this part of the benefits from patents is the same for good and bad innovations. The value of B is mostly determined by how the patents are granted.

In this sense, B captures a patent-office-specific patenting benefit. For example, the value of patents is higher with a tighter examination (Atal and Bar 2014). In other words, patent system design plays a role in affecting the value of B. Langinier and Marcoul (2016) argue in their theoretical paper that patent applicants can re-submit an application for a good innovation if it is mistakenly rejected a patent. The re-applying process will help an application of a good innovation eventually get granted a patent. Thus, following Langinier and Marcoul (2016), we assume that a "good innovation" is always granted a patent and a bad innovation can be granted a patent with probability ψ. To apply for a patent, the firm has to pay an application fee, P. To this end, define the expected payoff of a firm with θ from a patent application as

$$\pi^p(\theta) = \theta(G+B) + (1-\theta)\psi B - P \tag{1}$$

where the first part of the equation is the expected payoff if the innovation is good with probability θ and it is granted a patent with certainty, and the second part is the expected payoff if the innovation is bad with probability $(1-\theta)$ and it is granted a patent with probability ψ. To the contrary, if the firm decides not to patent, its expected payoff is

$$\pi^{np}(\theta) = \theta g. \tag{2}$$

Equations (1) and (2) indicate that a firm decides to patent only if $\pi^p \geq \pi^{np}$. For illustration purposes, we plot these two functions in the following figure. Figure 1 shows that there exists a threshold θ^*, which makes the firm indifferent between patenting and not patenting. However, for firms with $\theta > \theta^*$, it would be better to patent.

To summarize, the net benefit between the firm's choice to patent and not to patent, $Patenting^*$ can be written as:

$$Patenting^* = \pi^p(\theta) - \pi^{np}(\theta) = \theta[(G-g) + (1-\psi)B] + \psi B - P. \tag{3}$$

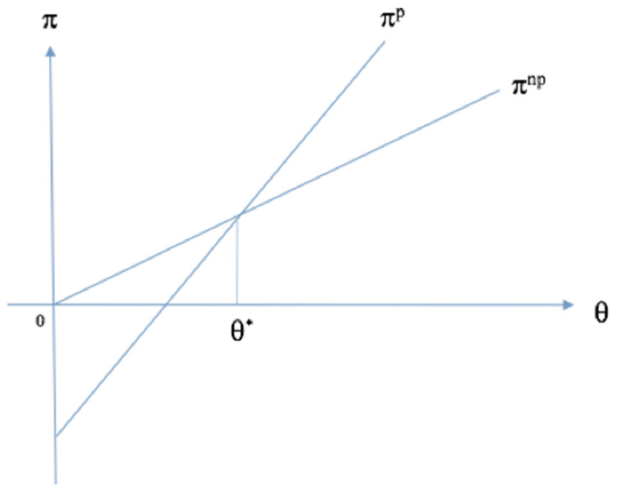

Fig. 1 Firms' decision to patent

Equation (3) indicates that $Patenting^*$ is determined by firm-level factors (θ), business opportunities ($G - g$), and patent system design (B, ψ, P). We will empirically investigate if these three groups of factors play a role in patenting decisions in subsequent sections.

4 Econometric Framework

The above conceptual framework shows us what factors may affect firms' decisions to patent. This section describes how we can empirically investigate the factors affecting firms' patenting decisions.

Applying for patents or not depends on firms' evaluation of the net benefit from patenting, as shown in the conceptual framework. Empirically, let $Patenting^*_{ijpt}$ denote the net benefit between the choices of patenting and not patenting for firm i that belongs to industry j and operates in province p in year t, and is determined by an independent variable vector X_{ijpt} such that

$$Patenting^*_{ijpt} = X_{ijpt}\alpha + \delta_j + \delta_p + \delta_t + \varepsilon_{ijpt}, \tag{4}$$

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.

The observable variable $Patenting_{ijpt}$ is associated with this latent variable in the following way,

$$Patenting_{ijpt} = \begin{cases} 1 & \text{if } Patenting^*_{ijpt} > 0, \\ 0 & \text{Otherwise.} \end{cases} \tag{5}$$

For the empirical analyses, we define $Patenting_{ijpt}$ as a dummy variable, which equals 1 if at least one patent application was filed by firm i of industry j that operates in province p in year t at the United States Patent and Trademark Office (USPTO) or CIPO. Similarly, we define $Patenting\_CA_{ijpt}$ ($Patenting\_US_{ijpt}$) as a dummy variable, which equals 1 if at least one patent application was filed by firm i in year t at CIPO (USPTO). As USPTO only provides information on granted applications, we consider patent applications that were eventually granted when patenting in the USA is involved (e.g., $Patenting\_US_{ijpt}$). To investigate if this treatment affects our results, we use all patent applications at CIPO regardless of the granting status (e.g., $Patenting\_CA_{ijpt}$) as a robustness check in Section 6.2.

5 Data, Variable Construction, and Summary Statistics

This paper merges data of Canadian firms' patenting activities in Canada and the USA with firm-level and industry-level variables. This section provides some details of datasets, defines the independent variables, and presents summary statistics.

5.1 Data and Sample Construction

We have access to Canadian firms' patenting in Canada (CIPO data) and the USA (USPTO data). When a patent application is submitted to CIPO, it will not be examined until the applicant requests an examination. In contrast, an application will be automatically examined when it is submitted to USPTO. In our sample, it took 2.8 more years at CIPO than at USPTO for a patent application to receive a granting decision. USPTO patent data are available for patents granted by 2011 at USPTO, and CIPO data are available for patents granted by 2014 at CIPO. Due to the truncation problem, the number of patent applications declined sharply due to truncation issues, so we used data for 2000–2008. We define the dependent variables as binary variables in this paper; thus, the exact number of patents should have a limited impact on our analyses.

Firm-level variables are constructed based on the National Accounts Longitudinal Microdata File (NALMF), maintained by Statistics Canada. NALMF contains information on firms' employment, locations where they operate, revenue, ages, etc. Patent data at CIPO and USPTO are matched to NALMF based on firms' names and addresses.[2]

Industry-level factors are the proxy of business opportunities. We download data of industry-level exports from the Government of Canada's website,[3] and data on industry-level FDI were downloaded from the website of Statistics Canada: Table 36-10-0009-01 (formerly CANSIM 376-0052).[4]

5.2 Variable Construction

This subsection discusses the variable construction. We identify firm- and industry-level factors and pay special attention to business opportunity measures.

First, we consider several firm-level factors. We use the natural logarithm of the year gap between a firm's establishment year to the current year to measure firm age,

[2]The NALMF dataset does not have information on individuals and universities. Therefore, we exclude patents applied for or held by individuals and universities. Besides, some patents cannot be assigned to any firm in NALMF. Overall, about 20 percent of patents cannot be matched to firms in NALMF.

[3]Search by industry (North American Industry Classification System codes) - Trade Data Online. https://www.ic.gc.ca/app/scr/tdst/tdo/crtr.html?&productType=NAICS&lang=eng. Last accessed January 2, 2018.

[4]It should be noted that data of industry-level exports from the Government of Canada's website is self-reported by firms and may suffer from the selection bias. However, this is the best available export data we can use for this paper.

$log(firm\ age + 1)_{it}$. Firm size is measured by the logarithm of the total number of employees $log(employee)_{it}$.[5] To differentiate domestic firms from foreign-owned firms, we create a dummy $Canadian\ control_{it}$, which equals 1 if firm i is registered in Canada and owned by a Canadian entity in year t. We also measure firms' R&D intensity as a ratio between total R&D expenses and total assets, $R\&D\ intensity_{it}$.[6] As well, firms' profitability is proxied by the ratio between gross profit and total assets, $profitability_{it}$. Furthermore, we use the ratio between total liabilities to total assets as a proxy for financial constraints, $debt\ ratio_{it}$.

Second, we measure business opportunities by considering industry-level factors. If a firm faces intense competition, patents will become more critical. The Herfindahl-Hirschman Index measured the competition intensity at the 3-digit North American Industry Classification System (NAICS) level, HHI_{jt}. Moreover, we construct two measures of business opportunities at the industry level. The first one is the industry-level export, $log(industrial\ export)_{jt}$, which is the natural logarithm of annual Canadian exports of firm i's 3-digit NAICS industry to the USA. It captures how Canada-Made products are demanded in the USA. The other is based on industry-level FDI, $log(industrial\ FDI)_{jt}$, which is the natural logarithm of the annual FDI in the USA of firm i's 3-digit NAICS industry. This variable aims to capture how Canadian firms perceive investment opportunities in the USA.

Finally, we construct a variable to measure changes in the Canadian patent system. During 2000–2008, the major change is that CIPO started its services as the ISA for PCT applications in 2004. This paper aims to investigate whether CIPO's participation in PCT encouraged more Canadian firms to patent. We compare firms with at least one patent at CIPO to firms without patents during 1995–2003. We generate a dummy variable, $CIPO\_2004_{it}$, which equals 1 for the former and 0 for the latter firms. We then generate a dummy variable, ISA_t, which equals 1 for years after 2004. The interaction term of $CIPO\_2004_{it}$ and ISA_t, $isaxcipo_{it}$, allows us to investigate if patenting firms at CIPO reacted to CIPO's role as an ISA differently from those that did not patent at CIPO. Table 1 collects the definitions of all variables for easier reference.

5.3 Summary Statistics

Table 2 provides summary statistics to compare non-patenting firms and patenting firms, where patenting firms are those that have at least one patent application during our study period, and the remaining are non-patenting firms. NALMF contains all Canadian firms, but only a small fraction of them can be identified as patenting firms (roughly 0.1%).[7]

[5] We have explored the potentially non-linear effect of firm size and firm age by including their squared term in the regressions. The squared term is not significant in these explorations. As such, we keep firm size and firm age in their logarithm forms.

[6] Reporting R&D is not mandatory in the data collection process. However, one 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 acceptable to assume that this firm has not done any R&D.

[7] The proportion of patenting firms seems too low. After carefully checking all the matching programs, we also discussed this issue with the data maintenance staff at Statistics Canada. This rate was confirmed what we could obtain by matching CIPO data and NALMF data for 2000–2008. It is worth noting that 20% of patents in CIPO data cannot be matched to firms in NALMF, and this proportion was based on firms without missing values for these variables used in regressions. Thus, there should be more patenting firms than these included in our regression analyses.

Table 1 Definition of Variables

Variables	Definition	Data Sources
Patenting variables		
$Patenting\_CA_{ijpt}$	Dummy variable, which equals 1 if firm i of industry j that operates in province p applies for patents in Canada at t	CIPO
$Patenting\_US_{ijpt}$	Dummy variable, which equals 1 if firm i of industry j that operates in province p applies for patents (eventually granted) in the USA at t	USPTO
$Patenting_{ijpt}$	Dummy variable, which equals 1 if firm i of industry j that operates in province p applies for patents (eventually granted) at t in either the USA or Canada	CIPO & USPTO
Firm characteristics		
$log(firm\ age + 1)_{it}$	Number of years since the firm was established of firm i in year t	NALMF
$log(employee)_{it}$	Natural logarithm of employees of firm i in year t	NALMF
$Canadian\ control_{it}$	Dummy variable that indicates if firm i is Canadian controlled in year t	NALMF
$R\&D\ intensity_{it}$	Ratio of R&D expenditure to the amount of tangible asset of firm i in year t	NALMF
Productivity	Return on assets ratio defined as gross profits divided by total assets of firm i in year t	NALMF
Debt ratio	Ratio of total liabilities and total assets of firm i in year t	NALMF
Business opportunities		
$log(industrial\ export)_{jt}$	3-digit NAICS industry-level of Canadian export to the USA (Millions C$),	Industry Canada
$log(industrial\ FDI)_{jt}$	3-digit NAICS industry-level of Canadian FDI in the USA (Millions C$),	Statistics Canada
HHI_{jt}	Herfindahl-Hirschman Index: sum of squared market share of each firm in the same industry j in year t. We times this index with 100 to adjust for the magnitude of estimators	NALMF
Design of Patent System		
$CIPO\_2004_{it}$	Dummy variable indicating if a firm only started to patent at CIPO after 2004	CIPO
ISA_t	Dummy variable indicating years after 2004	CIPO
$isaxcipo_{it}$	The product of $CIPO\_2004_{it}$ and ISA_t	CIPO

Patenting firms are older, larger, and operating in more concentrated industries, spending more in R&D, and have lower profitability than non-patenting ones. There is no substantial difference in the debt ratio between patenting and non-patenting firms.

Table 3 reports the correlation coefficients of key independent variables based on the sample of patenting firms. The statistics suggest that our regression analysis is not subject to the multicollinearity problem as these variables are not highly correlated.

Table 2 Summary statistics for non-patenting 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)
No. of observations	3994818	4797

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

6 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. 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 USA in the auto industry. Changes in the economic conditions of the USA will likely have a more sizable impact on firms' profitability in the auto industry than firms' profitability in other sectors of other provinces. To mitigate the endogeneity concern, we include industry fixed

Table 3 Correlation coefficients of key variables for patenting firms

	1	2	3	4	5	6	7	8
1: log(firm age+1)	1							
2: Debt ratio	− 0.19	1						
3: Profitability	0.01	0.00	1					
4: R&D intensity	− 0.30	0.38	0.04	1				
5: HHI	0.03	− 0.02	− 0.13	0.08	1			
6: log(employee)	0.36	− 0.23	− 0.28	− 0.32	0.24	1		
7: log(industrial FDI)	− 0.01	0.00	− 0.06	0.16	0.08	0.03	1	
8: log(industrial export)	0.03	− 0.01	− 0.10	− 0.03	0.26	0.13	0.40	1

effects, year fixed effects, and province fixed effects to capture the effects of these unobserved factors. As a robustness check, we compare the results using the whole sample and the sub-sample of manufacturing industries.[8]

6.1 Overall Patenting Propensity

We first investigate Canadian firms' overall patenting propensity by considering their patenting in Canada and the USA as a whole. Table 4 panel A reports estimates of the factors affecting firms' patenting decisions using the whole sample. A few results deserve our attention. First, several firm-level factors have shown significant effects on Canadian firms' patenting decisions. For example, young firms are more likely to apply for patents than old ones. Interestingly, while profitable firms are reluctant to apply for patents, firms with intensive R&D tend to patent. Meanwhile, the debt ratio's financial constraint has no significant effect on firms' patenting decisions.

Second, the industry-level factor, HHI, does not show a significant effect on patenting decisions. Regarding the impact of industrial concentration on patenting decisions, no consensus is reached in the literature. While firms have incentives to apply for patents to maintain their monopolistic position (Gilbert and Newbery 1982), firms may be reluctant to patent as they do not want to disclose information (Graham et al. 2009). The results suggest that Canadian firms generally keep a balance on the opposite effects of competition.

Finally, the coefficient of the dummy variable $isaxcipo_{it}$ is positive and statistically significant, suggesting that after CIPO became an ISA, more Canadian firms that have never patented at CIPO submitted patent applications at CIPO. This suggests that Canadian firms' decisions to patent are associated with patent system design.

In our dataset, patent applications of firms in manufacturing industries account for about 60% of total patent applications. However, these manufacturing firms represent only 8% of all firms. As a result, Table 4 panel B reports the estimates focusing on manufacturing firms. The key difference is that we include industry-level export and FDI in our regression analysis as proxies of business opportunities. Overall, the results of manufacturing industries regarding firm age, Canadian ownership, debt ratio, profitability, R&D intensity, and firm size are consistent with those of the whole sample. However, the coefficient of $isaxcipo_{it}$ becomes insignificant. Firms in manufacturing industries have intensively patented, so they were not sensitive to CIPO's role as an ISA.

Furthermore, the probability that a firm decides to patent is positively associated with the manufacturing sector's exports, whereas firms in FDI intensive sectors do not show a preference for patenting. Besides, the coefficient of HHI becomes significant, suggesting that competition is an essential factor affecting manufacturing firms' patenting decisions.

In terms of the magnitude of the coefficients, the coefficients from the whole sample are generally larger than those from the manufacturing firms except for firm size. However, the difference is not substantial. This may reflect that manufacturing firms are the main patent applicants, so their patenting behavior is likely to represent firms from all industries.

[8] 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.

Table 4 Regressions on Canadian firms' decisions to patent

Dependent variable	Panel A: All industries Patenting	Panel B: Manufacturing Patenting
Firm characteristics		
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)
log(employee)	1.0823***	1.1260***
	(0.0190)	(0.0329)
Design of patent system		
isaxcipo	0.2130**	0.1439
	(0.1063)	(0.1583)
Business opportunities		
HHI	0.0060	0.0085***
	(0.0011)	(0.0027)
log(industrial FDI)		0.0520
		(0.0410)
log(industrial export)		0.2348***
		(0.0580)
No. of observations	3998293	322747
No. of firms	859923	65476

Coefficients are the average marginal effects of Logit models. Panel A is based on firms from all industries, and panel B focuses on manufacturing firms only. All regressions include two digits industry, firms' operating province, and year fixed effects. Standard errors are in parentheses. * indicates significance at 10% level. ** indicates significance at 5% level. *** indicates significance at 1% level

6.2 Robustness Check

A firm that has no patents can be attributed to the following reasons. First, the firm has not invested in R&D, or it has but failed, and thus has no innovation to patent. Second, the firm may have patentable innovation, but it strategically decides not to apply for patents. We cannot identify the second reason through our data, but the first one can be observed. To check if including all firms overestimate firms' decisions to not patent, we re-estimate Canadian firms' decisions to apply for patents by only including firms that have either done R&D or patented during our study period (hereafter, innovating firms). The estimation results are presented in Table 5.

Table 5 shows that excluding firms that have neither applied patents nor conducted R&D reduces the number of observations drastically. This suggests that innovating firms account

Table 5 Regressions on decisions to patent by Canadian innovating firms

	Panel A: All industries	Panel B: Manufacturing
Dependent variable	Patenting	Patenting
Firm characteristics		
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)
log (employee)	0.7002***	0.8822***
	(0.0258)	(0.0395)
Design of patent system		
isaxcipo	0.4550***	0.1147
	(0.1125)	(0.1710)
Business Opportunities		
HHI	0.0034	0.1366***
	(0.0156)	(0.0310)
log(industrial FDI)		− 0.0241
		(0.0483)
log(industrial export)		0.0968
		(0.0710)
No. of observations	230444	80521
No. of firms	39179	16003

Coefficients are the average marginal effects of Logit models. Panel A and panel B are based on firms that have reported R&D, and they are from all industries and manufacturing industries, respectively. All regressions include two digits industry, firms' operating province, and year fixed effects. Standard errors are in parentheses. * indicates significance at 10% level. ** indicates significance at 5% level. *** indicates significance at 1% level

for only a small fraction of all firms in our sample. The results indicate that our results in Table 4 are robust and consistent with the only exception regarding the impact of industrial export, which suggests that when we consider innovating firms only, the impact of R&D may dominate that of industrial export. If an innovating firm has no patents, it potentially keeps its innovation secrets other than has no innovation. Thus, our results to some extent reflect the determinant of firms' choice of patenting over secrecy, although we cannot refer to any specific data on secrecy.

Another concern regarding the analyses in Table 4 is that Canadian firms' patenting behavior in the USA can be different from that in Canada (Eckert et al. 2020). We estimate

Table 6 Regressions on innovating firms' decisions to patent in Canada and the USA

	Panel A: All industries		Panel B: Manufacturing	
Dependent variable	Patenting_CA	Patenting_US	Patenting_CA	Patenting_US
Firm characteristics				
log (firm age+1)	– 0.3331***	– 0.4224***	– 0.1752***	– 0.3459***
	(0.0374)	(0.0386)	(0.0636)	(0.0685)
Canadian control	0.7500***	0.5258***	0.7624***	0.1449
	(0.1781)	(0.1782)	(0.2329)	(0.2236)
Debt ratio	0.0421	0.0211	0.1310*	0.0240
	(0.0374)	(0.0337)	(0.0707)	(0.0713)
Profitability	– 0.8562***	– 0.9421***	– 0.4714***	– 0.7784***
	(0.0594)	(0.0581)	(0.1174)	(0.1261)
R&D intensity	1.4564***	1.7770***	1.3132***	1.7582***
	(0.0848)	(0.0862)	(0.1730)	(0.1850)
log (employee)	1.0083***	1.0245***	1.0773***	1.0265***
	(0.0206)	(0.0226)	(0.0364)	(0.0391)
Design of patent system				
isaxcipo	0.0145	– 0.1105	0.1138	– 0.0716
	(0.1225)	(0.1297)	(0.1786)	(0.1933)
Business opportunities				
HHI	0.3133	1.2341	3.6394	9.7813***
	(1.2861)	(1.2518)	(3.0498)	(3.3668)
log(industrial FDI)			– 0.0103	0.0366
			(0.0459)	(0.0506)
log(industrial export)			0.2821***	0.2325***
			(0.0634)	(0.0727)
No. of observations	230444	230444	80521	80521
No. of firms	39179	39179	16003	16003

Coefficients are the average marginal effects of Logit models. Panel A and panel B are based on firms that have reported R&D, and they are from all industries and manufacturing industries,respectively. All regressions include two digits industry, firms' operating province, and year fixed effects. Standard errors are in parentheses. * indicates significance at 10% level. ** indicates significance at 5% level. *** indicates significance at 1% level

Canadian firms' patenting propensity in Canada and the USA in Tables 6 and 7. Tables 6 and 7 focus on innovating firms and all Canadian firms, respectively. In these two tables, while panel A considers firms in all industries, panel B is restricted to manufacturing firms. In each panel, we first investigate firms' patenting propensity in Canada ($Patenting\_CA$) and then in the USA ($Patenting\_US$). The results in both tables are consistent with the results in Table 4. WIPO statistics suggest that Canadian patent applicants obtained 74% of their patents from either of these two countries during 2000–2008, so our sample here is representative of Canadian firms' patenting.

Table 7 Regressions on Canadian firms' decisions to patent in Canada and the USA

	Panel A: All industries		Panel B: Manufacturing	
Dependent variable	Patenting_CA	Patenting_US	Patenting_CA	Patenting_US
Firm characteristics				
log (firm age+1)	− 0.2527***	− 0.3071***	− 0.1741***	− 0.3244***
	(0.0466)	(0.0501)	(0.0723)	(0.0808)
Canadian control	0.6284***	0.3870**	0.5523**	− 0.1292
	(0.1885)	(0.1917)	(0.2456)	(0.2394)
Debt ratio	− 0.0019	− 0.0118	0.1292	0.0034
	(0.0408)	(0.0362)	(0.0794)	(0.0773)
Profitability	− 0.8737***	− 0.9268***	− 0.3420***	− 0.6438***
	(0.0731)	(0.0733)	(0.1366)	(0.1471)
R&D intensity	0.3913***	0.5532***	0.6565***	1.0101***
	(0.1159)	(0.1078)	(0.2088)	(0.2127)
log (employee)	0.6450***	0.5827***	0.8558***	0.7473***
	(0.0256)	(0.0290)	(0.0417)	(0.0469)
Design of patent system				
isaxcipo	0.1584	0.1068	0.0936	− 0.0344
	(0.1295)	(0.1338)	(0.1898)	(0.2019)
Business opportunities				
HHI	− 0.2949	1.6778	7.8076**	13.9660
	(1.7406)	(1.7369)	(3.3110)	(3.7946)
log(industrial FDI)			− 0.0696	− 0.0353
			(0.0521)	(0.0589)
log(industrial export)			0.1780**	0.1126
			(0.0731)	(0.0880)
No. of observations	3998293	3998293	322747	322747
No. of firms	859923	859923	65476	65476

Coefficients are the average marginal effects of Logit models. Panel A and panel B are based on firms from all industries and manufacturing industries, respectively. All regressions include two digits industry, firms' operating province, and year fixed effects. Standard errors are in parentheses. * indicates significance at 10% level. ** indicates significance at 5% level. *** indicates significance at 1% level

7 Conclusions

This paper investigates what factors affect firms' decisions to patent. We first demonstrate in a conceptual framework that firms' patenting decisions are determined by firm-level factors, business opportunities, and patent system design factors. We then use Canadian firm-level data for 2000–2008 to investigate if Canadian firms' patenting decisions are affected by these three groups of factors as suggested.

The empirical results show that Canadian firms' patenting decisions are associated with firm-level factors such as firm size, age, profitability, R&D intensity, and foreign ownership. Canadian firms' decisions to patent are also related to industry-level factors that affect business opportunities, such as industrial concentration and export intensities. Moreover, when

CIPO started its service as an ISA in 2004, more Canadian firms were induced to apply for patents at CIPO.

Several policy implications deserve policymakers' attention. First, the results show that large and young firms are more likely to patent. Preferential subsidies can be given to small and old firms to encourage more firms to apply for patents. Second, firms in export-intensive sectors tend to patent more than firms in other sectors. If trade barriers can be further removed, firms may be more likely to apply for patents. Moreover, when CIPO participated in PCT as an ISA, more Canadian firms submitted patent applications at CIPO. This suggests that more firms will be encouraged to apply for patents if a country's patent office can work with other patent offices to reduce the differences in patenting regulations and rules.

This paper investigates the factors that affect firms' decisions to apply for patents theoretically and empirically. Nevertheless, many questions remain unanswered regarding how these factors affect firms' patenting decisions. For example, it would be insightful to investigate how the business cycle and the interaction between R&D intensity and profitability (Kovač and Spruk 2021) affect firms' patenting propensity. Besides, this paper has investigated firms' patenting decisions against all other intellectual property protection mechanisms. Thus, another topic of interest to explore is firms' choice between patenting and secrecy. Further, after CIPO became an ISA, more Canadian firms were encouraged to patent. However, we do not know how being an ISA changes firms' patenting incentives. As such, it is left for future research.

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