The Evolution and Spatial Dimensions of Invention in Canada, 1991 - 2011

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Abstract

The rapid development of information technology and medical research in the 21st century is a result of the increasing number of inventions. Inventive activity is thought to be an important catalyst for economic change and increased productivity. In order to measure a location's inventive potential, different aspects such as geographic location, corporate assistance, and socio-economic factors can be studied. This study examines the spatial distribution and typology of Canadian inventions for the years 1991, 2001, 2006, and 2011, using patent data issued by the United States Patent and Trademark Office.

The research results suggest that inventive activity is declining in major metropolitan areas such as Toronto, Vancouver, and Montreal. On the other hand, medium-sized metropolitan areas like Ottawa, Calgary, Kitchener-Waterloo, and Saskatoon are experiencing increasing inventiveness. These areas have specialized economies based on high technology and petroleum. The regression analysis shows that regional innovation can be explained by census variables in groups of dwelling type, education level, and industry sector. The analysis also shows Canada has shifted from a manufacturing economy to a high technology and services-based economy.

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1.0 Introduction

The rapid development of information technology and medical research in the 21st century is a result of the increasing number of inventors and innovations (Erne, 2011). The relationship between innovation and economic success of a geographic region is well studied in academia and many researchers have examined the topic using various quantitative measures. Castaldi et al. (2015) suggest that related variety of inventions will enhance innovation because related technologies are more easily transformed into a new technology. Unrelated variety enhances technological breakthroughs because radical innovation often connects to previously unrelated technologies opening up whole new functionalities and applications. Innovation and new technological knowledge could influence a firm's direction of technical change and sustain long-run endogenous growth (Irmen & Tabakovic, 2017).

The degree of innovation relies on criteria such as the geographic location, corporate assistance, amenities, and socio-economic factors. In Canada, education attainment and business investments in research and development (R&D) can be considered to be the key factors to improve outputs across all industry sectors. The extent to which innovation is taking place in Canada can be quantified by using invention-based data. The number of the inventions can be measured by patents granted by the United States Patent and Trademark Office (USPTO). USPTO has a collection of patents that records the geographic location of the inventors, including those that resided in Canada at the time of application. In the years of 1991, 2001, and 2006, a higher number of inventors in Canada chose to seek a patent from the USPTO than from the Canadian Intellectual Property Office (CIPO), which makes U.S. patent data as a useful source to measure Canadian innovation (Erne, 2011).

Ceh (1996; 1997) studied the geography of innovation in Canada for the time period of 1975 to 1989; Kosior (2006) and Erne (2011) added to the literature for the time period of 1991 to 2006. The purpose of this paper is to explore the rate of Canadian inventions for the period 1991 to 2011, at both spatial and non-spatial levels. The research questions are:

1. What are the non-spatial and spatial patterns of inventions in Canada?
2. How do patents of 2011 change compare to the previous years?
3. What leads to inventiveness?

Understanding the geographic location of inventors in Canada is vital to understanding where and what parts of the economy are being led by creative endeavors. In addition, the comparison between patents of 2011 with patents of previous years will show the rising and declining hubs of inventions, which also includes the comparison of independent assignees versus organization assignees. Among the thousands of patents granted to Canadians each year, some inventions may be more useful than the others. Such measure of inventive output reveals which industries and which organizations are the key players in industrial creativity. Lastly, finding out the socio-economic factors and other variables relating to patent counts would help uncover the relationship to inventions and further support research questions 1 and 2. It should be noted that patents granted by the USPTO are actually collected for up to the time period of 2016. This is because patents applied in 2011 took a few years to be granted, usually 2-3 years, though some took longer.

2.0 Literature Review

The analysis of invention and innovation can be dated as early as 1939 by Schumpeter, who argues that inventive activity is essential for the growth of industrial economies. Until this day, the process of innovation is studied continuously by scholars worldwide. Since economic infrastructure is different from one country to another, scholars tend to construct each study for a single country. For example, Mckenzie (2012) conducted a research in Canada on the tax support for R&D; Sedgley and Elmslie (2011) measured the rates of innovation of American metropolitan areas; Mukim (2012) studied the relationship between agglomeration economies and innovation in India. Measuring creativity takes many forms, but typically includes analyses of R&D expenditures, patents, trademarks, and other similar measures.

This section of the paper explores the context of related academic journal articles. The focus is placed on the Canadian economy and the methods of quantifying the inventive output in Canada.

2.1 Innovation in Canada

Innovation in Canada has been a common topic of research in academia. Nicholson (2009) describes the Canadian market is as being small and he suggests that Canada offers lower potential gain for the difficulties associated with innovation. As a result, the market provides less motivation and less competition for inventing.

Furthermore, Nicholson (2009) argues that Canada is declining in creating business strategies focused on innovation. It can be argued that Canada’s lagging invention rates are tied partly to its levels of productivity over time, being lower than in other industrialized countries, particularly compared to the U.S. Nicholson considers Canada to be in a good position in relation to the whole of North American industries, meaning that Canadian companies are more likely to provide the resources to create new products and not necessarily the last link in the supply chain, limiting the relationships between production and end consumers.

Yakabuski (2009) found that between 1981 and 2000, Canadian companies invested a relatively significant amount in R&D. Approximately ten percent increase in R&D funding annually. The majority of the R&D work was focused on improving existing products and less on bringing new product innovations to market.

Wolfe (2009) provides insights on the policies behind innovation in Canada. The governments are lacking in establishing policies that would encourage economic activities and potential investments. Despite the challenges, Canada has the potential to take advantage of forces that are conductive to innovation.

2.2 Economic Impacts

Schumpeter (1939) explains that innovation is a new form of economic activity, it includes the introduction of new products and services, new processes, or configurations of production. Innovation changes the “production function” under which a system operates.

Romer (1990) analyzed studies that emphasize the relationship between innovative changes and capital & labour, and suggests that even though the relationship of both are important, the key question is what causes innovation and how does innovation impact an economic model.

2.3 Sources of Innovation

When observing innovation, it is helpful to look at inputs and outputs to innovation. Some common inputs are industry research, academic research, and the presence of industries and businesses (Feldman & Florida, 1994). Scholars suggest that because innovation is a product of people's work, it is important to have an appeal for people to perform the innovation process within the same location. Such appeal could be common amenities such as diversity, mobility, social structures, and more (Florida, 2000; Glaeser, 2005). Output is the outcome from creative inputs and can take the form of innovation, invention, trademarks, and similar.

2.3.1 Industry Structure

Inventive activity is necessary for industrial economies to progress (Mukim, 2012). Between 1999 and 2008, Indian inventive enterprises filed patents on many process inventions, primarily in the mechanical, chemical, computer/electronics, and drug industries. Many inventive enterprises were affiliated with a business organization and benefited from an environment in which business information and contacts were likely abundant (Mukim, 2012).

2.3.2 Human Capital

According to Goldin (2002), "Human capital is the stock of skills that the labour force possesses. The flow of these skills is forthcoming when the return to investment exceeds the cost (both direct and indirect)". In the context of this paper, human capital can be viewed as an input for innovation. Kosior (2009) identified three variables that can capture the labour force that conducts inventive activity: level of education, metropolitan size, and urban density. The census of Canada contains variables that can represent the same ones outlined by Kosior and are taken as the parameters for analysis in this study.

2.3.3 Amenities

Florida (2000) and Glaeser (2005) suggest that analyzing what attracts individuals is more important than what attracts firms. It is the creative class of individuals that strengthen innovation infrastructure. Florida (2014) further suggests that a city's openness, measured by the size of the population that is gay and lesbian, foreign-born, or minority, is a reason to attract innovative people. Coccia (2015) identified that climate and weather can influence people's decision on where to work and relocate. It was found that the innovative output in the technology sector is higher in temperate regions across 109 countries.

2.4 Measurements of Invention

Invention and innovation is thought to be an important catalyst for economic change and increased productivity (Erne, 2011; Kosior, 2009). An invention is a new product or a new process created using existing methods with discrete technical changes (Pred, 1966). An invention may or may not be an innovative output because of its usability. A way to distinguish invention versus innovation is the usability and the productivity yield by a product or a process. When an invention is complete and is committed to the market in a meaningful way, such invention is considered as a product of innovation (Nicholson, 2009). On the other hand, if an invention is delivered but failed to attract any user, such invention is not considered as an innovative output. In sequence, R&D must occur as inputs to an invention, then the invention has the potential to lead to the broader process of innovation. An input of R&D may or may not result in the output of an invention; the output of an invention may or may not result in an innovation (Johnson & Evenson, 1997; Ceh & Gatrell, 2006). Because invention is necessary for innovation to take place, quantifying inventive output using patents is useful to understanding regional innovation potential and outcome.

2.4.1 Research and Development

R&D is a proxy for measuring innovation. It is commonly depicted as the monetary expenditure for an invention rather than as the product of innovation (Boasson & Boassson, 2015). Creszenzi and Rodríguez-Pose (2013) examined the relationship between the role of socio-economic factors and returns of R&D expenditure at the U.S. Bureau of Economic Analysis-Economic Area level. The results show that U.S. local R&D investments are important predictors for regional innovative performance and their impact is highly localized.

Ceh and Gatrell (2006) examined the relationship between R&D expenditures and inventive activity at the U.S. state level. The study also incorporates socio-economic variables as part of the analysis process, such as education, wealth, and industry sectors. However, the authors concluded that using R&D expenditure is not a sufficient method to measure a region's innovative output. R&D expenditure reflects an organization's or an economy's motivation for creating inventions. It is an important input to new technology and is essential to firm innovation often being a pre requisite to technological development. Therefore, it more direct and accurate to measure innovation by using variables that are at the later stages of the innovative process. In this regard, patents are ideal as they show intent by firms to bring new ideas to market and the workplace.

2.4.2 Patents

Patents are commonly used as an acute measure of innovation. A patent is a set of rights that is granted by a governing agency to the patentees for a limited period of time (World Intellectual Property, 2004). The rights protect patentees by trying to prevent others from using the invention without permission. There are many patent offices around the world and to date there is no single patent granting agency that protects a patent worldwide. As a result, inventors need to file one or multiple patents according to their need and geographic market. In Canada, many inventors and organizations file patents in the USPTO because of economic ties or market potential in the U.S. and possible buyers of the patent itself.

Researchers found that using patents as a measure of technology to be reliable and relatively accessible, cheap data source (Ceh, 1996; 1997; 2001; Johnson & Brown, 2002; Carlino et al., 2007; Creszenzi et al., 2007). Mukim (2012) suggests patents are a good measure of innovation because there is a positive relationship between private R&D spending and patent applications. Griliches (1990) stated that the cost of patenting an invention is high and needs a lot of resources. Therefore, when a person or an organization is patenting an invention, the resultant product or process must have a significant value or is needed in the market. Additionally, a patent office has its own mechanism to determine the significance and commercial value of an invention. Overall, the patenting process creates a good filter for innovative output and patents can be used a measure of innovation.

2.4.3 Forward Citations

Citation data has been used to measure innovative output. Ceh (1996; 1997) and Ejermo (2009) describe a limitation of using invention-based data in that it is hard to measure and quantify the success of inventions unless surveys of every inventor is conducted. Forward citation is the number of citations received by a patent, and can act as a quality control to signify the importance of each patent. Ejermo (2009) suggests quality-adjusted patents can provide a better measure of innovation, which is also more geographically concentrated. However, the approach of using forward citations needs a larger amount of data that includes citations, renewals, and records from multiple patent offices. In addition, there is no common method that relates USPTO patent parameters with forward citation counts. It is unclear to determine the inputs, outputs, or combinations of multiple variables to be used to measure the innovative output. As such, the process of creating a method of measuring innovation is beyond the scope of this study.

2.5 Geography of Innovation

The geographic distribution of inventive activity is often uneven and is attributed to many factors. The literature in Section 2.3 explains the sources of innovation as being related to industry sector, human capital, and amenities. When a region has the ideal infrastructure in all three sources, the magnitude of innovation will be high. Ceh (2001) found that the number of professionals (a variable of human capital) has a significant correlation with American patent counts at the state level. Feldman and Florida (1994) found that some states and regions in the U.S. perform very well in measures of innovation based on citations from over a hundred scientific and trade journals. When the number of American inventions was broken down by industry, the Northeastern U.S. clearly had the most innovative industries. It can be expected that invention and innovation will concentrate to places and regions in Canada too, as has happened elsewhere in other countries.

2.5.1 Regional Innovation System

Regional innovation system (RIS) is a concept that innovations are carried out through a network of various mediums underpinned by an organization framework (Asheim, 2002; Cooke, 1996). The study of RIS has grown significantly over past decade driven by the interest in innovation as a source of competitive advantage, need for new policies to address regional inequalities and divergence, and advances in theoretical analysis (Asheim, 2011). Variations on

RIS have been developed over time, either at various geographic levels (national and regional) or specific sectors or technologies. Asheim (2011) identified three key areas of RIS:

- Demarcation of types and varieties of RIS, their efficiency and their impact on regional competitive advantage
- Boundaries of RIS, clusters and networks and the role of cognitive frontiers, knowledge transfer and learning
- Creation, attraction, utilization and renewal of human capital within RIS and the role of the labour market

Benneworth et al. (2009) provides an example of RIS using Lund University's role within its RIS and how it affected the regional innovation of Scania, Sweden. Initially, the university became involved in a science park which was supported by local agencies. The university started as a supplier of generative human capital, then shifted toward to actively shaping changes within regional organizations, and ensuring those organizations work together better as a coherent RIS. The university has deepening its involvement in the RIS and moved from being involved purely with knowledge exploration to concerns with its subsequent exploitation.

2.5.2 Geographic Spillovers

Inter-regional spillover is a notion of transferring knowledge based on the principle of geographic proximity, also known as geographic spillover. The spillover phenomenon occurs when knowledge is spread to inventors in surrounding areas through means of shared labour, human interaction, intra-firm collaboration, and knowledge transfer session (Mckenzie, 2012; Gersbach & Schmutzler, 1999). Many prior studies indicate the existence of inter-regional knowledge. Creszenzi et al. (2007) found spillover to range up to 80 to 110 kilometers from metropolitan areas; the European Union (EU) had spillovers ranging between 200 and 300 km from the point of origin. Innovation in the EU is dependent on the linked networks that allow individuals and organizations to communicate throughout the innovative process. Shang et al. (2012) indicates that proximate location to innovative neighbors can help to raise the innovation capability of a province in China. Evidence also shows that R&D expenditure and skilled personnel of research institutes and universities positively affect invention and utility patents.

It can be argued that innovation spillover by Canadian city would be even more geographically confined due to the nature of the country's spatial economic system having few urban conurbations and their being vast distances between major cities. Da Silva (2012) suggests the area of economic geography plays a key role in determining the ability to learn and the innovative capabilities of individual firms. The geography of economic advantage and innovative capability is highly uneven due mostly to special variation in the socio-institutional features of regions or locations. That is to say, geographic spillover of knowledge could only happen when two regions have similar characteristic.

2.6 Recent Trends

Regional disparity and complexity of invention have increased over time. Balland and Rigby (2017) suggest complexity of knowledge produced in the U.S has generally increased over the last thirty years. Knowledge complexity is unevenly distributed across the U.S., cities with the greatest technological structures are not necessarily those with the highest rates of patenting. Complex knowledge tends to be produced in relatively few places and remained in the same places. On the other hand, low complexity, more routinized, forms of knowledge are easier to move over space. Similarly, Usai (2011) found that highly inventive regions of the Organization for Economic Co-operation and Development (OECD) countries tend to cluster together and motivate endogenous growth. This spatial dependence is found to have increased over time. Availability of human capital and research and development expenditure have influenced the inventive performance of a region. Local agglomeration factors are also found to have a significant impact and some negative effects appear when regions are mainly rural or when they are mainly service-based. Buzard et al. (2017) further supported the idea of uneven spatial distribution of inventive clusters using the locations of private R&D labs in the U.S. It was found that four major clusters in the Northeast Corridor (one each in Boston, New York–Northern New Jersey, Philadelphia–Wilmington, and Washington, D.C.) and three major clusters in California (one each in the Bay Area, Los Angeles, and San Diego).

Besides researches from the U.S., other parts of the world are also having regional disparity and less indication of spillover effect. Caragliu and Del Bo (2011) examined the knowledge absorptive capacity of regions in Italy, measured by local R&D expenditure and social capital. The results imply a reduction of outward knowledge spillover. Eshtehardi et al. (2017) found that there was no significant spatial knowledge spillover between the neighboring regions in Iran. Karlsson and Tavassoli (2016) examined the innovation strategies applied by firms in Sweden. The results show that firms are not homogenous in choosing innovation strategies. Even though firms do use some common innovation strategies, but they still have a wide range of preferred strategies. The study suggests that cooperation variables have little effect on innovation, regardless of the innovation strategy of choice (Karlsson & Tavassoli, 2016). Cooperation with suppliers does have some positive effect on most commonly used innovation strategies. A similar pattern of cooperation was observed for outsourcing of R&D (external R&D activities) with very little effect on innovation choices, except for the most complex innovation strategy. In contrast, internal R&D is a powerful explanatory variable for most choices of innovation strategies. International connections (import and export) have a positive effect on the choice of firms to choose product innovation as well as complex innovation (Karlsson & Tavassoli, 2016).

3.0 Methodology

This study examines regional innovation patterns in Canada by using patented inventions as a proxy. To help achieve this investigation four study periods are examined, they being 1991, 2001, 2006, and 2011. The reason for studying the four selected years is to match innovation data with the Canadian census years and to leverage with the research results produced by Kosior (2009), Erne (2011), and Abraham (2016). Patents filed under and granted by USPTO are the primary dataset because they are effective for analyzing inventive activity in Canada. Also, patent data is publicly accessible and inexpensive to obtain. Further, the patent dataset is analyzed descriptively in both non-spatial and spatial aspects. The descriptive statistics show the temporal changes and the spatial patterns of innovative output across Canada. To further justify the changes and patterns, a linear regression analysis is conducted by modelling the relationship between the patents and Canadian census data.

3.1 Data

The primary data for this study comes from the USPTO and is for patents granted to Canadian inventors up until 2015, though the patents were filed in 2011. This dataset aligns with Erne's (2011) research and is a reliable option for measuring innovation as suggested by literature cited in Section 2.4.3. Only patents that have a Canadian as the first inventor are considered. Since the acquired dataset contains all patents granted before 2015, patents granted after this date are not considered in this study.

Each patent contains two dates: application date and grant date. Application date records the time that the inventor filed the patent application, and grant date records the time that USPTO issued the given patent to the inventor. In this study, patent application date is used for data aggregation and to provide a snapshot of the innovative output of an individual year. For example, patents with the application year of 2011 are considered as the innovative output of 2011. As a result, not all patents applied in 2011 are considered because the dataset used for this study contains patent grants before 2015. While the vast majority of patents filed in 2011 would have been granted by 2015, a small portion would have been granted after this date.

The USPTO records the patent description, assignee name, inventor names, industrial classification in United States Patent Classification (USPC) standard, and geographic location of the inventors. The patent description is used to distinguish the patent type – product, process, or both. The assignee name reveals whether if a patent belongs to an organization or an individual. The names of the inventors being given a patent provide the number of inventors per patent. The industrial classification shows the type of market that a patent may be involved.

The location of an inventor is usually the name of a city, town, or metropolitan area. For this study, the location of the first inventor is considered as the geographic location of a patent. These location names are geocoded using the Canadian geographic boundaries and Canadian Geographical Names Database (CGNDB) for accurate results. Afterward, the location names with failed results are geocoded using Google Maps API. Lastly, all locations without a successful geocode are excluded in this study. For the purpose of data aggregation and analysis, Canada national boundary, provincial boundaries, census divisions (CDs), and census metropolitan areas (CMAs) are the geographic units.

Environics Analytics' CensusPlus dataset is used to assess the patterns of innovation to socio-economic variables in 2011. Because of data quality issues of non-response error and associated significant biases in the 2011 census data collected by Statistics Canada, the census data cannot be used for this study. Instead, this study employs the CensusPlus, an enhanced version of the 2011 census. It fills in missing values and eliminates random rounding in both National Household Survey and short form census. The result is a comprehensive set of demographic variables available for standard census geographies or custom client trade areas. The census provides demographic and socio-economic measures to support the factors that induce innovation. For the years of 1991, 2001, and 2006, data and results are extracted from Erne's (2011) study.

3.2 Descriptive Statistics

Non-spatial and spatial descriptive statistics are summarized for the study period. Each statistical variable is organized yearly to reflect the temporal trends. The variables of interest are the following:

Non-spatial:

- Ownership type (organization or individual)
- Number of inventors (single, two, or three or more inventors)
- Top industries by industrial classification (USPC)

Spatial:

- Shares of patent grants by province
- Shares of patent grants by CMA
- Invention rates by province (patent grants per 100,000 people)
- Invention rates by CMA (patent grants per 100,000 people)
- Location quotients (local invention rate / national invention rate)

Data used to compile variables in the statistical analyses are given as relative percentages of a given year and are given in addition to absolute counts. For example, ownership is measured in proportion of organizational patents and proportion of individual patents. This is because relative percentages are more meaningful when comparing year to year. It is known that nearly 100 percent of patents are granted within 3 years of application in the U.S., and as such this study is confident that most patents are accounted for by 2015. Secondly, the count of patents of a given year could be altered by the demographic variables significantly. A further analysis of patents relative to demography is conducted with the help of spatial statistics. As a result, when interpreting temporal changes, it is more meaningful to measure the change in proportion for a given variable.

Location quotient is a method to compute the standardized indices for comparing one region to another. It measures a region's value relative to a larger geographic unit, usually at the national level. The formula for the location quotient is a ratio of patents per capita in a province or CMA versus patents per capita in Canada:

$$LQ = \frac{I_C \div P_C}{I_N \div P_N}$$

Where:
LQ = Location quotient
I_C = Number of patents in a province or CMA
I_N = Number of patents in Canada
P_C = Population of a province or CMA
P_N = Population of Canada

3.3 Linear Regression Analysis

The goal of linear regression analysis is to identify the demographic and socio-economic factors that influence innovation. The analysis is conducted using the invention rate (number of patents normalized by population) and census variables. Invention rate is the dependent value and census variables are the independent values. Census Division (CD) is the spatial unit because it represents the entire country and can be associated with patents and census variables. In order to build a regression model, only a subset of CDs is selected for the analysis. This is because CDs with low population or no innovative output are meaningless. The criteria for the CD selection are (Erne, 2011):

- The CD must have at least one patent application for each given year
- The CD must have a population of at least 200,000

1991, 2001, and 2006 regression models developed by Erne (2011) are referenced by this study, and 2011 is the newly developed model. To help the 2011 model be consistent and comparable with the 1991 – 2006 models, linear regression is chosen as the modelling method.

According to the literature referenced in Section 2.3, the common sources of innovation can be identified by matters relating to industry sector, human capital, and amenities. Therefore, the selected independent variables for the 2011 model are gathered from CensusPlus dataset. Some CensusPlus variables such as age groups are aggregated to produce a more meaningful variable. Appendix A contains the descriptions of the selected 57 census variables.

All census variables are then transformed into standardized Z-scores. Only one linear regression is performed per year unless the removal of outliers or selecting different methods of fitting prove desirable. In such a case, more iterations are performed in an attempt to produce a better model.

4.0 Analysis and Results

This section contains the outputs of two analyses – descriptive statistics and linear regression analyses. The descriptive statistics section summarizes the patent data and reflects the temporal changes from 1991 to 2011. Overall, the results suggest that Southern Ontario is the most innovative region in Canada. Major metropolitan areas are also identified as generating higher innovative output. The linear regression analysis section contains the models developed for the study period. The models reveal that census variables relating to industry sector, occupation type, and education level can be successful predictors of innovation.

4.1 Descriptive Statistics

4.1.1 Non-Spatial Statistics

Table 4.1 shows the temporal change of top inventive industries in Canada. In 1991, static structures, liquid purification, and device supports were the top industries. By 2001 and onward, the three top industries in 1991 no longer existed and were replaced by telecommunication and information technology industries. Changes among the top industries of innovation show that product and process patent grants for basic needs decreased from 1991 to 2001. Beginning in 2001 the technology sectors began to patent significantly more. BlackBerry (formerly Research in Motion), IBM, Xerox, and Nortel had the most patent grants from 2001 to 2011. In spite of these successes, Nortel has disappeared and BlackBerry has lost part of the telecommunication market.

Table 4.1 Top industries base on the number of patent grants

Year	Count of Canadian USPTO Patents	Top Industries
1991	2297	(1) Drug
		(2) Static Structures (e.g., Buildings)
		(3) Surgery
		(4) Liquid Purification or Separation
		(5) Supports (devices which carry the weight of an article or articles)
2001	4648	(1) Drug
		(2) Multiplex Communications
		(3) Chemistry: Molecular Biology and Microbiology
		(4) Surgery
		(5) Electrical Computers and Digital Processing Systems: Multicomputer Data Transferring
2006	5017	(1) Multiplex Communications
		(2) Drug
		(3) Telecommunications
		(4) Electrical Computers and Digital Processing Systems: Multicomputer Data Transferring
		(5) Data Processing: Database and File Management or Data Structures
2011	4446	(1) Telecommunications
		(2) Multiplex Communications
		(3) Recording, Communication, or Information Retrieval Equipment
		(4) Electrical Computers and Digital Processing Systems: Multicomputer Data Transferring
		(5) Drug

The drug industry remained dominant throughout the study period. It had a mix of inventors from academia, public sector, and the private sector. Post-secondary institutions such as the University of British Columbia and private firms such as Merck & Co were the top inventors in the industry. In addition, the count of patents grants in 2001, 2006, or 2011 is approximately twice what they were in 1991. This is an indicator of the rise of innovation in the telecommunication and information technology industries. This could indicate a greater complexity in the types of inventions being produced over time, requiring a greater human resource input.

Moreover, patent ownership type shown in Figure 4.1 illustrates that the share of individually-owned patents (independent inventors owning the invention under their own name rather than a firm or institution) declined steadily from 1991 to 2006 (42.45% to 14.89%), and remained constant from 2006 to 2011 (14.89% to 14.46%). On the other hand, the share of organization-owned patents increased from 1991 to 2006 (57.55% to 85.11%). This reveals Canadian patents were shifting away from independent inventors towards those in firms and organizations.

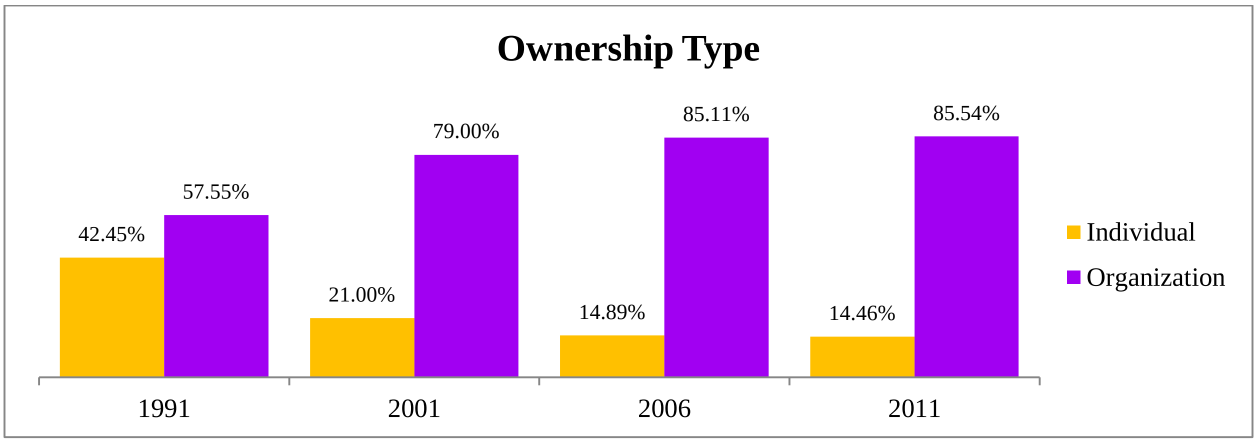

Figure 4.1 Shares of patent grants by ownership type

Similar to patent ownership type, the number of inventors per patent reflects the pattern that inventors are working together to create inventions. Figure 4.2 shows 60.56% of patent grants in 1991 were credited to a single inventor, 43.57% in 2001, 34.54% in 2006, and 34.37% in 2011. The share of single-inventor patents declined from 1991 to 2006, then stabilized in 2011. Contrastingly, the share of three-or-more-inventor patents increased from 16.67% in 1991 to 40.52% in 2006, then stabilized in 2011 with 39.38%. The share of two-inventor patents was similar in all four study years, and the overall change saw an increase from 22.77% in 1991 to 26.25% in 2011.

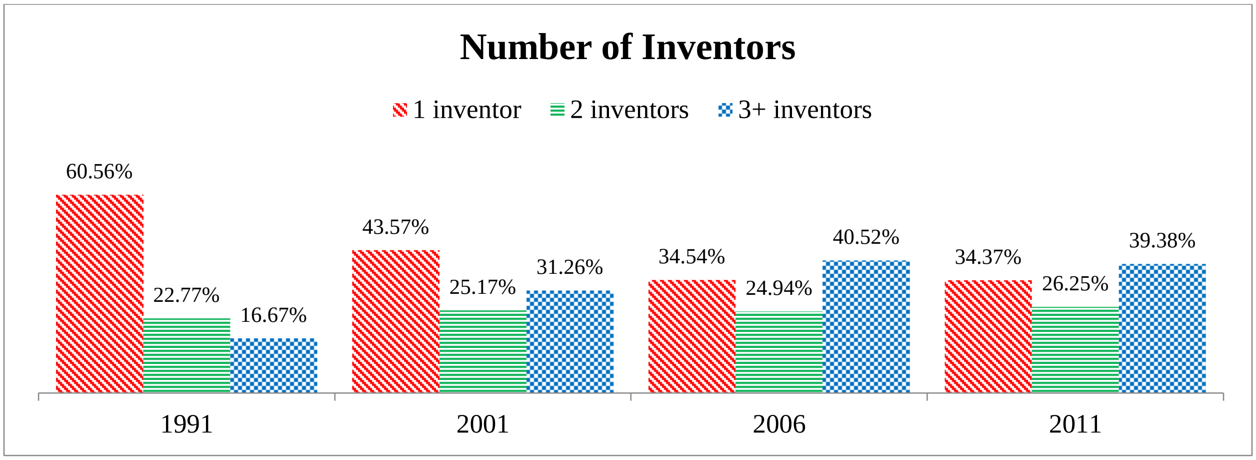

Figure 4.2 Shares of patent grants by number of inventors

Inventive activity in Canada has come to rely more on teams of inventors than any time in the recent past. Even though almost 40% of 2011 patent grants were credited to three-or-more inventors, the share of single-inventor patents was around 5 percent. More importantly, the 2011 statistics are very similar to the 2006 statistics and shows the trend of inventing in every team format to be consistent over time and a reality for modern day inventing.

To further analyze the team format of inventors, the number of inventors is broken down by ownership type. Figure 4.3 reveals that single inventors were the dominant format by individually-owned patents throughout the study period. When examining non-firm patents the individual inventor is still important. For example, the individual accounted for nearly 78 and 73 percent of such patents in 1991 and 2011, respectively. The share of three-or-more-inventor patents increased from 4.41% in 1991 to 10.31% in 2006, then dropped to 7.47% in 2011. The share of two-inventor patents increased steadily throughout the study period; the overall change was an increase from 17.13% in 1991 to 19.44% in 2011.

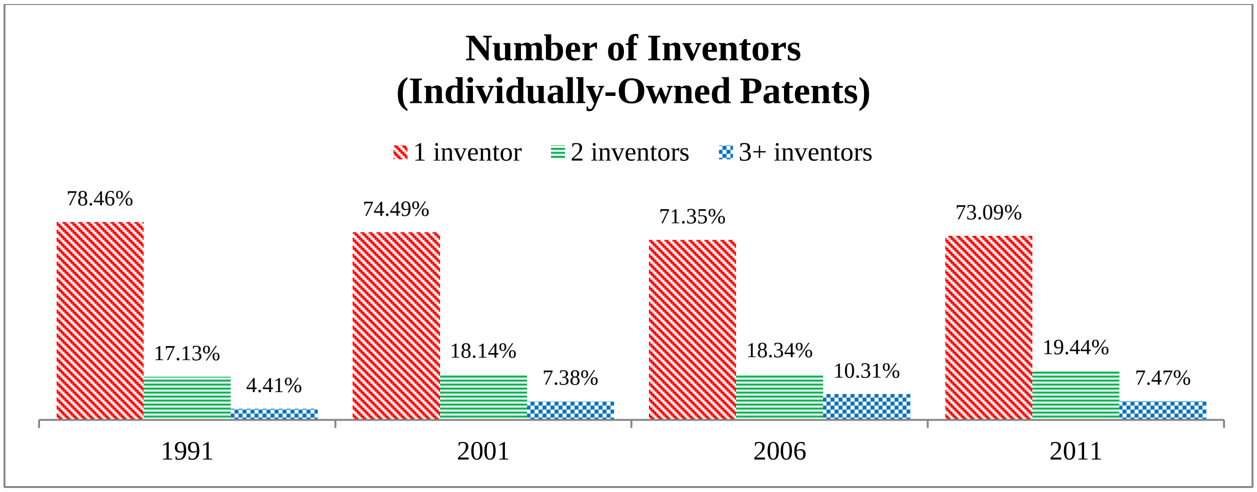

Figure 4.3 Shares of patent grants by number of inventors (individually-owned patents)

Even though the majority of the individually-owned patents were owned by a single inventor, it is worth noting that the share of multiple-inventor format had increased over the study period. This is likely due to the increasing amount of embedded knowledge required to invent.

Figure 4.4 shows that majority of the organization-owned patents were created by single inventors in 1991. A transition started in 2001 where multiple inventors became the dominant format. The share of single-inventor patents declined from 47.35% in 1991 to 27.87% in 2001. The share of three-or-more-inventor patents increased from 25.72% in 1991 to 45.81% in 2006, then slightly declined to 44.78% in 2011. The share of two-inventor patents stayed consistent throughout the study period.

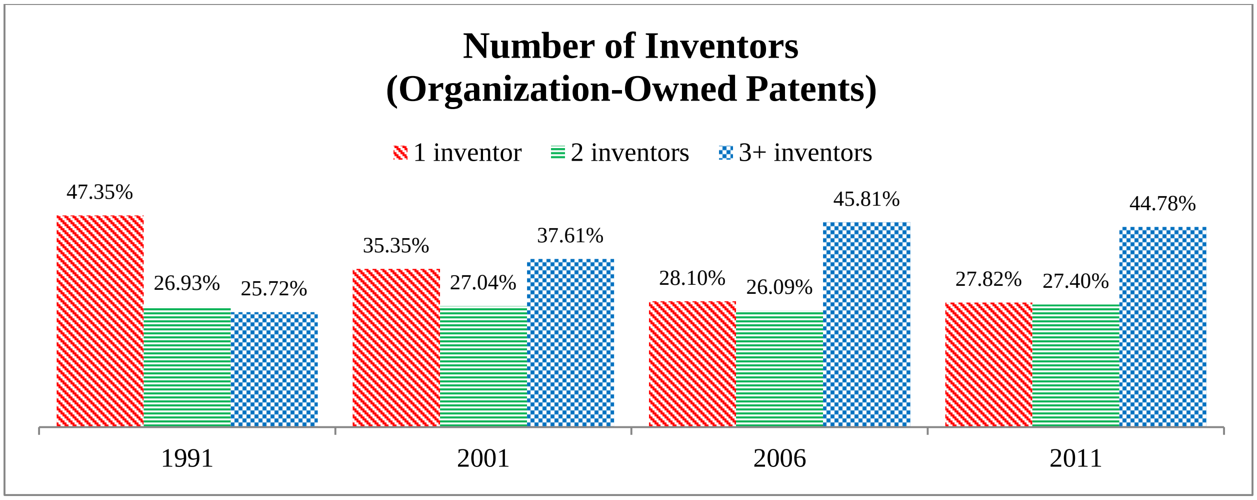

Figure 4.4 Shares of patent grants by number of inventors (organization-owned patents)

Figures 4.1-4.4 show that by 2001 teams of inventors became more prevalent. This trend could indicate that inventions are becoming more complex, and hence requiring greater human and knowledge input per patent.

4.1.2 Spatial Statistics

The spatial distribution of Canadian patented inventions over the past 20 years are shown in Table 4.3 and Figures 4.5-4.8. Some provinces showed consistent declines such as British Columbia, Manitoba, and Nova Scotia, while Ontario showed more consistent gains. Other provinces had fluctuating invention levels showing no real gains or declines. When comparing the raw counts shown in Table 4.2, the populous provinces (Ontario, Quebec, British Columbia, and Alberta) had more than doubled their patent counts in from 1991 to 2001, despite that provincial population growth varied between 5% to 19%. This reveals the invention rate had approximately doubled in populous provinces across the two study years (Table 4.6). Similarly, the national invention rate had an 84% growth from 1991 to 2001.

Table 4.2 Patent counts of Canadian provinces, ranked by 2011 population

Province	1991		2001		2006		2011	
	Patent	Population	Patent	Population	Patent	Population	Patent	Population
Ontario	1,096	10,084,885	2,418	11,410,046	2,752	12,160,282	2,636	12,851,821
Quebec	367	6,895,963	761	7,237,479	873	7,546,131	717	7,903,001
British Columbia	300	3,282,061	612	3,907,738	640	4,113,487	483	4,400,057
Alberta	167	2,545,553	406	2,974,807	377	3,290,350	366	3,645,257
Manitoba	69	1,091,942	104	1,119,583	84	1,148,401	76	1,208,268
Saskatchewan	57	988,928	80	978,933	68	968,157	85	1,033,381
New Brunswick	10	899,942	44	908,007	32	913,462	37	921,727
Nova Scotia	24	723,900	34	729,498	34	729,997	27	751,171
Newfoundland and Labrador	6	568,474	13	512,930	15	505,469	5	514,536
Prince Edward Island	1	129,765	3	135,294	4	135,851	1	140,204
Northwest Territories	0	57,649	1	37,360	6	41,464	1	41,462
Yukon	1	27,797	0	28,674	1	30,372	0	33,897
Nunavut	0	21,000	0	26,745	0	24,730	0	31,906
No geocode	199		172		131		12	
Total	**2,297**	**27,317,859**	**4,648**	**30,007,094**	**5,017**	**31,608,153**	**4,446**	**33,476,888**

Table 4.3 Shares of national total by Canadian province

	Share of National Total				Change in Share of National Total			
Province	1991	2001	2006	2011	1991 to 2001	2001 to 2006	2006 to 2011	1991 to 2011
Ontario	52.24%	54.02%	56.32%	59.45%	1.78%	2.30%	3.13%	7.21%
Quebec	17.49%	17.00%	17.87%	16.17%	-0.49%	0.87%	-1.70%	-1.32%
British Columbia	14.30%	13.67%	13.10%	10.89%	-0.63%	-0.57%	-2.21%	-3.41%
Alberta	7.96%	9.07%	7.72%	8.25%	1.11%	-1.35%	0.54%	0.29%
Manitoba	3.29%	2.32%	1.72%	1.71%	-0.97%	-0.60%	-0.01%	-1.57%
Saskatchewan	2.72%	1.79%	1.39%	1.92%	-0.93%	-0.40%	0.53%	-0.80%
New Brunswick	0.48%	0.98%	0.65%	0.83%	0.51%	-0.33%	0.18%	0.36%
Nova Scotia	1.14%	0.76%	0.70%	0.61%	-0.38%	-0.06%	-0.09%	-0.54%
Newfoundland and Labrador	0.29%	0.29%	0.31%	0.11%	0.00%	0.02%	-0.19%	-0.17%
Prince Edward Island	0.05%	0.07%	0.08%	0.02%	0.02%	0.01%	-0.06%	-0.03%
Northwest Territories	0.00%	0.02%	0.12%	0.02%	0.02%	0.10%	-0.10%	0.02%
Yukon	0.05%	0.00%	0.02%	0.00%	-0.05%	0.02%	-0.02%	-0.05%
Nunavut	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Ontario had the largest increase in the share of national patent grants, including an overall increase of 7.21%. New Brunswick had the second largest overall increase, but with merely 0.36%, which was significantly less than Ontario. It reveals Ontario was the most noticeable inventive province, but it does not provide enough information to justify why Ontario was the primate inventive region. The province level does not tell the full story because population density varies by regions. Carlino et al. (2007) suggest a higher urban density results in a higher patent intensity. They also suggest there is an optimal level, after which intensity falls off. Therefore, analyzing inventive activity at the urban level is necessary because metropolitan areas tend to be the cores of inventive activity.

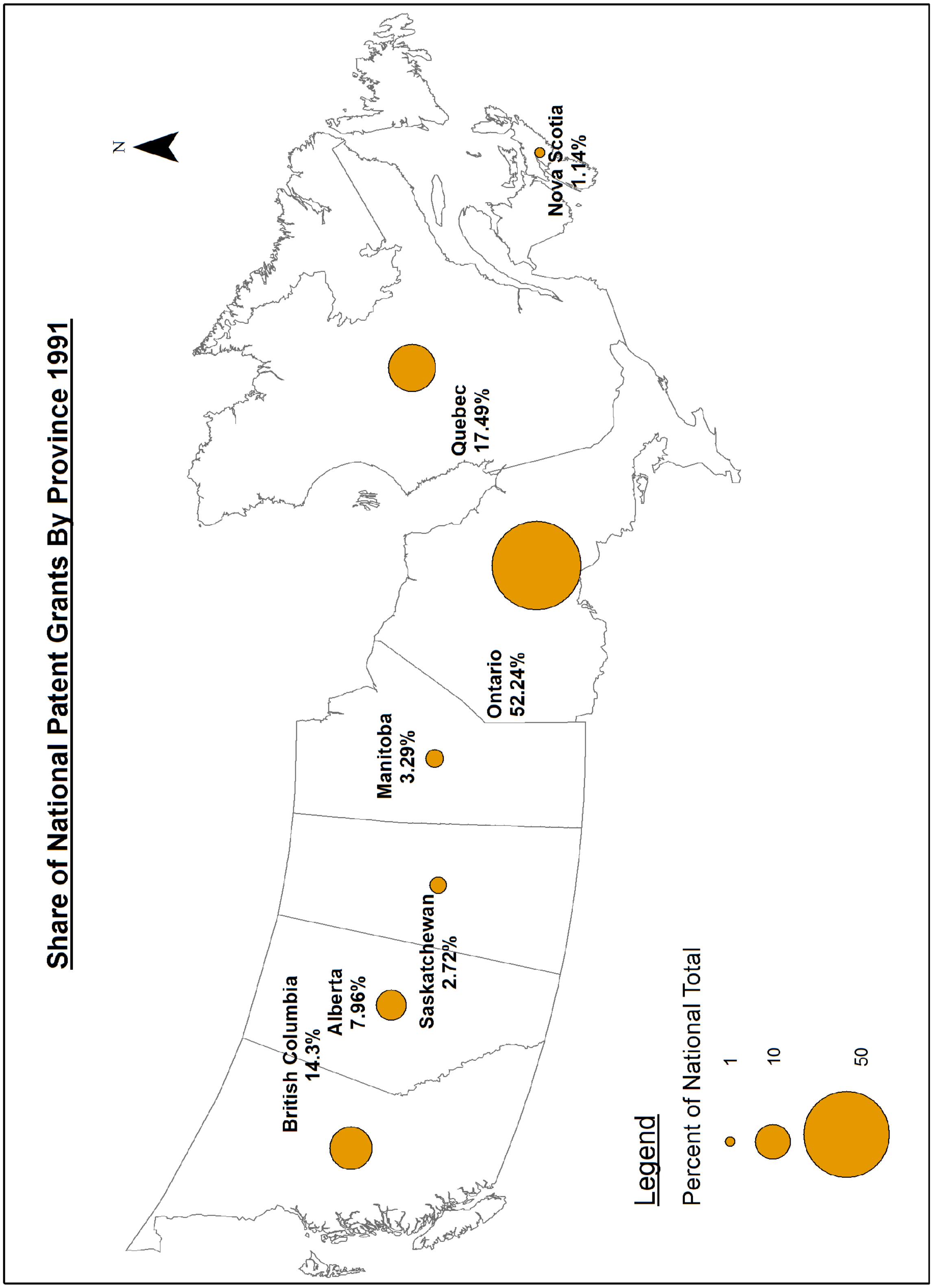

Figure 4.5 Share of national patent grants by province, 1991

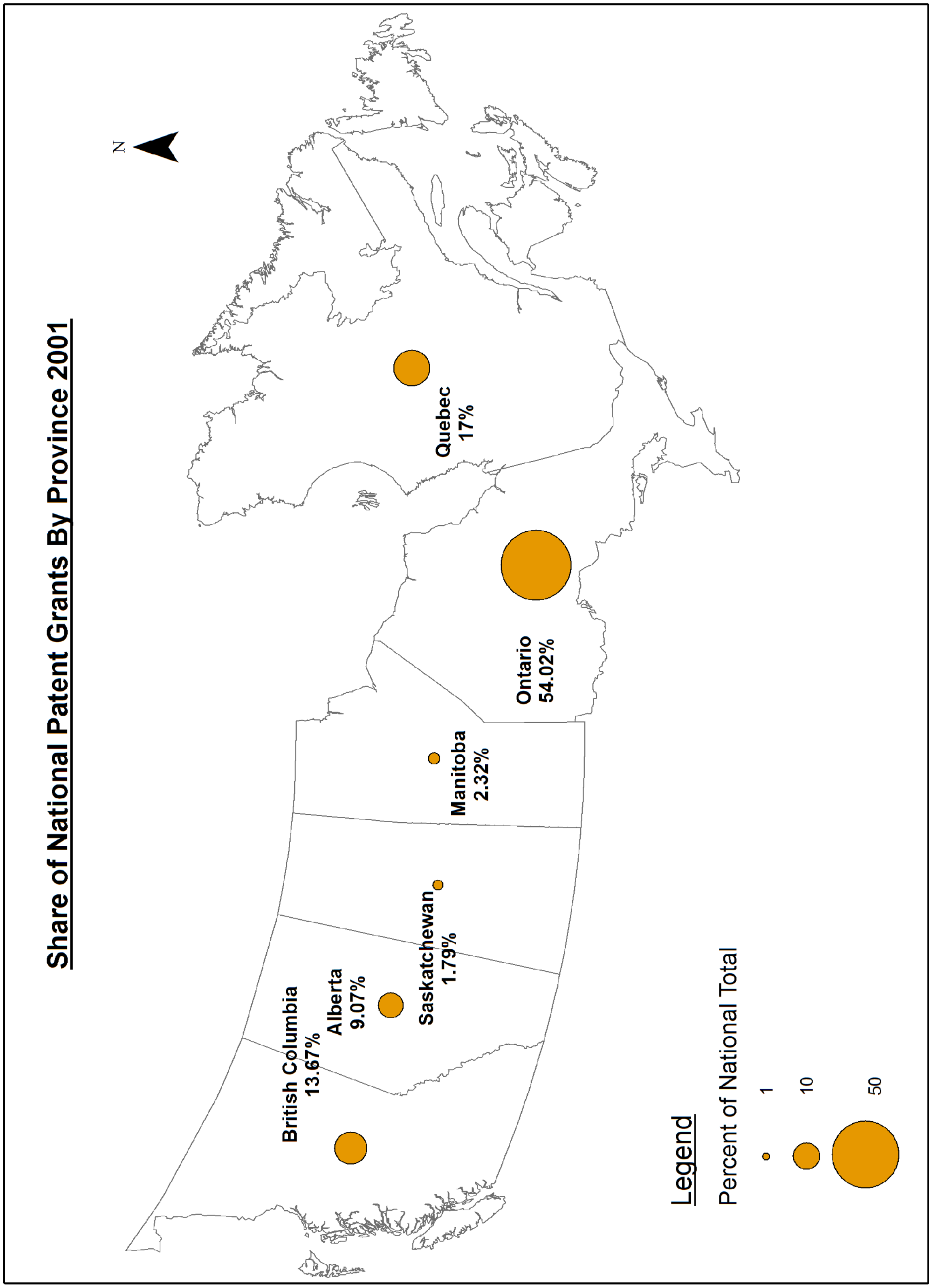

Figure 4.6 Share of national patent grants by province, 2001

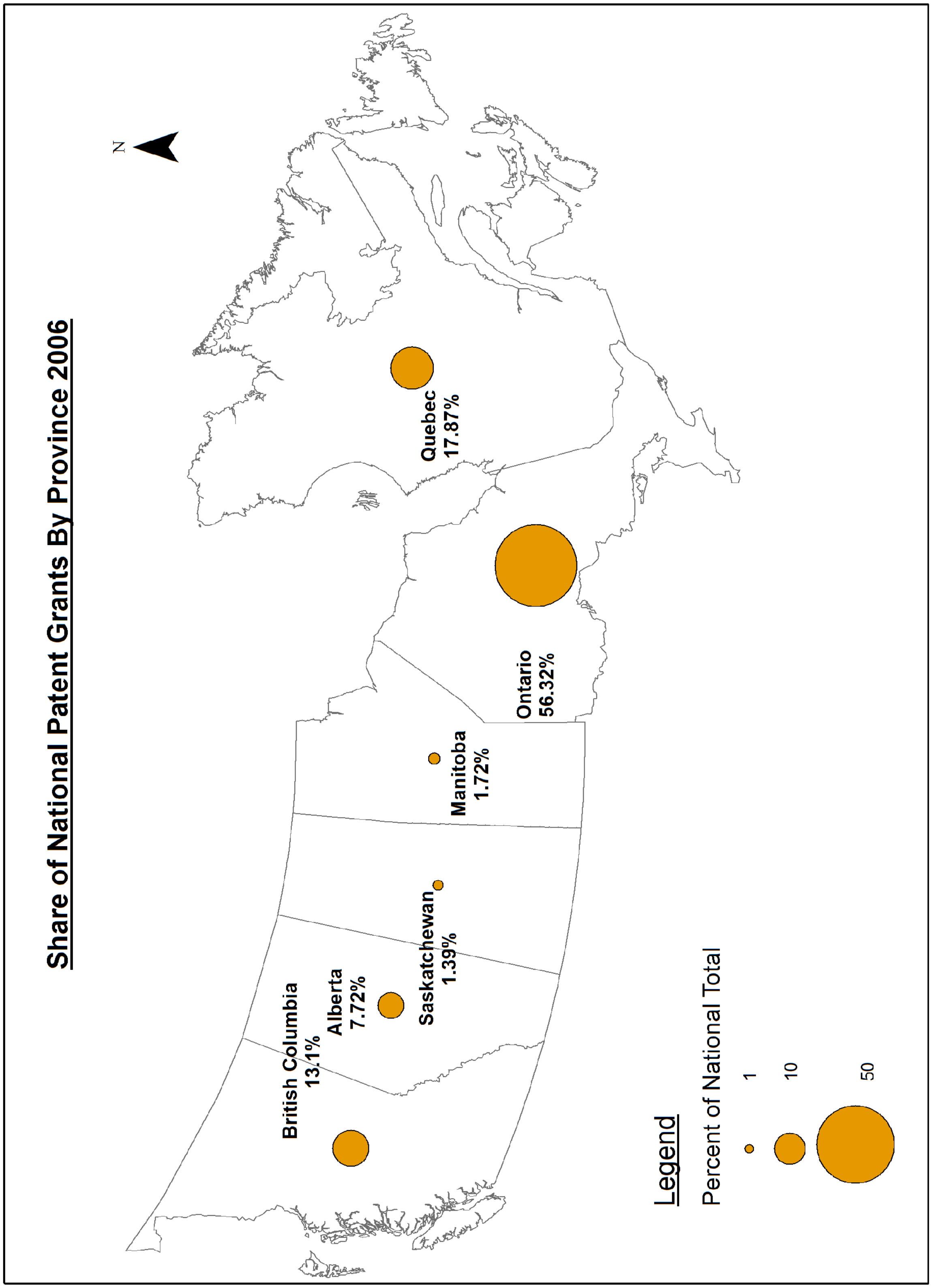

Figure 4.7 Share of national patent grants by province, 2006

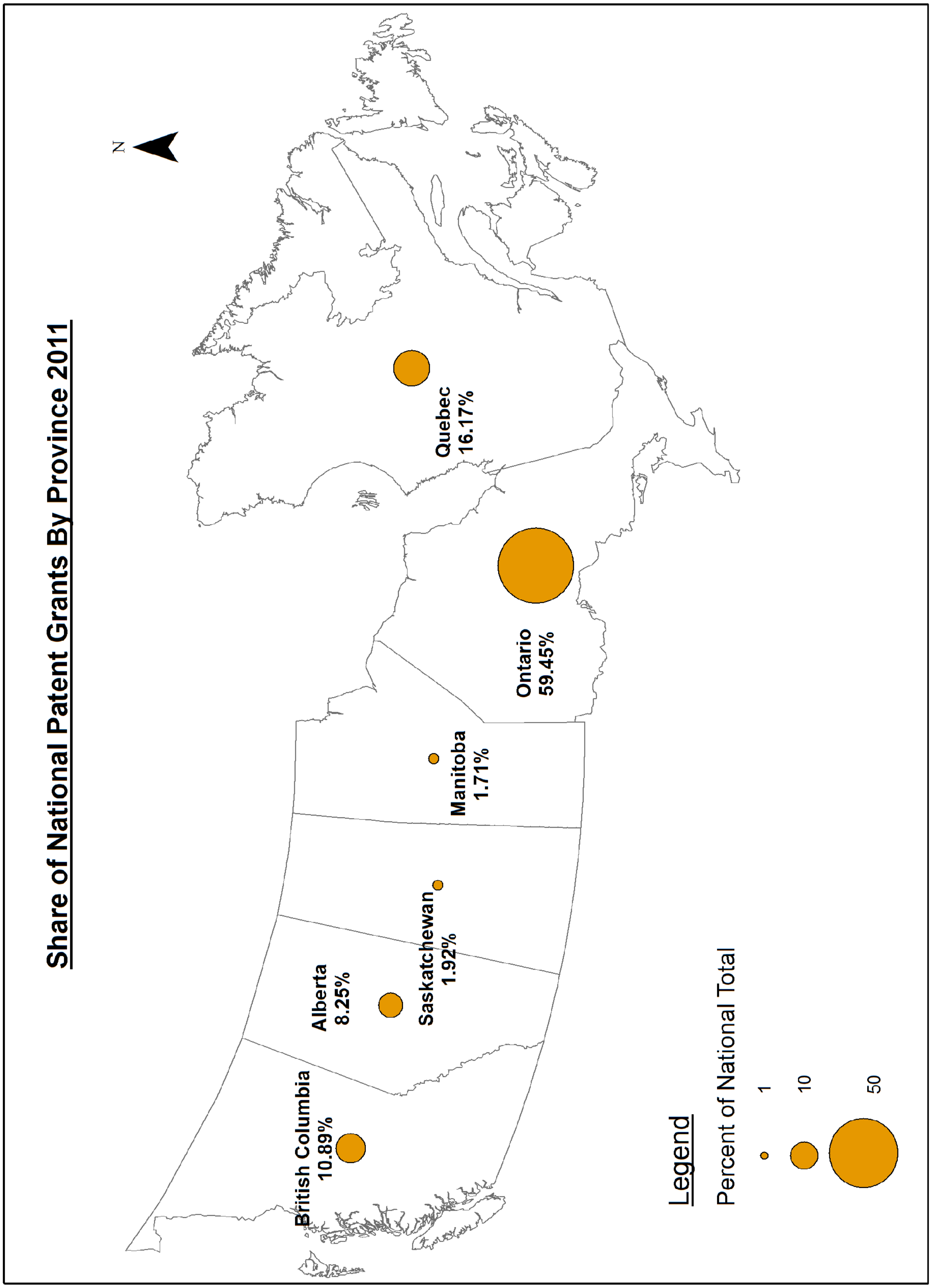

Figure 4.8 Share of national patent grants by province, 2011

Canadians cities and metropolitan areas experienced fast population growth from 1991 to 2011. Table 4.4 shows Toronto's population expanded from 3.89 million in 1991 to 5.58 million in 2011, which was approximately a 43% increase over the span of 20 years. In the same way, Vancouver's population had a 44% increase, and Calgary's population had an impressive 61% increase over the same time period. Significant population growth among large cities in Canada was influenced by expanding CMA boundaries, incoming new immigrants, and continuing migration to the city from neighboring areas.

In spite of rising populations in Canadian metro regions, Table 4.5 and Figure 4.9 to 4.12 show an overall decrease in the share of patents in populous areas including Toronto, Vancouver, and Montreal. Notably, Toronto had the highest population and the greatest share of patents in all four study years, but it had the greatest drop in the share of patents in periods of 1991 to 2001, 2006 to 2011, and 1991 to 2011. It seems Toronto had reached the optimal population density for the highest patent intensity in 2006 and could not maintain the same level in 2011. In contrast, K-W (Kitchener, Waterloo, and Cambridge) was a unique area that had an impressive 11.56% overall increase, and Ottawa was ranked as the second highest with 5.51% overall increase. When comparing the 2011 statistics of K-W versus Ottawa, both areas had a similar share of patents (of around 13%), but K-W's population was only 40% of Ottawa's population. The data show that K-W is an outlier thereby making it difficult to compare this center with others in the country. The pattern derived from the share of patents prove that innovation in K-W grew fast from 2001 to 2011. While for other CMAs, the patent counts remained similar throughout the study period.

Table 4.4 Patent counts of selected CMAs, ranked by 2011 population

	1991		2001		2006		2011	
CMA Name	**Patent**	**Population**	**Patent**	**Population**	**Patent**	**Population**	**Patent**	**Population**
Toronto	503	3,893,045	965	4,682,898	1,154	5,113,149	926	5,583,064
Montreal	254	3,127,240	481	3,450,988	567	3,635,556	475	3,824,221
Vancouver	213	1,602,500	491	1,986,965	477	2,116,581	392	2,313,328
Ottawa	165	920,855	579	1,067,800	655	1,133,633	593	1,236,324
Calgary	66	754,035	198	951,536	179	1,079,310	204	1,214,839
Edmonton	67	839,925	129	937,840	125	1,034,945	107	1,159,869
Quebec	38	645,550	71	686,562	91	719,153	72	765,706
Winnipeg	33	652,350	70	676,594	67	694,668	51	730,018
Hamilton	57	599,760	120	662,401	74	692,911	84	721,053
K-W	40	356,420	148	414,284	428	451,235	597	477,160
London	33	381,525	63	435,601	62	457,720	53	474,786
St. Catharines	26	364,550	46	377,009	27	390,317	28	392,184
Halifax	18	320,500	21	359,183	21	372,858	17	390,328
Oshawa	8	240,100	16	296,298	23	330,594	17	356,177
Victoria	32	287,895	43	311,904	45	330,088	28	344,615
Windsor	38	262,075	70	307,877	69	323,342	53	319,246
Saskatoon	18	210,025	42	225,928	42	233,923	61	260,600

Table 4.5 Shares of national total by selected CMA

	Share of National Total				Change in Share of National Total			
CMA Name	**1991**	**2001**	**2006**	**2011**	**1991 to 2001**	**2001 to 2006**	**2006 to 2011**	**1991 to 2011**
Toronto	23.98%	21.56%	23.62%	20.88%	-2.42%	2.06%	-2.73%	-3.09%
Montreal	12.11%	10.75%	11.60%	10.71%	-1.36%	0.86%	-0.89%	-1.39%
Vancouver	10.15%	10.97%	9.76%	8.84%	0.82%	-1.21%	-0.92%	-1.31%
Ottawa	7.86%	12.94%	13.41%	13.37%	5.07%	0.47%	-0.03%	5.51%
Calgary	3.15%	4.42%	3.66%	4.60%	1.28%	-0.76%	0.94%	1.45%
Edmonton	3.19%	2.88%	2.56%	2.41%	-0.31%	-0.32%	-0.15%	-0.78%
Quebec	1.81%	1.59%	1.86%	1.62%	-0.23%	0.28%	-0.24%	-0.19%
Winnipeg	1.57%	1.56%	1.37%	1.15%	-0.01%	-0.19%	-0.22%	-0.42%
Hamilton	2.72%	2.68%	1.51%	1.89%	-0.04%	-1.17%	0.38%	-0.82%
K-W	1.91%	3.31%	8.76%	13.46%	1.40%	5.45%	4.70%	11.56%
London	1.57%	1.41%	1.27%	1.20%	-0.17%	-0.14%	-0.07%	-0.38%
St. Catharines	1.24%	1.03%	0.55%	0.63%	-0.21%	-0.48%	0.08%	-0.61%
Halifax	0.86%	0.47%	0.43%	0.38%	-0.39%	-0.04%	-0.05%	-0.47%
Oshawa	0.38%	0.36%	0.47%	0.38%	-0.02%	0.11%	-0.09%	0.00%
Victoria	1.53%	0.96%	0.92%	0.63%	-0.56%	-0.04%	-0.29%	-0.89%
Windsor	1.81%	1.56%	1.41%	1.20%	-0.25%	-0.15%	-0.22%	-0.62%
Saskatoon	0.86%	0.94%	0.86%	1.38%	0.08%	-0.08%	0.52%	0.52%

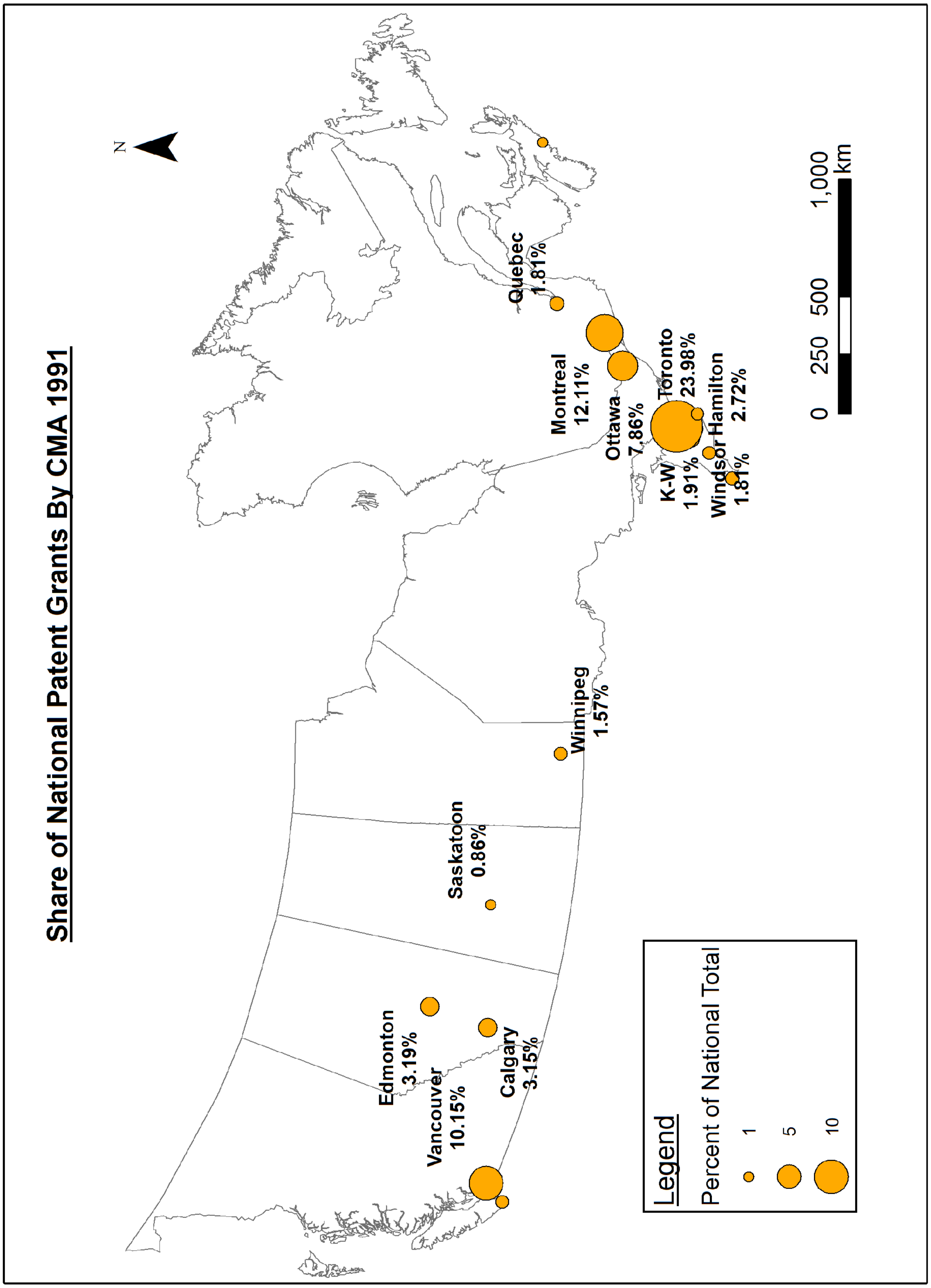

Figure 4.9 Share of national patent grants by CMA, 1991

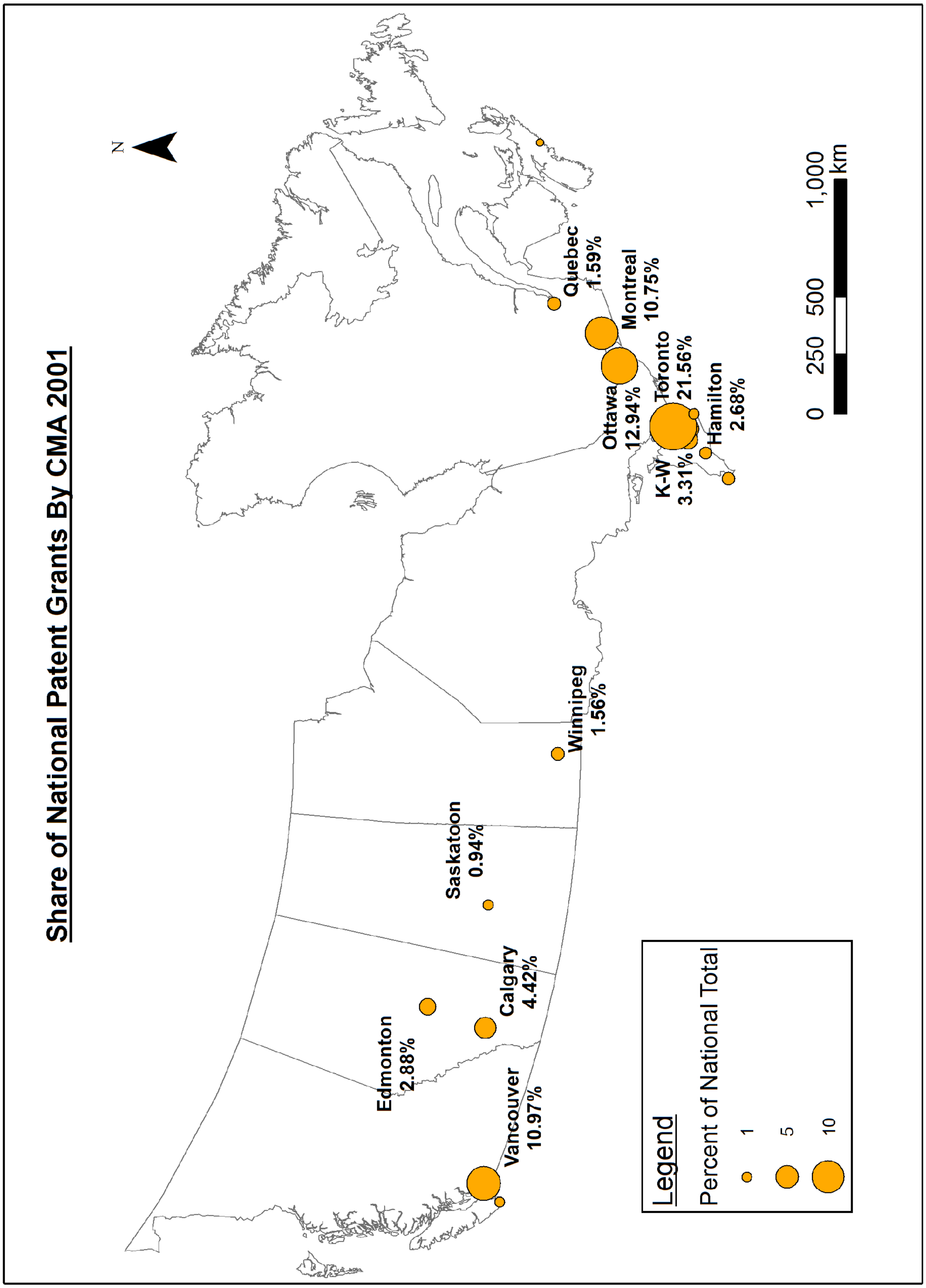

Figure 4.10 Share of national patent grants by CMA, 2001

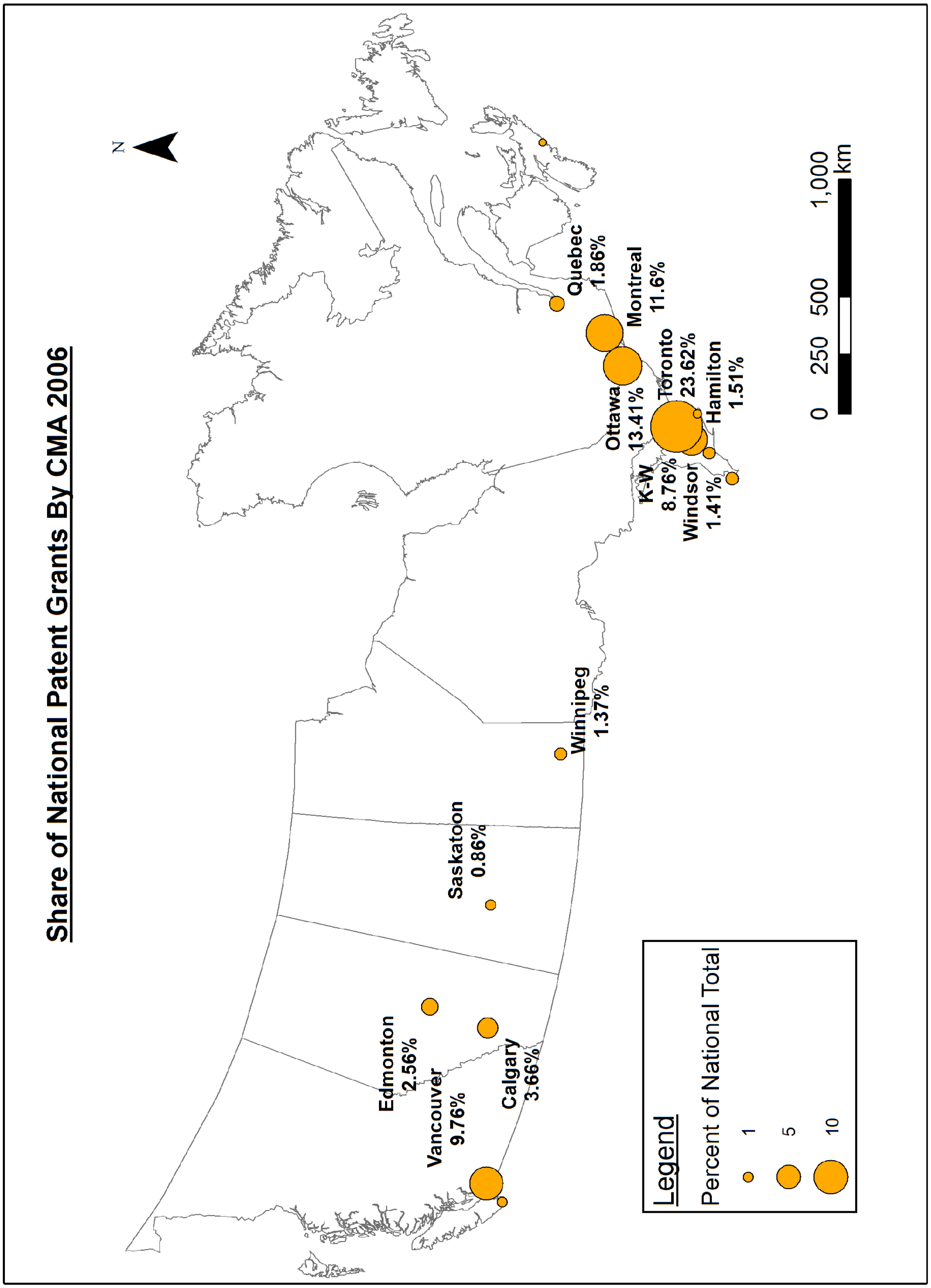

Figure 4.11 Share of national patent grants by CMA, 2006

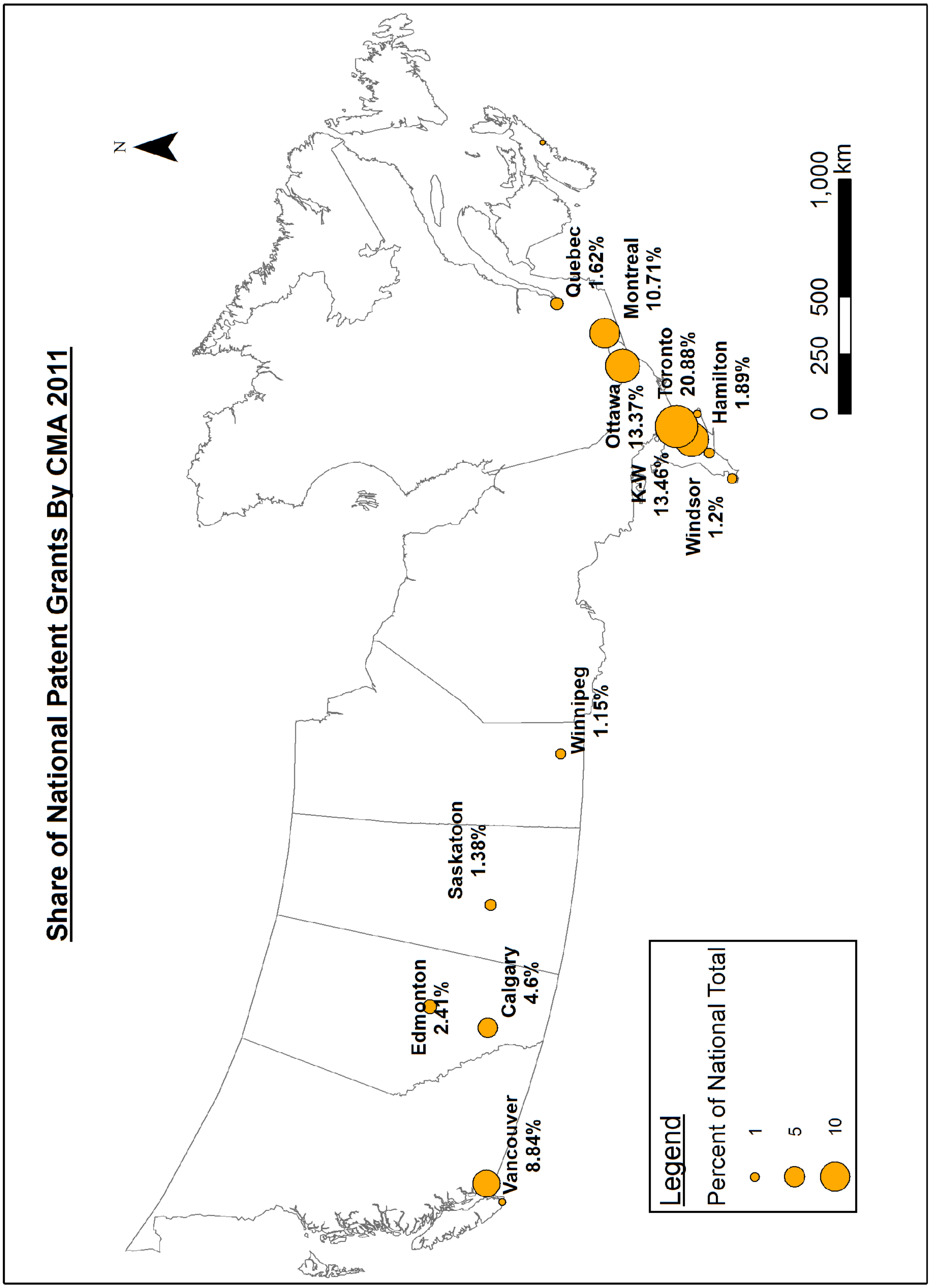

Figure 4.12 Share of national patent grants by CMA, 2011

Invention rate and location quotient (LQ) provide standardized values for comparing provinces or CMAs to one another and show the over-performing or under-performing areas. For this section of the study, invention rate is the patent count normalized per 100,000 people; and location quotient is the invention rate of a province or CMA divided by the invention rate of Canada. Table 4.6 shows both the invention rates and location quotients of provinces. In 1991 and 2001, both Ontario and British Columbia had LQs above the national average, and all other provinces were below the national average. In 2006 and 2011, only Ontario remained above the national average and it suggests most of Canadian inventive activities were taken place in Ontario.

Table 4.7 illustrates both the invention rates and location quotients of selected CMAs. In 1991, 12 of the 20 included CMAs performed at LQs above the national average. Ottawa was the highest performing area with 17.92 patents per 100,000 people and LQ of 2.33. The LQ value means the invention rate in Ottawa was twice as high as the national average. The under-performing areas in 1991 were Sherbrooke, Quebec City, St. Catharines, Winnipeg, Oshawa, and the CMAs in Atlantic Canada. In 2001, 9 of the 20 CMAs over-performed. In 2006, 8 of the 20 CMAs over-performed. Lastly in 2011, 7 of the 20 CMAs over-performed. The number of over-performing CMAs decreased steadily from 1991 to 2011, as if the inventive activity was shifting to fewer areas. Similar to the statistics shown in Table 4.4 and 4.5, K-W was clearly the outlier from the rest of the nation. The invention rates were fast growing from 2001 to 2011. K-W had reached a LQ of 6.14 in 2006 and 9.45 in 2011; these two figures did not exist in any other CMAs.

Table 4.6 Invention rates and location quotients of provinces, ranked by 2011 location quotient

	1991		2001		2006		2011	
Province	**Rate/ 100k**	**Location Quotient**	**Rate/ 100k**	**Location Quotient**	**Rate/ 100k**	**Location Quotient**	**Rate/ 100k**	**Location Quotient**
Ontario	10.87	1.29	21.19	1.37	22.63	1.43	20.51	1.54
British Columbia	9.14	1.09	15.66	1.01	15.56	0.98	10.98	0.83
Alberta	6.56	0.78	13.65	0.88	11.46	0.72	10.04	0.76
Quebec	5.32	0.63	10.51	0.68	11.57	0.73	9.07	0.68
Saskatchewan	5.76	0.69	8.17	0.53	7.02	0.44	8.23	0.62
Manitoba	6.32	0.75	9.29	0.60	7.31	0.46	6.29	0.47
New Brunswick	1.11	0.13	4.85	0.31	3.50	0.22	4.01	0.30
Nova Scotia	3.32	0.39	4.66	0.30	4.66	0.29	3.59	0.27
Northwest Territories	0.00	0.00	2.68	0.17	14.47	0.91	2.41	0.18
Newfoundland and Labrador	1.06	0.13	2.53	0.16	2.97	0.19	0.97	0.07
Prince Edward Island	0.77	0.09	2.22	0.14	2.94	0.19	0.71	0.05
Yukon	3.60	0.43	0.00	0.00	3.29	0.21	0.00	0.00
Nunavut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4.7 Invention rates and location quotients of selected CMAs, ranked by 2011 location quotient

	1991		2001		2006		2011	
CMA Name	**Rate/ 100k**	**Location Quotient**	**Rate/ 100k**	**Location Quotient**	**Rate/ 100k**	**Location Quotient**	**Rate/ 100k**	**Location Quotient**
K-W	11.22	1.46	35.72	2.39	94.85	6.14	125.12	9.45
Ottawa	17.92	2.33	54.22	3.64	57.78	3.74	47.96	3.62
Saskatoon	8.57	1.12	18.59	1.25	17.95	1.16	23.41	1.77
Vancouver	13.29	1.73	24.71	1.66	22.54	1.46	16.95	1.28
Calgary	8.75	1.14	20.81	1.39	16.58	1.07	16.79	1.27
Windsor	14.50	1.89	22.74	1.52	21.34	1.38	16.60	1.25
Toronto	12.92	1.68	20.61	1.38	22.57	1.46	16.59	1.25
Montreal	8.12	1.06	13.94	0.93	15.60	1.01	12.42	0.94
Sherbrooke	5.03	0.65	30.14	2.02	13.06	0.85	11.89	0.90
Hamilton	9.50	1.24	18.12	1.21	10.68	0.69	11.65	0.88
London	8.65	1.13	14.46	0.97	13.55	0.88	11.16	0.84
Quebec	5.89	0.77	10.34	0.69	12.65	0.82	9.40	0.71
Edmonton	7.98	1.04	13.76	0.92	12.08	0.78	9.23	0.70
Victoria	11.12	1.45	13.79	0.92	13.63	0.88	8.13	0.61
St. Catharines	7.13	0.93	12.20	0.82	6.92	0.45	7.14	0.54
Winnipeg	5.06	0.66	10.35	0.69	9.64	0.62	6.99	0.53
Oshawa	3.33	0.43	5.40	0.36	6.96	0.45	4.77	0.36
Halifax	5.62	0.73	5.85	0.39	5.63	0.36	4.36	0.33
St. John's	2.91	0.38	4.63	0.31	6.63	0.43	2.54	0.19
Regina	5.74	0.75	6.74	0.45	4.10	0.27	1.90	0.14

4.2 Linear Regression Analysis

Attempts were made to create the 2011 linear regression model using various combinations of variables suggested by Kosior (2009) and Eshtehardi et al. (2017). However, none of them show a correlation as strong as the models developed by Erne (2011). Two of the unsuccessful attempts are included in Appendix B. For this reason, exploratory stepwise regression was chosen as the method of fitting because it involves an automatic and iterative procedure that analyzes the most fitting variables from a list of predictive variables. At each iteration, the process determines to add or subtract a variable based on a set of criteria. The probability of F criterion for an independent value in the model is 0.05, while the criterion for removal is set at 0.1.

By using the criteria for the CD selection stated in Section 3.3, the selected CDs for each study year are shown in Table 4.8. For the 2011 model, the Waterloo CD was removed because of it being too large of an outlier. Attempts were made to create a regression model using the 2006 CD selection and 2011 census variables, but none of the results were successful. After removing Waterloo, the model picked up three predictors with an acceptable standardized regression coefficient. Thus, removing K-W as an outlier is justifiable and it helped refining the spatial statistics in Section 4.1.2.

Table 4.8 CDs used in regression model analysis

1991		**2001**		**2006**		**2011**	
Calgary	Peel	Calgary	Ottawa	Calgary	Ottawa	Calgary	Ottawa
Edmonton	Quebec	Edmonton	Peel	Edmonton	Peel	Edmonton	Peel
Gatineau	Regina	**+ Fraser Valley**	Quebec	Fraser Valley	Quebec	Fraser Valley	Quebec
Halifax	Saskatoon	Gatineau	Regina	Gatineau	Regina	Gatineau	Regina
Halton	Simcoe	Halifax	Saskatoon	**+ Guelph**	Saskatoon	Guelph	Saskatoon
Hamilton	St. John's	Halton	Simcoe	Halifax	Simcoe	Halifax	Simcoe
Laval	Toronto	Hamilton	St. John's	Halton	St. John's	Halton	St. John's
London	Vancouver	Laval	Toronto	Hamilton	Toronto	Hamilton	Toronto
Longueuil	Victoria	London	Vancouver	Laval	Vancouver	Laval	Vancouver
Montreal	Waterloo	Longueuil	Victoria	London	Victoria	London	Victoria
Niagara	Windsor	Montreal	Waterloo	Longueuil	Waterloo	Longueuil	~~**Waterloo**~~
Oshawa	Winnipeg	Niagara	Windsor	Montreal	Windsor	Montreal	Windsor
Ottawa	York	Oshawa	Winnipeg	Niagara	Winnipeg	Niagara	Winnipeg
			York	Oshawa	York	Oshawa	York

Census variables included in the regression models for 1991 (107 variables), 2001 (99 variables), and 2006 (110 variables) vary slightly because Statistics Canada aims to improve the quality and breadth of data obtained from the census (Erne, 2011). The 2011 model uses the CensusPlus data due data quality issues relating to census data by Census Canada, therefore the inputted variables are different compared to other three models. The 2011 model contains 57

CensusPlus variables taken from the groups of age, mobility, industry sector, occupation type, income, employment and dwelling type.

Table 4.9 Stepwise regression results

Parameter	Variable Group	Coefficients		
		Beta	T	Sig
1991 Model (n = 26): R^2 value = 0.930				
(Constant)			11.940	0
Religion	Occupation Type	-0.355	-3.740	0.001
Medicine & Health		-0.549	-6.301	0
Other Crafts & Equipment Operating		-0.321	-3.853	0.001
Semi-Detached	Dwelling Type	-0.561	-6.078	0
Row Houses		0.206	2.547	0.020
Less Than High School	Education Level	-0.510	-6.843	0
Transportation and Storage	Industry Sector	0.507	6.531	0
2001 Model (n = 27): R^2 value = 0.834				
(Constant)			1.060	0.301
Individual Income $60k+	Income Bracket	0.479	4.214	0
Utilities	Industry Sector	-0.257	-2.486	0.021
Natural and Applied Sciences	Occupation Type	0.259	2.292	0.032
Ages 10 - 19	Age Range	0.259	2.292	0.032
Ages 40 - 49		-0.335	-2.891	0.009
2006 Model (n = 28): R^2 value = 0.542				
(Constant)			-3.283	0.003
Row Houses	Dwelling Type	0.231	1.486	0.150
Manufacturing	Industry Sector	0.586	3.821	0.001
Natural and Applied Sciences	Occupation Type	0.526	3.142	0.004
2011 Model (n = 27): R^2 value = 0.893				
(Constant)			0.821	0.420
Row Houses	Dwelling Type	0.491	4.756	0
University Degree Above Bachelor Level	Education Level	0.549	5.236	0
Administrative and Support, Waste Management and Remediation Services	Industry Sector	-0.338	-3.542	0.002

The 1991 model has an R^2 value of 0.93 and contains predictors in variable groups of occupation, dwelling type, education level, and industry sector. The proportion of row houses and the transportation & storage industry are the positive predictors of the invention rate. The proportion of row houses explains an area's population density. The transportation & storage industry explains that a robust transportation network is necessary to create an environment for engaging inventive activity. Similarly, this kind of infrastructure can be considered a component of the amenity that was discussed by Florida (2000). A few predictors have negative standardized regression coefficient: employment in religion, employment in medicine & health, employment in other crafts & equipment handling, the proportion of semi-detached houses, and education level of less than high school. It is surprising to find the medicine & health variable has a negative relationship with invention rate. According to a paper produced by MacInnes and McAlister (2001), the 1990s was a period that Canadian hospitals experienced amalgamation and increased cost to patient care. As a result, hospitals were forced to reduce costs or reduce services. In addition, it is also possible that biotechnology and related fields were not as mature and not as significant in Canada before 1991.

The 2001 model has an R^2 value of 0.834. Variables pertaining to industry sector, occupation type, income bracket, and age range are selected by the model. The percentage of individuals with an annual income greater than $60,000, employment in natural and applied sciences, and proportion of people between the age of 10 and 19 are the positive predictors of the invention rate. The individual income variable shows that employment in technology oriented sectors pay better. Industry sectors such as the natural and applied sciences are likely to attract and create an educated population that is involved in inventing. The relative size of the utility sector and persons between the ages of 40 to 49 are the negative predictors. The utility sector seems to predict that basic innovations have slowed down since 2001. The age 40 to 49 variable shows areas with a higher percentage of a baby-boomer workforce have a lower level of inventive activity.

The 2006 model has an R^2 value of 0.542. Such R^2 value is the lowest one out of all four models and it suggests that innovation activity was harder to associated with socio-economic at the time. Similar to the previous two models, variables by industry sector and occupation type are important in explaining invention rate. The proportion of row houses, employments in natural & applied sciences, and the manufacturing industry are positive predictors of an area's invention rate. Both row house and natural & applied science variables appeared in the 1991 or the 2001 models, which prove they are significant variables in general.

Despite the difference in the 2011 model's data, the resultant predictors are similar to the other three models. The model has an R^2 value of 0.893 and contains predictors in variable groups of dwelling type, education level, and industry sector. The row house variable is chosen again, but this time for the 2011 model and it re-enforces the correlation between population density and invention rate. The predictor in the education level group reveals that areas with high patent intensity will have a greater proportion of highly educated population above Bachelor's level. The education variable is important because it tells the recent trend of innovation is gearing toward creating complex products and processes. People with higher education are the essence of being innovative. Overall, these variables explain some portions of each year's model and provide insights into an area's features. The regression models can conclude that inventive activity occurs in areas with high population density and a large proportion of educated labour force in the high-tech and science related occupations.

5.0 Discussion

5.1 Industry Sector

In this study, the proclivity of regions to innovate is partly related to industrial activities. Over the span of 20 years covered by this study, the most inventive industries have changed from ones that focus on basic needs to the ones that focus on high technology. The regression analysis results in Section 4.2 emphasize that higher education and science related occupations are factors of inventiveness. High-tech firms and pharmaceutical firms are known for hiring highly educated people and cause the corresponding industries to create more inventions than others.

5.2 Patent Ownership

Who is inventing in Canada has changed with time away from the independent, "garage" type inventor to those that are employed in organizations. This suggests the amenities provided by organizations are more suitable for R&D and other inventive processes. Generally, organizations provide easier access to resources and expenditure, which are essential for developing complex inventions. As the recent trend of innovation is leaning toward technological patents, these are usually complex products or processes and require teams of people to develop the invention.

When observing patterns among non-firm-owned patents the individual inventor working by themselves is still important, particularly in light of joint ownership issues. A co-owner licensing the patent right to a third-party, a co-owner starting a competing company using the patented products, and all co-owners must jointly file an infringement lawsuit are the common problems in joint ownership. As a result, a common solution is to start a company then file the patent under the company's entity, which will classify a patent to be organization owned. In addition, forming an indie team of multiple inventors is more difficult because of the very limited access to resources. Altogether, single or work-alone type inventors remains popular as a format among individually-owned patents.

Further, teams of inventors as a format for inventing did rise within individually-own patents. The reason could be the increasing number of garage inventions and startup companies in the technology sector. Since the early 2000's, emerging technologies such as web applications and native applications made entrepreneurship possible with limited resources.

5.3 Spatial Patterns

As suggested by the data and methodology used in this study, the spatial patterns of innovation in Canada have changed from 1991 to 2011. Looking at the provincial level, Ontario represented a larger portion of Canadians applying for USPTO patents and produced more than 50% of all Canadian USPTO patents in any given year. Ontario consistently increases its share of national patents which in turn decreased the shares of patents in the other provinces. There are many simple reasons behind the inventiveness of Ontario, including it has the largest population in Canada, the most post-secondary institutes, and the highest concentration of businesses and multinational corporations. Quebec and British Columbia represented 27% to 31% of the national patent total. These two provinces are important because they contain the second (Montreal) and third (Vancouver) largest economies of Canadian cities based on GDP. In addition, Quebec and British Columbia had a larger share of technology patents, which is similar to Ontario. The Prairie provinces contributed at minimum 10% of the share of patents for any given year. Even though the number of patents is very low when compared to Ontario or Quebec, but their patents are more likely process inventions related to agriculture and petroleum production. Because the Prairies rely heavily on innovation within the resources or primary industries, their innovation base is very different from that of Ontario, Quebec, or British Columbia.

At the CMA level, areas like St. Catharines, Windsor, Vancouver and Victoria are located close to the American border. This could be a cause for inventors in those areas to file patents under the USPTO. Ottawa experienced an overall growth of approximately 5% in the share of patents, Toronto, Montreal and Vancouver also experienced shifts of between -3% and +3%. Ottawa's stronger performance might be contributed by the greater number of technology-based companies in the Kanata area. In 2011, the top innovators within these major CMAs were telecommunication and information technology companies, such as BlackBerry, ATI, IBM, Xerox, QNX, InterDigital, and Apple.

A key element that caused the temporal change in the geography of invention is observed to be the strong concentration in the technology sector. K-W's dramatic rise is contributed by BlackBerry and other technology firms. In 2011, BlackBerry filed 787 patents (17.7% of the national total) and Google Canada filed 32 patents (0.7% of the national total). Both companies are headquartered in K-W and both take advantage of the high concentration of information technology companies, and new graduates from engineering and computer science programs. In addition, the University of Waterloo in K-W is well known for having a strong infrastructure that leads students to innovate and to be entrepreneurial. Startup companies have been branching out from the university and occupying shared office spaces (startup garages) within K-W. These collective reasons have transitioned a region based on industrialism to one based on information and communication.

5.4 Linear Regression Analysis

The linear regression models successfully explain some aspects of inventiveness in Canada. Similar to the to the results of Kosior's (2009) and Abraham's (2016) studies on Canadian patents under CIPO, census variables in groups of dwelling type, education, and industry sector are the predictors of invention rate. The coefficients of determination (R^2) were significant in 1991, 2001, and 2011 models. The coefficient is lower in the 2006 model, and the lower coefficient represents a case where the census variables are unable to explain the invention rate as successful as the other three models.

5.5 Limitations

There are limitations in the data and methods included in this study. The patent dataset obtained from USPTO contains errors accumulated from human input, data corruption, and inconsistent format. For example, the location associated with each record often contains obvious spelling error, or the record contains no location at all. Some records have only a city name and no province, and vice versa. In Canada, it is common that the same name can be referred to different areas in the country. For example, the text "Victoria" could refer to the city of Victoria in British Columbia, county of Victoria in Ontario, Victoria Street in Toronto, or Town of Victoria in Newfoundland. A geocoder will produce ambiguous results when geocoding with an incomplete address and hence will lead to interpretation error in the analysis. The dataset contains only records of patent grants and does not contain records of patent applications. That is to say, some patents could be missing because they are still undergoing the verification process. In contrast, using only available patent grants may improve the overall accuracy of spatial patterns and regression results because it could reduce the number of applications that may never be patented in the future.

The methodology used in this study is chosen to align with past research conducted by Kosior (2009), Erne (2011), and Abraham (2016). The use of patents does not provide the full scope of the true innovative potential of an area. Patents capture the inventions that have the potential to generate a revenue for businesses and can protect inventors from impermissible use of their intellectual properties. In the scenario that an invention is open for public use or does not generate a significant amount of revenue, filing a patent is unnecessary. For example, social inventions are not captured by patents because they usually exist in the form of a new law, bill, act, or organization. The goal for social inventions is usually to change human behaviour or implement moral standards. This study limits the dataset to only USPTO patents, while Canadians do file patents under CIPO and patent offices of other countries. Therefore, the results of this study are biased towards American companies and companies with an American market.

The process of excluding certain CMAs and CDs could have changed the results. Some areas could have important inventions and are excluded in this study. But even so, the research questions of this study are focusing on the general spatial patterns of Canadian innovation and not looking in-depth into any specific topic. As a result, the methods of selecting the CMAs and CDs are acceptable and representative of the nation.

6.0 Conclusion

This study examined the non-spatial and spatial patterns of USPTO patents filed by Canadians. The four study years, 1991, 2001, 2006, and 2011 provide a time period of twenty years and reveal the temporal changes that occurred in the innovation scene. Canadian innovation coheres with the shift in the economy, from an industrial economy to a service-based economy. The types of inventions have changed from manufacturing-based to technology-based.

The level of patent complexity has risen from simple inventions that can be done by one person to complicated inventions that need a team of inventors with different specialization.

The spatial patterns of innovation have changed as well. Although the patenting activity is always clustered in Ontario, Canada's major metropolitan areas (Toronto, Montreal, and Vancouver) have a flat or declining invention rate. The growth of invention rate has shifted to medium sized areas like K-W and Ottawa. Both K-W and Ottawa have their own hubs of where technology companies are located. It is worth noting that K-W has the most impressive growth that outnumbered any other areas in Canada. Its growth is a collective cause attributed to universities' entrepreneurship programs, local startup firms, and Canadian headquarters of major technology companies. The characteristics of K-W are unique enough that it became an outlier in the linear regression modelling process.

The regression models were successful in selecting variables that explained some aspects of a CMA's invention rate. Census variables that describe dwelling type, education, and industry sector are the predictors of invention rate. However, variables that describe population size, immigration, and mobility failed to explain the geography of invention in Canada. Further research of a similar topic should address the issue related to the limitations of the data. Supporting datasets such as the independent variables of the regression models do not need to limit to census data and could be expanded to behavioural data.

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Appendix A: 2011 CensusPlus Variables

Category	Variable Description
Total Population	Total Population
Age Ranges of the Population (proportion of total population)	0 to 14 years
	15 to 24 years
	25 to 34 years
	35 to 44 years
	45 to 54 years
	55 to 64 years
	65+ years
Dwelling Type (proportion of occupied dwellings)	Single-detached house
	Apartment, building that has five or more storeys
	Semi-detached house
	Row house
	Apartment, duplex
	Apartment, building that has fewer than five storeys
	Other single-attached house
Education Level (proportion of population 15+)	No certificate, diploma or degree
	High school diploma or equivalent
	Postsecondary certificate, diploma or degree
	Apprenticeship or trades certificate or diploma
	College, CEGEP or other non-university certificate or diploma
	University certificate or diploma below bachelor level
	University certificate, diploma or degree at bachelor level or above
	Bachelor's degree
	University certificate, diploma or degree above bachelor level
Labour Force by Industry (proportion of total labour force)	11 Agriculture, forestry, fishing and hunting
	21 Mining, quarrying, and oil and gas extraction
	22 Utilities
	23 Construction
	31-33 Manufacturing
	41 Wholesale trade
	44-45 Retail trade
	48-49 Transportation and warehousing
	51 Information and cultural industries
	52 Finance and insurance
	53 Real estate and rental and leasing
	54 Professional, scientific and technical services
	55 Management of companies and enterprises

	56 Administrative and support, waste management and remediation services
	61 Educational services
	62 Health care and social assistance
	71 Arts, entertainment and recreation
	72 Accommodation and food services
	81 Other services (except public administration)
	91 Public administration
Labour Force by Occupation (proportion of total labour force)	0 Management occupations
	1 Business, finance and administration occupations
	2 Natural and applied sciences and related occupations
	3 Health occupations
	4 Occupations in education, law and social, community and government services
	5 Occupations in art, culture, recreation and sport
	6 Sales and service occupations
	7 Trades, transport and equipment operators and related occupations
	8 Natural resources, agriculture and related production occupation
	9 Occupations in manufacturing and utilities
Employment Status (proportion of total labour force)	Unemployed
Mobility (proportion of totall population moved within 1 year)	Immigrants
Average Household Income	Average Household Income (Current Year $)

Appendix B: 2011 Linear Regression Modelling Attempts

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.676[a]	.457	.257	10.59286	.457	2.285	7	19	.072	2.279

a. Predictors: (Constant), Zscore: % Labour Force Status | Unemployed, 2011, Zscore: % Labour Force by Industry | 54 Professional, scientific and technical services, 2011, Zscore: % Total Population by Ten Year Age and Sex | 25 to 34 years, 2011, Average Household Income (Current Year) | Average Household Income (Current Year $), 2011, Zscore: % Total Immigrant Population by Place of Birth | Immigrants, 2011, Zscore: % Labour Force by Occupation | 2 Natural and applied sciences and related occupations, 2011, Zscore: % Population 15 Years or Over by Educational Attainment | Bachelor's degree, 2011

b. Dependent Variable: PATRATE2011

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.780[a]	.609	.435	9.23897	.609	3.500	8	18	.013	1.665

a. Predictors: (Constant), Zscore: % Labour Force by Occupation | 1 Business, finance and administration occupations, 2011, Zscore: % Labour Force by Industry | 55 Management of companies and enterprises, 2011, Zscore: % Total Population by Ten Year Age and Sex | 25 to 34 years, 2011, Zscore: % Total Population by Ten Year Age and Sex | 35 to 44 years, 2011, Average Household Income (Current Year) | Average Household Income (Current Year $), 2011, Zscore: % Labour Force by Industry | 54 Professional, scientific and technical services, 2011, Zscore: % Labour Force by Occupation | 2 Natural and applied sciences and related occupations, 2011, Zscore: % Population 15 Years or Over by Educational Attainment | Bachelor's degree, 2011

b. Dependent Variable: PATRATE2011