The Evolution and State of the Science–Technology Knowledge Nexus across Canadian Regional Innovation Systems

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Key messages:

- Canada's science and innovation is highly concentrated: top five census metropolitan areas (CMAs) produce >70% of patents; top 11 CMAs generate >80% of publications
- Patents citing scientific literature receive ~30% more citations, and those citing local science receive ~50% more; evidence of powerful regional knowledge spillovers
- Scientific and technical knowledge maps show where regions have strengths to build on, helping target new specialties that fit local know-how but haven't materialized yet

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This paper is one of eight commissioned to support the CCA's 2025 assessment on the State of Science, Technology, and Innovation in Canada by synthesizing evidence and providing new insights into the assessment charge. The expert panel considered each paper alongside many other sources of evidence. These papers are the work of the authors alone and were not approved or endorsed by the expert panel.

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The State of Science, Technology, and Innovation in Canada

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Introduction

Since its initial assessment of *Science and Technology in Canada* in 2006, the Council of Canadian Academies (CCA) has been closely examining Canada's science and technology (S&T) and research and development (R&D) strengths and weaknesses. Measuring the performance of the outputs and the international ranking of Canada's scientific research has been a consistent part of this assessment, using both standard measures, as well as several specifically developed ones, for this purpose. Commencing with the report on *Innovation and Business Strategy* in 2009, the CCA has also conducted several assessments of Canada's performance in industrial R&D, using a range of standard measures of innovative performance. The most recent assessment, *Competing in the Global Innovation Economy*, found that despite Canada's robust research base and thriving community of technology start-ups, the areas of scientific expertise are not closely aligned with areas of industrial research strength at the national level. However, this linkage has never been closely examined by the CCA at the sub-national and metropolitan level.

Recent research advancements in the fields of innovation studies and economic geography open up the possibility for the CCA to examine this relationship in order to understand how Canada's respective areas of strength align at the sub-national level. The original foundation that advances in science and technology mainly result from the creation of new ideas, and the recombination of existing sources of knowledge, dates back to the work of Schumpeter (1911). Contemporary measures of novelty often rely on metrics that capture new combinations of knowledge that derive from previously unconnected disciplines and research fields (Wagner et al., 2019). In this context, work by Uzzi et al. (2013) and more recently by Shin et al. (2022), which investigates inter-disciplinary research outputs and associated scientific impact, is highly relevant given that it advances the impact evaluation of scientific research output beyond simple output metrics.

In parallel, another strand of research literature has started to examine the impact of scientific advances on inventions. Here, findings confirm that it is high-quality scientific works that provide essential knowledge inputs in patented inventions and that this matters significantly for the value of those inventions (Poege et al., 2019). This confirms that novel products and processes, as measured by patented inventions that rely on advanced scientific knowledge inputs, i.e., patent citations to the scientific literature, are likely to have a higher economic impact and greater commercial value (Li et al., 2017). Similar investigations confirm that there is an increased reliance by patents on scientific knowledge inputs over time and that this has a direct impact on the value of the patents (Ahmadpoor & Jones, 2017; Jefferson et al., 2018).

A recent study by Shin, Kogler & Kim (2024), which focuses on European metropolitan regions, confirms these research findings, and shows that "regions that hold competitiveness in both science and technology can accomplish higher technological advancements, which stresses the importance of scientific foundations for developing technological capabilities" (Shin et al., 2024: 203).

Building on these recent findings, further investigations into the "science-technology nexus" are of paramount importance to comprehend the complex interaction between scientific knowledge and technological inventions of commercial value in local and regional innovation systems. To date, much of the Innovation Studies literature has relied on anecdotal and special case-study evidence rather than large-scale comprehensive data-driven research. At this point it is unknown why certain local and regional innovation systems manage to produce and utilise locally generated scientific knowledge for innovation and growth whereas others fail in that endeavour. For example, despite being home to one of the largest and fastest growing technology talent hubs in North America (CBRE, 2024), Canadian cities lag behind their US equivalents in terms of inventive outputs (patents). The implications for regional economies that fail to convert investments in scientific knowledge production into innovation and growth are significant, especially if such locally generated knowledge is utilised and commercialised elsewhere.

The significant mismatch or potential underutilisation of resources between localised knowledge production and spillovers towards commercial innovation activities indicates a misallocation of resources in the national innovation system. Regional innovation systems at the forefront of connecting localised scientific outputs to the development of novel products and processes with economic value should be a focal point, and it is essential to understand how institutional and organisational configurations in these localities might apply more widely. Considering the highly regionalised nature of the Canadian economy, and the significant variation in both industrial structure and the research intensity of industry sectors across the country, it is imperative to gain a clearer insight into the nature of this relationship in general as well as at the metropolitan level.

With this goal in the forefront, i.e., providing a comprehensive and up-to-date picture of "The State of Science, Technology, and Innovation in Canada", this research report provides the following outputs:

1. An overview of scientific (publications) and technical (patents) knowledge production across Canadian Census Metropolitan Areas (CMAs)/Census Agglomerations (CAs) over the period 2010-2021.

2. An evaluation of the localisation of science-technology knowledge spillovers at the CMA level and its evolution over the study period.

3. A detailed regional analysis of inventions' novelty and impact based on the spatial origin of the science content that was utilised in the development of such novel products and processes of economic value.

The results of the various analyses offer the following key findings which will be elaborated on in the subsequent sections of this report:

- Inventors residing in the top 5 CMAs accounted for over 70% (50k) of total Canadian patent output, whereas the top 35 CMA/CAs account for over 96% (68k) of all patents (71k) developed in the observed period, 2010-2021.

- Over the observed 12-year timeframe, significant differences in the rate of patenting growth are observed whereby CMAs that account for a smaller proportion of national output have experienced significant increases, e.g., Halifax and Guelph; in contrast, some larger inventive centres, e.g., Ottawa and Kitchener-Cambridge Waterloo, display weak, and in the latter case even negative, growth rates.

- The top 11 CMAs that account for over 85% of patent output are also the most diverse regional economies – they utilised at least 50% of the 650 possible patent technology classes in the development of their inventions.

- The Ottawa-Gatineau CMA is much less diverse compared to other top ranking CMAs, but it displays a higher degree of specialisation (i.e. location quotients above the value of 1) across its utilised technology classes compared to other top ranking CMAs.

- The regional distribution of scientific knowledge production, indicated by publication counts, mirrors the highly skewed distribution observed with patented inventions. The top 11 CMAs account for over 80% of scientific output. This equates to approximately 650k out of 810k publications.

- On average, the output of the top 35 performing CMA/CAs grew by about 50% over the observed time period, while growth rates towards the bottom of the table, i.e. CMA/CAs with less output, were stronger but also varied more significantly.

- Every 10th publication associated with a Canadian institution originated at the University of Toronto, while this institution, along with the University of British Columbia and McGill University combined, accounted for close to one quarter of all published works from 2010 to 2021.

- All top 35 institutions experienced growth over the 2010-2021 time period with the exception of the two federal research institutions in the list, i.e., the National Research Council Canada (-47%) and the Agriculture & Agri Food Canada (-34%).

- Patents with Non-Patent Literature (NPL) citations, i.e. they contain references to prior scientific publications that were instrumental in the development of a novel product or process, receive on average over 30% more citations compared to patents without any references to the scientific literature.

- Patents with NPL references to local scientific knowledge (i.e., the science originated in the same CMA/CA as the patent) receive on average close to 50% more citations compared to the group of patents without any scientific references.

- Significant differences exist between the largest CMAs in terms of how patent assignees utilise local scientific knowledge inputs in the development of novel products and processes.

The following section will highlight the data and various methodological approaches that were utilised in this report. The subsequent sections will then provide the overall insights gained from the analyses whereas further methodological details, along with additional results, will be collected in the attached Appendix. The report concludes with a summary of key research findings along with potential policy implications and suggestions for future work in this line of inquiry.

Data and Methodological Approaches

In order to develop the detailed overview of scientific (publications) and technical (patents) knowledge production across Canadian Census Metropolitan Areas (CMAs) over the period 2010-2021 two primary data sources were consulted, while an additional dataset then facilitated the establishment of regional science-technology linkages. A detailed account of utilised data sources, as well as an overview of the relevant methodological approaches, and further details concerning the scope and timeframe of the study, are highlighted in turn.

Technical Knowledge

The relevant literature concerned with technical knowledge production, almost exclusively relies on patent data to capture the spatial and sectoral extent of inventive activities that translate into novel products and processes of economic value, i.e., innovation. Following this established approach, the present study utilises patent data, and specifically data derived from the United States Patent and Trademark Office (USPTO). The raw data for granted patent documents was obtained from the USPTO's 'PatentsView' website. Patents contain detailed address information, or at least the name of the resident locality, for each inventor listed on an individual patent document. This in turn allows for the spatial allocation of inventions; in the present case this was to relevant regional economic areas, such as Census Metropolitan Areas (CMAs) or Census Agglomerations (CAs) as defined by Statistics Canada via their standard geographic unit definitions and associated boundary files data provisions.

Once the data was geocoded based on inventors' residency, each patent that had at least one Canadian-based inventor listed, and that was granted in the timeframe 2010 to 2021 was selected for further analysis. To ensure a consistent allocation of inventions in space, i.e., regardless of the number of co-inventors and their respective residency at time of invention, fractional counting, which has become a common practice in the relevant literature, has been applied consistently throughout the entire study period. In addition to the interest in the rate and direction of technical knowledge production across regional economies, the present investigation also takes a close look at the actors behind initiating inventive outputs. Each patent document provides information on the individual or entity that has been legally assigned, i.e., the 'assignee', the rights to a granted patent. Research and development activities that eventually result in patent applications are frequently costly, just like the patent application process itself. Thus, the vast majority of patent applications are filed by entities and organisations rather than individuals.

An overview of the main actors that drive technical knowledge production and its commercialisation is expected to provide further insight to the evaluation of the current state of innovation in Canada. Of particular help in this regard is the fact that the 'PatentsView' database follows a disambiguation process that aims at tracking the patenting activity of inventors and assignees over time. This in turn ensures that data inconsistencies, such as typos, acronyms that might vary but refer to the same organisation, among other aspects are accounted for, and essentially enables a longitudinal study of patent assignees. The present study takes advantage of this and thus the presented results should be fairly consistent regardless if an entity consistently patents under the same legal name, or variations thereof.

Scientific Knowledge

The study of the evaluation of scientific knowledge production across countries and regions has been hampered by the scarcity of universal and harmonised data sources that would allow a large-scale investigation based on consistent panel data, albeit there have been many attempts to address this, e.g., Microsoft Academic Graph, OpenAlex, Scopus, amongst others. Nevertheless, most of these data sources are either biased towards certain scientific outlets and/or lack aspects of harmonisation, e.g., outputs are recorded multiple times along the publication process. Furthermore, if considerations concerning 'influence' and 'peer-review' status of scientific publications enter the discussion there is currently only one bibliographic database that is seen as superior and thus widely used amongst scholars interested in scientometric analysis, which is the Web of Science developed and maintained by Clarivate Analytics.

As a result, the present study utilises publication data derived from the Web of Science Core Collection[1] which, in addition to general information on scientific publications, also provides information on authors' names and their affiliation/address. Once addresses were geocoded using the same method as with inventors listed in patent documents, it was then possible to allocate authors/publications to their respective place of origin, i.e., CMAs/CAs. Where there are multiple authors we follow the same fractional counting method as with inventors on patent documents.

[1] Restrictions apply to the publication dataset used in this report. The Web of Science data is owned by Clarivate Analytics. To obtain the bibliometric data in the same manner as the author (i.e., by purchasing them), readers can contact Clarivate Analytics at https://clarivate.com/webofsciencegroup/solutions/web-of-science/contact-us/ in order to gain access to the Web of Science bibliographic database.

Establishing the Link Between Scientific and Technical Knowledge

It is only recently that the relevant literature has made attempts to engage in more detailed, quantitative orientated, evaluations of science-technology linkages that are considered instrumental in the development of advanced inventive outputs. A recent investigation, focused on European metropolitan regions, confirms prior research findings and shows that "regions that hold competitiveness in both science and technology can accomplish higher technological advancements, which stresses the importance of scientific foundations for developing technological capabilities" (Shin et al., 2024: 203). Following the approach and methodology set out in that publication, the goal here is to analyse science-technology linkages in the Canadian regional context.

Figure 1 highlights how this will be achieved by **1)** taking into consideration knowledge inputs for inventions derived from past technical and scientific knowledge production activities, while also **2)** taking into consideration future knowledge outputs generated by patented inventions that relied on scientific inputs in the first place. Of particular interest, in the present study, is a differentiation of local versus non-local scientific inputs in the development of inventions, and subsequently what difference it might make in terms of the future impact on new inventions via forward citations measures.

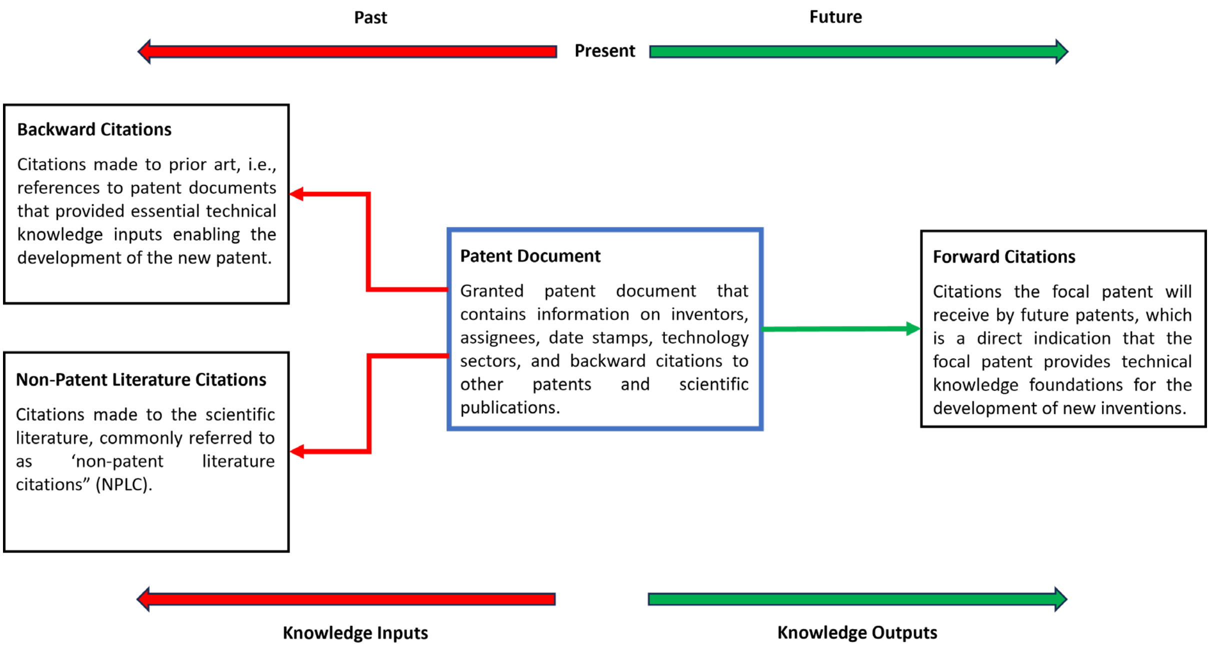

Figure 1 – Patent backward citations to prior art and the scientific literature, and patent forward citations as indicators of knowledge input/output relationships.

The actual link between scientific knowledge inputs (publications) and inventions (patents) is established via a "WoS_to_Patents" file that was provided by Clarivate Analytics. Similar to products offered by other data providers, e.g., the Lens, the principle idea is to first identify citations to the scientific literature in patent documents, and second to link those to a detailed publication database that offers additional metadata, i.e., WoS in the present case, which in turn can be utilised for analytic purposes.[2] The fractional counting approach that has been applied previously in the context of multiple inventors (patents) and authors (publications) is also applied in the context of science-technology linkages. Specifically, if a local knowledge input, which is a citation found in a patent document to a publication that was generated in the same CMA, was developed by two authors associated with institutions in different jurisdictions (one of them being the focal CMA), this particular citation would only a carry a weight of "0.5" in the analysis.

Scope and Timeframe of the Study

The scope of the present study concerns Canadian urban agglomerations, i.e., CMAs and CAs, as highlighted in the previous section. The timeframe refers to the period 2010-2021. Particularly, the analysis that follows includes patents and scientific publications published in 2010 to 2021, and for comparative reasons the 12-year timeframe will be separated into two time periods, i.e., 2010-2015 & 2016-2021. It has become the norm in the relevant literature to aggregate scientific and technical knowledge production indicators into time windows of variant lengths in order to avoid measuring annual fluctuations rather than long-term trends.

Technical Knowledge Production

Table 1 highlights the distribution of patented inventions across Canadian CMAs and CAs in the two time periods 2010-2015 and 2016-2021, respectively. It also shows the share of each top-performing (top 35) jurisdiction in the overall Canadian urban technical knowledge production system. The "other" category at the bottom of the table refers to the over 100 CMAs/CAs that are not listed individually above.

There are a number of aspects and trends that are noticeable when analysing these data, including:

- Inventors residing in the top 5 CMAs accounted for over 70% (50k) of total Canadian patent output, whereas the top 35 CMA/CAs account for over 96% (68k) of all patents (71k) developed in the 2010-2021 timeframe.
- All other urban centres in the country, i.e. 104 CMA/CAs, accounted for less than 4% of patented inventions. Notably, that share even slightly declines between the two periods

[2] To note, the file provided by Clarivate Analytics and utilised in the present study contains 50% more records compared to what is available in the equivalent data provided by the Lens according to their current database overview displayed on their website.

of interest, specifically there is a 0.2% decline between the period 2010-2015 and 2016-2021.

- Over the observed 12-year timeframe, significant differences in the rate of patenting growth are observed. Some CMAs that account for a smaller proportion of national output have experienced significant increases, e.g., Halifax and Guelph, whereas some larger inventive centres, e.g., Ottawa and Kitchener-Cambridge Waterloo, display weak, and in the latter case even negative, growth rates.

- These two CMAs (i.e., Ottawa and Kitchener-Cambridge-Waterloo) accounted for about 27.5% of the national output in the period 2010-2015, but only for just under 21% in the second observed period, 2016-2021. The distribution of specific technical knowledge production capabilities among these two CMAs, which are heavily directed towards computer, peripheral and communications equipment manufacturing sectors (see here for a more detailed overview of the Kitchener-Cambridge-Waterloo CMA's distribution of patent-industry linkages: https://www.rknowledge.org/dashboard/northamerica/541), indicates that Canada is perhaps underperforming in key technology sectors given that they have experienced exceptional growth rates elsewhere. A further investigation into the changing patterns of technical knowledge production in these two metropolitan areas, with the goal of identifying the key reasons for decline in output is thus highly recommended.

- Within the North American technical knowledge production system the largest Canadian CMAs rank 20th (Toronto), 30th (Ottawa-Gatineau), 35th (Vancouver), 38th (Montreal), and 48th (Kitchener-Cambridge-Waterloo) when ranked against top performing metropolitan areas in the United States, respectively. Looking at the 2010-2021 time period, the highest volume of patents in North America were produced in the two Californian metropolitan areas of San Jose-Sunnyvale-Santa Clara, and San Francisco-Oakland-Hayward, which produced about ten-times and seven-times the amount of patents compared to the Toronto CMA, respectively.

- In terms of growth rates, the top 35 Canadian CMA/CAs grew by 22% over the time period 2010-2021. All other Canadian metropolitan areas combined grew their output only by 14% over the same time period.

Table 1 – Distribution of patents across large Canadian urban centres

			Patent Granted at the USPTO by Canadian Inventors					
CMA and CA Name	**Prov**	**CMA/CA**	**2010-2015**		**2016-2021**		**2010-2021**	
			TOTAL	**SHARE**	**TOTAL**	**SHARE**	**TOTAL**	**SHARE**
Toronto	ON	CMA	7,499	22.8%	8,689	22.9%	**16,189**	**22.8%**
Ottawa–Gatineau	ON	CMA	4,921	15.0%	5,254	13.8%	**10,175**	**14.4%**
Vancouver	BC	CMA	3,945	12.0%	5,060	13.3%	**9,005**	**12.7%**
Montreal	QC	CMA	3,343	10.2%	4,783	12.6%	**8,126**	**11.5%**
Kitchener–Cambridge–Waterloo	ON	CMA	4,091	12.5%	2,611	6.9%	**6,702**	**9.5%**
Calgary	AB	CMA	1,578	4.8%	2,455	6.5%	**4,032**	**5.7%**
Edmonton	AB	CMA	1,045	3.2%	1,406	3.7%	**2,452**	**3.5%**
Hamilton	ON	CMA	586	1.8%	634	1.7%	**1,220**	**1.7%**
London	ON	CMA	461	1.4%	577	1.5%	**1,038**	**1.5%**
Windsor	ON	CMA	385	1.2%	581	1.5%	**966**	**1.4%**
Winnipeg	MB	CMA	486	1.5%	470	1.2%	**957**	**1.3%**
Saskatoon	SK	CMA	339	1.0%	538	1.4%	**877**	**1.2%**
Victoria	BC	CMA	296	0.9%	332	0.9%	**628**	**0.9%**
Guelph	ON	CMA	210	0.6%	310	0.8%	**519**	**0.7%**
Sherbrooke	QC	CMA	224	0.7%	284	0.7%	**509**	**0.7%**
Halifax	NS	CMA	180	0.5%	318	0.8%	**498**	**0.7%**
Quebec City	QC	CMA	240	0.7%	237	0.6%	**477**	**0.7%**
Kingston	ON	CMA	179	0.5%	226	0.6%	**405**	**0.6%**
Saint John	NB	CMA	139	0.4%	262	0.7%	**401**	**0.6%**
Oshawa	ON	CMA	157	0.5%	203	0.5%	**360**	**0.5%**
Barrie	ON	CMA	115	0.4%	183	0.5%	**298**	**0.4%**
Kelowna	BC	CMA	110	0.3%	185	0.5%	**295**	**0.4%**
Moncton	NB	CMA	101	0.3%	146	0.4%	**247**	**0.3%**
St. Catharines–Niagara	ON	CMA	142	0.4%	104	0.3%	**246**	**0.3%**
Fredericton	NB	CMA	78	0.2%	100	0.3%	**178**	**0.3%**
Brantford	ON	CMA	86	0.3%	80	0.2%	**167**	**0.2%**
St. John's	NL	CMA	97	0.3%	69	0.2%	**166**	**0.2%**
Regina	SK	CMA	63	0.2%	84	0.2%	**147**	**0.2%**
Granby	QC	CA	65	0.2%	79	0.2%	**144**	**0.2%**
Stratford	ON	CA	78	0.2%	61	0.2%	**139**	**0.2%**
Chatham-Kent	ON	CA	59	0.2%	80	0.2%	**138**	**0.2%**
Drummondville	QC	CMA	71	0.2%	65	0.2%	**135**	**0.2%**
Abbotsford	BC	CMA	60	0.2%	58	0.2%	**117**	**0.2%**
Peterborough	ON	CMA	50	0.2%	66	0.2%	**116**	**0.2%**
Centre Wellington	ON	CA	75	0.2%	37	0.1%	**112**	**0.2%**
Top 35			**31,553**	**96.1%**	**36,626**	**96.3%**	**68,179**	**96.2%**
Other			**1,286**	**3.9%**	**1,398**	**3.7%**	**2,684**	**3.8%**
Canada Total			**32,839**	**100.0%**	**38,024**	**100.0%**	**70,863**	**100.0%**

Note: Time periods (2010-2015 & 2016-2021) refer to USPTO patents granted in those calendar years, respectively. Total values refer to the sum of fractions based on co-inventor residency information. Share values refer to a jurisdiction's output share for all Canadian patents granted in the reference period. Top 35 is the sum of values for the top 35 performing urban centres. Other is the sum of all Canadian urban jurisdictions (139) other than the top 35.

Diversity and Specialisation in Technical Knowledge Production across Canadian Urban Centres

Simple output measures, while informative, do not reveal the unique composition of urban knowledge spaces. The diversity and the level of present specialised capabilities found in a regional economic structure have important implications in terms of generating externalities beneficial for future development and growth trajectories. The knowledge space methodology offers tools and measures that provide direct indicators of how diverse and specialised a particular national or regional technical knowledge production system is, while offering an opportunity to identify and target potential technology sectors that have a high potential to grow and create novel patterns of specialisation in the future.

The Knowledge Space aims to capture economic realities, and to subsequently translate them into a networked representation of existing capabilities and skills and allows for the testing of their inter-connectedness, while also offering an advanced tool for progressive economic development evaluation and planning purposes. **Figure 2** illustrates the conceptual framework of a Knowledge Space.

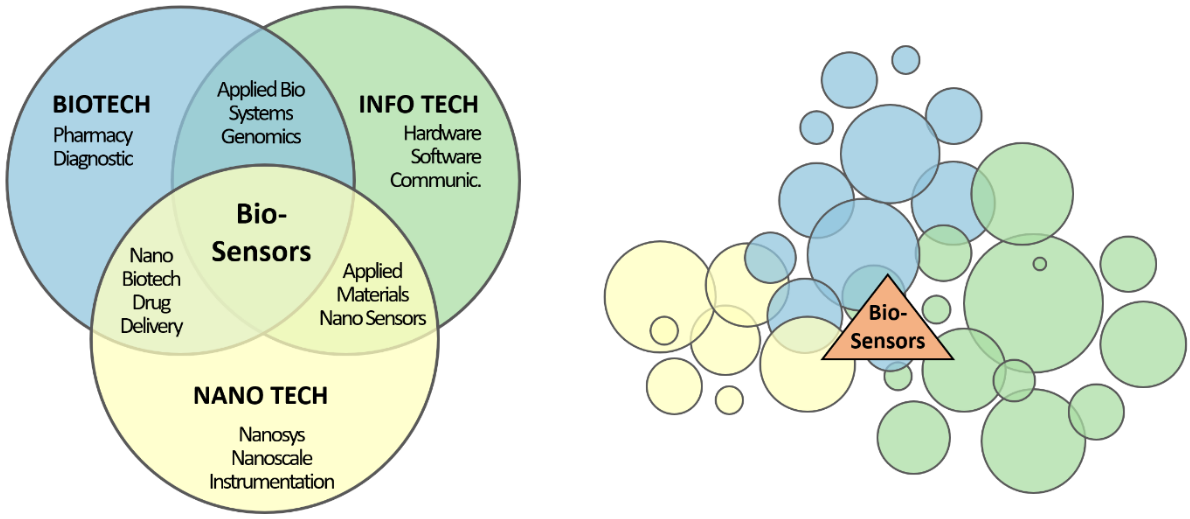

Figure 2 – Conceptual presentation of the Knowledge Space methodology[3]

Note: Biosensors are analytical devices that combine a biological recognition element with a transducer to detect and measure chemical or biological substances. They convert a biological response into an electrical, optical, or thermal signal, enabling precise monitoring of health, environment, or industrial processes. Biosensor patents typically fall into several core technological classes: biochemical detection mechanisms (e.g., enzymatic, immunological, or DNA-based), transduction technologies (electrochemical, optical, piezoelectric, or thermal), and device integration and miniaturization (such as lab-on-a-chip systems or wearable sensors). Additionally, patents often cover signal processing and data interpretation algorithms, material innovations, etc., which reflects both the interdisciplinary nature and rapid evolution of biosensor technologies.

[3] The graphic was developed by Dr. Dieter F. Kogler for the purpose of illustrating the "Knowledge Space" methodology at academic and policy-oriented conferences and meetings. It is the core methodology behind the European Research Council (ERC) funded project "Technology Evolution in Regional Technologies" (TechEvo); Principal Investigator: D. F. Kogler; 2017-2023; see: https://cordis.europa.eu/project/rcn/206490/factsheet/en [accessed, January 24th, 2025].

The initial aim is to capture and quantify the various types of knowledge that feed into development processes of a specific technology (sub-)sector; the left-hand side of the figure. For example, biosystems and biological systems engineering situated at the top-middle of the illustration is a field of engineering that draws knowledge inputs from both, biotechnology and information technologies. An example of one practical application in this context would be biosensors. Localities that have the capabilities and capacity of producing both of these underlying core technologies will in turn also have the advantage of entering into areas of the knowledge space, driven by recombinant knowledge inputs deriving from two or more sectors. The right-hand side of **Figure 2** displays a networked representation of a hypothetical Knowledge Space that a) identifies each sector in terms of its quantity (size of nodes) as well as its relative position to other sectors (the distribution among and distance between individual nodes).

Utilising the patent classification system, in conjunction with inventor residency location information, it is then possible to generate unique regional Knowledge Spaces. All patented inventions are classified according to the technical knowledge domain that underlies the development of a novel product or process. In most cases patents contain several of these underlying domains. The Cooperative Patent Classification (CPC) system, jointly developed by the United States Patent and Trademark Office (USPTO) and the European Patent Office (EPO), has established itself as the standard among national and international patent offices around the world, and consists of several hierarchical elements. The first digit is a letter and is labelled the "section symbol". For example, "C" stands for the "Chemistry and Metallurgy". The CPC scheme is organised in 9 sections, i.e. "A" to "H", including a "Y" section that indicates emerging cross-sectional technologies. The section is then followed by a two-digit number, which is referred to as the "class symbol". For example, "C01" represents "Inorganic Chemistry" in the "Chemistry and Metallurgy" section. The final letter then at the fourth digit of the code stands for the "subclass". Following on from the previous example, "C01B" represents "Non-Metallic Elements; Compounds Thereof". There are roughly 650 unique technology classes at the CPC 4-digit level. The analysis presented below will utilise this level of CPC definition.

This analysis will focus on one particular knowledge space measure, i.e., the Revealed Comparative Advantage (RCA) of particular technology classes, in a specific regional economy. This indicator, commonly known as a location quotient, is based on a variant of the original Balassa index and indicates if a region has a greater share of patents in a technology class when compared to a reference region, which in this case is the entire Canadian economy. Essentially, an RCA value indicates how "specialised" a knowledge domain is in the regional knowledge space. An RCA=1 indicates that the regional share (i.e., CMA/CA) of a technology class is equal to the share of that particular class in the entire Canadian space. Thus, an RCA>1 implies that the share of said class in the regional knowledge space is larger than what is observed in the portfolio of the entire Canadian knowledge space. Hence, classes with an RCA>1 indicate regional specialisation. Similar, an RCA ≤1 signals that a technology class is less prominent in the region than it is in the overall Canadian portfolio. Knowledge domains that are close to an RCA=1, and that are well embedded in the regional knowledge space, i.e., as indicated by their relative relatedness density values, would provide ample opportunities to initiate, perhaps via direct business and policy interventions, future patterns of regional diversification and specialisation. Appendix A offers further technical details regarding the methodology and associated metrics.

Table 2 presents the number of all technological knowledge domains (CPC classes) that were employed in the development of patented inventions across the top 35 CMAs in both observed time periods, as well as the number of specialised technology classes (RCA > 1). The results highlight the following:

- The top 11 CMAs that account for over 85% of Canadian patent output are also the most diverse regional economies, i.e., they utilised at least 50% out of the 650 possible CPC classes in the development of their inventions.
- Although second in patent output, the Ottawa-Gatineau CMA is much less diverse compared to other top ranking CMAs, i.e., only 419 CPCs in 2016-2021 (P2) compared to the over 500 CPCs present in the Toronto, Vancouver and Montreal CMAs, respectively.
- Nevertheless, Ottawa-Gatineau displays a higher degree of specialisation across its CPC classes compared to these 3 CMAs, i.e., it is specialised (RCA>1) in about 70% of all present CPCs, compared to the about 60% found across other top-ranking CMAs.
- Similar patterns are also observed for the Kitchener-Cambridge-Waterloo CMA.
- Technological knowledge diversity among the other 24 CMA/CAs listed in Table 2, indicated by CPC class counts, rapidly declines towards the bottom of the list, while the ratio of specialisation (comparing present vs specialised CPCs) considerably increases.
- With the exception of two cases (St. Catharines-Niagara CMA & Centre Wellington CA) all top 35 CMAs/CAs diversified into new technological knowledge domains (change in CPC counts from period 1 to 2).
- Strong diversification occurred in the Kelowna CMA (69%), Saint John CMA (59%), and the Barrie, Saskatoon and Regina CMAs (about 50%, respectively).
- Similarly, all CMAs/CAs, with the exception of the aforementioned two cases, increased their count of specialised (RCA>1) regional technical knowledge domains.
- The most significant increases in the number of specialisations occurred in the Kelowna CMA (69%), the Barrie CMA (61%), and the Saskatoon CMA (57%).
- In addition to the analysis of regional patterns of diversity and specialisation, indicated by the Revealed Comparative Advantage (RCA) measure, also Relatedness Density (REL Density) values were calculated for each CMA/CA and CPC node in the respective regional knowledge spaces. REL Density indicates how embedded a particular technical knowledge domain (CPC class) is in the regional knowledge space. From a STI policy perspective, nodes that have not reached a status of specialisation (RCA<1) but have a high Relatedness Density value in the regional knowledge space, are of particular interest for potential future economic diversification processes. While REL Density measures are not presented here, they are available via the rKnowledge Dashboard website along with additional knowledge space measures, e.g., betweenness and weighted degree centrality measures, which are further outlined in detail in Appendix A.
- It is recommended that further studies that focus on specific metropolitan areas take advantage of RCA and REL Density measures in tandem as they provide excellent guidance

in terms of the likelihood of a CPC class becoming specialised in the future. In other words, sector specific innovation support strategies can utilise these indicators in initial due diligence and feasibility studies to avoid failed investments into areas of the regional knowledge space that lack the critical foundations and embeddedness necessary to succeed into new capabilities in the future. The rKnowledge Dashboard offers the opportunity to investigate these two measures, along with other knowledge space indicators, for all Canadian CMAs, and thus provides a free, easy to use, regional technological knowledge intelligence interface that aims to directly support policy-makers in their quest for successful economic development strategies.

Table 2 – Present and specialised technology knowledge domains (CPC classes) among the largest Canadian urban centres

			Total Patents	Present and Specialised Technology Knowledge Domains (CPCs)					
CMA and CA Name	**Prov**	**CMA/CA**	**2010-2021**	**2010-2015**		**2016-2021**		**P1 --> P2**	
			Patent Count	**CPC Count (P1)**	**RCA > 1 (P1)**	**CPC Count (P2)**	**RCA > 1 (P2)**	**CPC + / -**	**RCA + / -**
Toronto	ON	CMA	16,189	520	307	552	325	32	18
Ottawa–Gatineau	ON	CMA	10,175	370	266	419	283	49	17
Vancouver	BC	CMA	9,005	486	311	529	314	43	3
Montreal	QC	CMA	8,126	480	304	521	307	41	3
Kitchener–Cambridge–Waterloo	ON	CMA	6,702	354	262	395	272	41	10
Calgary	AB	CMA	4,032	359	253	415	277	56	24
Edmonton	AB	CMA	2,452	361	255	425	276	64	21
Hamilton	ON	CMA	1,220	331	252	382	262	51	10
London	ON	CMA	1,038	228	204	301	238	73	34
Windsor	ON	CMA	966	272	228	313	246	41	18
Winnipeg	MB	CMA	957	264	219	328	245	64	26
Saskatoon	SK	CMA	877	136	134	203	191	67	57
Victoria	BC	CMA	628	198	185	263	227	65	42
Guelph	ON	CMA	519	176	166	227	203	51	37
Sherbrooke	QC	CMA	509	198	184	234	208	36	24
Halifax	NS	CMA	498	174	164	235	209	61	45
Quebec City	QC	CMA	477	214	195	238	210	24	15
Kingston	ON	CMA	405	176	166	193	183	17	17
Saint John	NB	CMA	401	71	71	113	113	42	42
Oshawa	ON	CMA	360	178	168	233	205	55	37
Barrie	ON	CMA	298	143	140	217	201	74	61
Kelowna	BC	CMA	295	113	112	191	181	78	69
Moncton	NB	CMA	247	134	133	162	159	28	26
St. Catharines–Niagara	ON	CMA	246	184	174	174	169	-10	-5
Fredericton	NB	CMA	178	96	95	129	129	33	34
Brantford	ON	CMA	167	125	123	151	148	26	25
St. John's	NL	CMA	166	67	67	88	88	21	21
Regina	SK	CMA	147	70	69	106	105	36	36
Granby	QC	CA	144	90	90	107	107	17	17
Stratford	ON	CA	139	54	54	59	58	5	4
Chatham-Kent	ON	CA	138	76	75	85	85	9	10
Drummondville	QC	CMA	135	79	79	90	90	11	11
Abbotsford	BC	CMA	117	94	93	111	111	17	18
Peterborough	ON	CMA	116	85	85	108	108	23	23
Centre Wellington	ON	CA	112	73	73	71	71	-2	-2

Note: Patent and CPC counts are based on USPTO patents granted in the respective time periods 2010-2015 (P1) and 2016-2021 (P2). All values refer to the sum of fractions based on co-inventor and 4-digit CPC class counts on individual patent documents. RCA refers to the Revealed Comparative Advantage (RCA) measure outlined in the main text.

Scientific Knowledge Production

Table 3 provides an overview of how scientific knowledge production has progressed in Canada overall, and across the top performing CMAs/CAs, over the timeframe 2010-2021. Some of the highlights are:

- The regional distribution of scientific knowledge production, indicated by publications counts, mirrors the highly skewed distribution of technical knowledge production already observed previously. The top 11 performing CMAs account for over 80% of scientific output. This equates to approximately 650,000 out of 810k publications.
- Over the observed 12-year period, the top four performing CMAs (Toronto, Montreal, Vancouver, Ottawa-Gatineau) accounted for 20%, 15%. 10% and 7%, respectively, and thus in total over 50% of the national share of scientific published output.
- The top 35 CMA/CAs accounted for almost all (98%) of Canadian scientific output over the timeframe 2010-2021.
- On average, the output of the top 35 performing CMA/CAs grew by about 50% over the observed time period, while growth rates towards the bottom of the table, i.e., CMA/CAs with less output, were stronger, but also varied more significantly.
- The Toronto CMA, by far the largest CMA in terms of scientific knowledge production, grew by 54% over the 12-year period, outperforming the CMAs that follow in the ranking, e.g., the Montreal and Vancouver CMAs grew by 34% and 27%, respectively.
- Weak growth of scientific knowledge output over the 12-year period was observed for Fredericton (4%) and Saint-Hyacinthe (7%), while Kelowna (228%), Moncton (126%), and St. Catharines–Niagara (125%) experienced strong growth.
- In terms of the main subject areas, ‘Life Sciences & Biomedicine’ related research outputs significantly increased their share over other areas, i.e., ‘Physical Sciences’ and ‘Technology’.

Table 3 – Scientific knowledge production across large Canadian urban centres

CMA and CA Name	Prov	CMA/CA	Scientific Outputs Published in 2010 to 2021												
			COUNT					SHARE				GROWTH			
			LS & BIO	PHYS	TECH	OTHER	TOTAL	LS & BIO	PHYS	TECH	TOTAL	LS & BIO	PHYS	TECH	TOTAL
Toronto	ON	CMA	103,103	12,081	20,586	22,465	**158,235**	23.1%	12.8%	13.0%	**19.5%**	44.3%	-10.9%	8.5%	**53.9%**
Montreal	QC	CMA	62,630	12,849	29,798	16,247	**121,524**	14.0%	13.6%	18.8%	**15.0%**	20.8%	-3.9%	6.9%	**33.5%**
Vancouver	BC	CMA	45,330	8,465	12,967	11,718	**78,480**	10.2%	9.0%	8.2%	**9.7%**	25.1%	-20.1%	-23.4%	**26.7%**
Ottawa–Gatineau	ON	CMA	29,359	6,754	13,266	8,551	**57,930**	6.6%	7.2%	8.4%	**7.2%**	42.7%	-13.4%	-17.7%	**37.2%**
Edmonton	AB	CMA	26,796	6,826	10,772	5,345	**49,739**	6.0%	7.2%	6.8%	**6.1%**	17.1%	3.4%	27.6%	**30.9%**
Calgary	AB	CMA	22,903	3,960	7,196	4,188	**38,247**	5.1%	4.2%	4.5%	**4.7%**	63.9%	-10.2%	-29.4%	**43.3%**
Hamilton	ON	CMA	20,141	3,276	5,120	3,118	**31,655**	4.5%	3.5%	3.2%	**3.9%**	47.6%	-6.4%	25.2%	**49.4%**
London	ON	CMA	19,037	3,768	4,763	4,289	**31,857**	4.3%	4.0%	3.0%	**3.9%**	38.0%	-27.1%	-3.4%	**39.2%**
Kitchener–Cambridge–Waterloo	ON	CMA	6,555	7,487	11,532	4,543	**30,117**	1.5%	7.9%	7.3%	**3.7%**	97.2%	18.2%	-13.5%	**39.9%**
Quebec City	QC	CMA	16,103	3,097	4,518	2,968	**26,686**	3.6%	3.3%	2.9%	**3.3%**	17.4%	-5.4%	-11.5%	**21.1%**
Winnipeg	MB	CMA	14,074	2,122	3,587	2,754	**22,537**	3.2%	2.3%	2.3%	**2.8%**	38.4%	4.7%	26.0%	**49.2%**
Kingston	ON	CMA	8,966	2,440	5,249	3,158	**19,812**	2.0%	2.6%	3.3%	**2.4%**	17.6%	-27.0%	-10.4%	**20.7%**
Halifax	NS	CMA	11,299	2,586	2,894	2,900	**19,679**	2.5%	2.7%	1.8%	**2.4%**	19.8%	-19.8%	22.7%	**33.4%**
Saskatoon	SK	CMA	10,218	2,359	2,854	1,918	**17,349**	2.3%	2.5%	1.8%	**2.1%**	20.6%	20.9%	11.2%	**33.2%**
Guelph	ON	CMA	9,404	1,505	1,526	1,873	**14,308**	2.1%	1.6%	1.0%	**1.8%**	9.4%	63.2%	39.8%	**35.7%**
Victoria	BC	CMA	4,665	3,031	2,845	2,569	**13,110**	1.0%	3.2%	1.8%	**1.6%**	34.3%	-19.6%	-28.5%	**23.8%**
Sherbrooke	QC	CMA	4,815	1,325	2,122	805	**9,068**	1.1%	1.4%	1.3%	**1.1%**	6.1%	8.6%	-9.0%	**12.8%**
Windsor	ON	CMA	1,407	836	2,442	907	**5,592**	0.3%	0.9%	1.5%	**0.7%**	36.9%	-15.7%	2.0%	**32.9%**
Saint John	NB	CMA	1,890	941	1,978	479	**5,288**	0.4%	1.0%	1.2%	**0.7%**	138.5%	-9.5%	62.7%	**83.1%**
St. John's	NL	CMA	2,559	902	699	848	**5,008**	0.6%	1.0%	0.4%	**0.6%**	25.0%	12.6%	43.4%	**55.7%**
Fredericton	NB	CMA	1,591	927	1,567	874	**4,959**	0.4%	1.0%	1.0%	**0.6%**	-5.9%	-28.2%	-19.2%	**3.7%**
St. Catharines–Niagara	ON	CMA	1,764	533	316	1,560	**4,172**	0.4%	0.6%	0.2%	**0.5%**	40.8%	-5.8%	90.2%	**124.6%**
Kelowna	BC	CMA	1,658	510	1,299	483	**3,951**	0.4%	0.5%	0.8%	**0.5%**	223.3%	42.7%	251.5%	**227.5%**
Regina	SK	CMA	1,235	577	1,374	756	**3,941**	0.3%	0.6%	0.9%	**0.5%**	58.8%	45.8%	8.4%	**69.4%**
Oshawa	ON	CMA	578	764	2,085	322	**3,749**	0.1%	0.8%	1.3%	**0.5%**	159.8%	2.6%	79.7%	**80.1%**
Lethbridge	AB	CMA	2,202	480	212	707	**3,601**	0.5%	0.5%	0.1%	**0.4%**	3.5%	-28.0%	-26.3%	**11.8%**
Thunder Bay	ON	CMA	1,157	444	803	338	**2,743**	0.3%	0.5%	0.5%	**0.3%**	29.8%	-22.9%	119.4%	**64.0%**
Peterborough	ON	CMA	1,466	287	165	785	**2,703**	0.3%	0.3%	0.1%	**0.3%**	12.3%	11.3%	-23.2%	**39.6%**
Greater Sudbury	ON	CMA	1,301	519	300	504	**2,624**	0.3%	0.6%	0.2%	**0.3%**	18.7%	-3.4%	-0.5%	**39.4%**
Trois-Rivières	QC	CMA	1,006	314	631	360	**2,311**	0.2%	0.3%	0.4%	**0.3%**	105.4%	17.5%	4.9%	**90.9%**
Saguenay	QC	CMA	489	375	906	90	**1,861**	0.1%	0.4%	0.6%	**0.2%**	115.2%	-10.5%	50.1%	**54.3%**
Saint-Hyacinthe	QC	CA	1,559	40	17	63	**1,680**	0.3%	0.0%	0.0%	**0.2%**	4.9%	-67.9%	96.2%	**6.6%**
Charlottetown	PE	CA	1,139	168	111	241	**1,659**	0.3%	0.2%	0.1%	**0.2%**	0.7%	-19.2%	401.7%	**22.6%**
Prince George	BC	CA	731	164	195	255	**1,345**	0.2%	0.2%	0.1%	**0.2%**	20.5%	22.0%	35.1%	**47.0%**
Moncton	NB	CMA	593	146	205	329	**1,273**	0.1%	0.2%	0.1%	**0.2%**	145.8%	-70.2%	152.6%	**126.3%**
Top 35			**439,724**	**92,860**	**156,896**	**109,310**	798,791	**98.5%**	**98.6%**	**99.1%**	98.6%				
Other			**6,564**	**1,312**	**1,430**	**1,858**	11,165	**1.5%**	**1.4%**	**0.9%**	1.4%				
Canada Total			**446,288**	**94,172**	**158,326**	**111,169**	809,955								

Note: Data Source is the Web of Science Core Collection data; publications with multiple authors are fractionally allocated across urban areas.

Table 4 shows the results from the investigation into scientific knowledge production by Canadian institutions, which includes the following findings:

- The top 35 performing institutions account for about 80% of published scientific output over the period 2010-2021.
- Every 10th publication associated with a Canadian institution originated at the University of Toronto, while this institution along with the University of British Columbia and McGill University combined accounted for close to one quarter of all published works from 2010 to 2021.
- U15 Canada[4] institutions are ranked 1-15, and account for about 60% of overall output.
- Growth rates over the 2010-2021 period are stronger for the top 35 institutions (over on average 40%) compared to all other Canadian institutions involved in publishing scientific outputs (approx.. 21%)
- Balanced growth amongst U15 Members (avg. around 50%) with the exception of the Universite de Montreal, which experienced growth of almost 200% in terms of scientific outputs. Without that one outlier the average growth among the remaining 14 U15 Members is close to 40%.
- The most notable growth among the top 35 institutions occurred at the University Health Network Toronto with 377%.
- All top 35 institutions experienced growth over the 2010-2021 time period with the exception of the two federal research institutions, i.e., the National Research Council Canada (-47%) and the Agriculture & Agri Food Canada (-34%).

[4] U15 Canada is an association of fifteen leading research universities across Canada.

Table 4 – Scientific knowledge production by Canadian institutions, 2010-2021

		Published in 2010 to 2021			
RANK	**INSTITUTION**	**TOTAL**	**SHARE**	**GROWTH**	**U15 Canada Member**
1	UNIVERSITY OF TORONTO	86,629	10.7%	38.9%	x
2	UNIVERSITY OF BRITISH COLUMBIA	54,428	6.7%	37.3%	x
3	MCGILL UNIVERSITY	47,808	5.9%	29.0%	x
4	UNIVERSITY OF ALBERTA	43,865	5.4%	32.2%	x
5	UNIVERSITY OF CALGARY	32,249	4.0%	41.5%	x
6	MCMASTER UNIVERSITY	28,180	3.5%	47.2%	x
7	WESTERN UNIVERSITY (U. OF WESTERN ONT)	27,894	3.4%	38.5%	x
8	UNIVERSITE DE MONTREAL	27,345	3.4%	197.3%	x
9	UNIVERSITY OF OTTAWA	26,664	3.3%	52.3%	x
10	UNIVERSITY OF WATERLOO	24,489	3.0%	33.2%	x
11	LAVAL UNIVERSITY	18,282	2.3%	26.1%	x
12	UNIVERSITY OF MANITOBA	17,840	2.2%	47.0%	x
13	QUEENS UNIVERSITY	17,260	2.1%	27.7%	x
14	DALHOUSIE UNIVERSITY	15,601	1.9%	38.8%	x
15	UNIVERSITY OF SASKATCHEWAN	15,497	1.9%	40.1%	x
16	SIMON FRASER UNIVERSITY	12,243	1.5%	26.8%	
17	UNIVERSITY OF QUEBEC	12,318	1.5%	36.8%	
18	UNIVERSITY OF GUELPH	13,574	1.7%	39.1%	
19	YORK UNIVERSITY	11,492	1.4%	130.8%	
20	CONCORDIA UNIVERSITY	11,198	1.4%	68.2%	
21	UNIVERSITY OF VICTORIA	10,068	1.2%	33.0%	
22	CARLETON UNIVERSITY	9,793	1.2%	53.6%	
23	UNIVERSITY OF SHERBROOKE	8,194	1.0%	14.3%	
24	RYERSON UNIVERSITY	7,507	0.9%	79.1%	
25	MEMORIAL UNIVERSITY NEWFOUNDLAND	8,152	1.0%	67.6%	
26	UNIVERSITY HEALTH NETWORK TORONTO	8,805	1.1%	377.4%	
27	HOSPITAL FOR SICK CHILDREN (SICKKIDS)	6,638	0.8%	2.7%	
28	NATIONAL RESEARCH COUNCIL CANADA	4,855	0.6%	-46.5%	
29	BROCK UNIVERSITY	3,833	0.5%	128.1%	
30	WILFRID LAURIER UNIVERSITY	3,019	0.4%	165.3%	
31	UNIVERSITY OF NEW BRUNSWICK	4,578	0.6%	4.3%	
32	UNIVERSITY OF WINDSOR	5,246	0.6%	33.4%	
33	UNIVERSITY OF REGINA	3,476	0.4%	78.5%	
34	SUNNYBROOK HSS & RI	4,106	0.5%	40.4%	
35	AGRICULTURE & AGRI FOOD CANADA	5,191	0.6%	-33.7%	
	Top 35	**638,318**	**78.8%**	**42.2%**	
	Other	**171,638**	**21.2%**	**30.0%**	
	Canada Total	**809,955**			

Note: The allocation of publications towards institutions is based on authors' affiliation information provided in publications' metadata. Publications with multiple authors are fractionally allocated across urban areas, while multiple affiliations are treated in the same way. Particular institutional practices, .e.g., authors predominantly only listing the main institutional name on publications versus those who tend to list exclusively, or jointly, sub-units (research centres, research hospitals, etc.) within their main institutional affiliation may result in varying output measures, which need to be taken into consideration when referring to the results presented.

Science-Technology Linkages

The underlying methodology that enables an investigation into regional science-technology linkages in terms of knowledge inputs and outputs (see also **Figure 1**, above) is comprised of the following steps.

1) Identifying patents that have received forward citations out of the total Canadian sample (i.e., the one illustrated in Table 1).
2) Separating those patents that have received forward citations versus those that have not.
3) Determining which of these cited patents contain ‘non-patent literature citations’ (henceforward referred to as “NPL References”) and thus build on scientific knowledge inputs in their original development.
4) Establishing two sub-samples of cited patents with NPL References: a) those with any NPL References regardless of their spatial origin versus b) those with regional NPL References (i.e., where the origin CMA/CA of the patent coincides with that of a NPL Reference).
5) Analysing if there are differences between the average number of received forward citations for patents without NPL References compared to those that contain general or even regional NPL References.
6) Investigating the potential forward citation premium that is enjoyed by patents with NPL References.

Following these steps, **Table 5** highlights the total number of Canadian patents that were granted between the two periods of interest, i.e., 2010-2015 & 2016-2021.[5] About 31% of those patents generated in the initial time period subsequently received forward citations, whereas that ratio falls to 14% in the second time period. It should be noted that a patent that was granted in 2011 had 10 more years to receive a forward citation compared to a patent that was granted only in 2020. Thus, the declining forward citation ration between the two observed time periods is not surprising.

Table 5 – Number of Canadian patents that received forward citations

PERIOD	Patents	Not Cited	Cited	Cited Ratio
2010-2015	32,839	22,682	10,157	31%
2016-2021	38,024	32,523	5,501	14%
TOTAL	70,863	55,204	15,658	22%

Note: Refers to patents that were granted by the USPTO between 2010 and 2021. Forward citations were determined via USPTO data released via PatentsView “Data update: 12/31/2023.[6]

[5] Note that the total number of patents in Table 1 corresponds to the total listed here in Table 5.
[6] See here for PatentsView version history and release notes: https://patentsview.org/release-notes

In the following step patents that received forward citations (**Table 5**) are further divided into three categories: 1) those that contain no reference at all to the scientific literature in the main patent document text; 2) those that contain at least one NPL Reference; and 3) patents that contain at least one NPL Reference that originated in the same jurisdiction as the patent itself as determined by inventor residency and author affiliation information derived from patent documents and publications, respectively. **Table 6** summarises the results of this exercise, showing that about three quarters of forward-cited Canadian patented inventions contain no NPL References, whereas only less than 8% of all forward-cited patents contain a regional NPL Reference, i.e., these are patents that utilised scientific knowledge inputs that originated in the same jurisdiction as the patent itself. In terms of changes between the two observed 6-year time periods it is evident that the share of patents with NPL References has increased by about 3 percentage points whereas the share of patents with regional NPL References has increased by over 1.5 percentage points. This confirms results from other studies, which have pointed towards the increasing relevance of scientific inputs in the development of novel products and processes in recent times (Ahmadpoor & Jones, 2017; Jefferson et al., 2018).

Table 6 – Number of Cited Patents Considering General and Regional Scientific Foundations

PERIOD	All Patents	Patents without NPL References	Patents with NPL References	Patents with Regional NPL References
2010-2015	10,157	7,807	2,351	713
2016-2021	5,501	4,056	1,445	477
TOTAL	15,658	11,863	3,796	1,191

In the next analysis, the number of received forward citations for each of these three categories of patents are calculated. The results are summarised in **Table 7**. As mentioned previously, patents that have been granted in more recent years have less time to accumulate citations and thus numbers significantly decline from the first to the second observed time period. Nevertheless, and given that the objective of the exercise is to investigate if patents with regional NPL References are more impactful towards new innovations, i.e., if they serve more frequently as knowledge inputs in the development of new technologies compared to patents that do not reference scientific knowledge, it is not the absolute values that are of interest here, but rather it is the citation ratios between categories within the two time periods that will be directly compared.

Table 7 – Number of Forward Citations Received by Type of Cited Patent

PERIOD	All Patents	Patents without NPL References	Patents with NPL References	Patents with Regional NPL References
2010-2015	37,335	26,752	10,583	3,655
2016-2021	13,000	8,676	4,324	1,582
TOTAL	50,335	35,428	14,907	5,237

The average number of citations received by the various types of patents, i.e., all patents compared to those without, with, or with regional NPL References follow the same increasing trend between both observed time periods as illustrated in **Table 8**. Focusing on the patents, that contain regional NPL References, these receive on average significantly more forward citations than their counterparts. For example, patents granted in 2010-2015 that contained at least one reference to regionally produced scientific knowledge, received on average over 5 forward citations, while patents with NPL References that came from jurisdictions other than where the patent originated from only received on average 4.5 forward citations on average. For patents that contain no references to the scientific literature this ratio further declines to about 3.4 forward citations per patent.

Table 8 – Average Number of Received Forward Citations for Cited Patents

Ratio of Citations Received by Type of Cited Patent

	Average Number of Received Forward Citations for Cited Patents			
PERIOD	**All Patents**	**Patents without NPL Ref.**	**Patents with NPL Ref.**	**Patents with Regional NPL Ref.**
2010-2015	3.68	3.43	4.50	5.12
2016-2021	2.36	2.14	2.99	3.31
TOTAL	3.21	2.99	3.93	4.40

In the final exercise, the objective is to investigate the actual forward citation premium that is enjoyed by patents with NPL References, and especially those that have utilised regional scientific knowledge inputs. **Table 9** highlights the results of this exercise and clearly indicates that patents that build on scientific knowledge on average receive over 30% more forward citations than patents that were developed without any of such inputs. For patents that contain regional NPL References that premium is even higher, almost 50%. Looking at the trend between the two observed time periods, it is evident that it is increasing, e.g., patents granted in 2016-2021 that contain NPL References to regional scientific knowledge received 55% more citations than patents without any NPL References.

Table 9 – Additional citation premium of patents that contain NPL references versus those without NPL References

	Premium versus Patents without NPL References	
PERIOD	**Patents with NPL Ref.**	**Patents with Regional NPL Ref.**
2010-2015	+31%	+49%
2016-2021	+40%	+55%
TOTAL	+31%	+47%

In summary, the analysis pertaining to: a) Canadian science-technology (publications-patents) linkages, and b) the impact of science-technology knowledge spillovers on future innovative outputs as measured by forward citations received, highlights the following patterns:

- The share of patents produced by inventors residing in Canada that relied on scientific inputs in the development process increased from 23% to 26% between the time period 2010-2015 to 2016-2021.
- In parallel, also the share of regional scientific inputs, i.e., references in patents to scientific foundations that enabled the development of a patented invention that were produced in the same CMA/CA, also increased from 7% to 8.6%. This confirms, for the first time in the Canadian context, that there is an increasing reliance on science in the development of inventions, and also that a significant proportion of this prior scientific knowledge derives from within the same regional economy.
- Taking a close look at the additional citations received by patents that either rely on scientific knowledge inputs in general, and also at those that contain locally produced scientific knowledge, it is evident that there is a significant premium compared to those patents without any scientific, i.e., non-patent literature (NPL), references.
- Specifically, patents with NPL References receive on average over 30% more citations compared to patents without an NPL Reference.
- Patents with NPL References to local scientific knowledge (i.e., the science originated in the same CMA/CA as the patent) receive on average close to 50% more citations compared to the group of patents without any NPL References.

Science-Technology Linkages in Canadian Metropolitan Areas

Following the same methodological approach that was applied in the overall Canadian context, in this section the objective is to investigate the science-technology linkages, and in particular their potential uniqueness, across the largest Canadian CMAs. For the purpose of comparison, the five largest Canadian urban centres, based on patent output, were selected. **Table 10** provides an overview of the inventive output and share of these 5 CMAs in the Canadian economy. Combined they account for over 70% of patents that have been granted to Canadian resident inventors over the time period 2010-2021.

Table 10 – Distribution of patents across the 5 most inventive Canadian CMAs

Census Metropolitan Area	Patents Granted at the USPTO to Canadian Resident Inventors					
	2010-2015		2016-2021		2010-2021	
	TOTAL	SHARE	TOTAL	SHARE	TOTAL	SHARE
Toronto	7,499	22.8%	8,689	22.9%	**16,189**	**22.8%**
Ottawa–Gatineau	4,921	15.0%	5,254	13.8%	**10,175**	**14.4%**
Vancouver	3,945	12.0%	5,060	13.3%	**9,005**	**12.7%**
Montreal	3,343	10.2%	4,783	12.6%	**8,126**	**11.5%**
Kitchener–Cambridge–Waterloo	4,091	12.5%	2,611	6.9%	**6,702**	**9.5%**

The ratio of patents that have received at least one forward citation across these 5 specific CMAs, and across either observed time period, correspond closely to the Canadian average that was shown in **Table 5**.[7] In terms of the share of patents granted to inventors residing in a particular CMA, and which subsequently also get cited by future patents, i.e., forward citations, the Vancouver CMA is a slight outlier. It outperforms the four other jurisdictions on that measure by about 5 percentage points in the first period, and by about 2-3 percentage points in second period. In aggregate, 36% of all Vancouver CMA patents granted in 2010-2015 subsequently received at least one forward citation, while in 2016-2021 this ratio is 17%.

Looking at only patents that received forward citations among the 5 CMAs of interest, and in terms of their scientific knowledge foundations, a more nuanced picture emerges compared to the overall Canadian insights that are highlighted in **Table 6**, above. For example, in the first time period only about 20% of those patents generated in the Montreal CMA contained at least one NPL Reference, compared to a ratio of almost 32% in the Vancouver CMA. In the second time period the gap among CMAs in terms of the ratio of patents that relied on scientific knowledge inputs in the development process closes as all jurisdictions also increased their share of patents that refer to the scientific literature. Again, Vancouver is taking the lead, i.e., one in three patents granted in that jurisdiction between 2016-2021 include at least one reference to the scientific literature. Perhaps noteworthy, the Toronto

[7] **Appendix B** provides the same series of detailed tables that have been highlighted in the pan-Canadian analysis in the previous section for each of the focal 5 CMAs that are discussed here.

CMA is the jurisdiction that experienced the smallest increase in the share of patents that first build on scientific knowledge inputs and subsequently also get cited by future patents between the two observed time periods.

In the next step of the analysis the focus shifts towards regional science-technology linkages rather than just general NPL References. The share of patents with regional NPL References, i.e., patents that received forward citations and contain at least one reference to scientific knowledge that was generated in the same jurisdiction as the invention, varies significantly among the 5 CMAs and over time. **Table 11** shows the distribution of patents that received forward citations and further the number and share of cited patents that contain at least one NPL reference, and finally the number of patents with Regional NPL References and their share based on patents that contain NPL references. In the first period only about 13% of Ottawa CMA patents fall into the category of inventions that contain regional NPL references and exert impact on future inventions via forward citations. At the same time mor than 37% of the Vancouver CMA patents fulfil that criteria. In the second period most CMAs increased the share of patents with regional NPL References, e.g., to 46% and 38% in the Vancouver and Toronto CMAs, respectively, while the Montreal CMA is the only jurisdiction that actually experienced a declining trend, i.e., only 25% of patents generated in that jurisdiction in 2016-2021 with NPL References and subsequent forward citations also contained references to regional scientific knowledge inputs. The pan-Canadian average, in comparison, in the two observed time periods was 30% and 33%, respectively.

Table 11 – Distribution of patents that received forward citations and contain general/regional NPL references across major Canadian CMAs

Census Metropolitan Area	**Cited Patents**	**Patents with NPL References**		**Patents with Regional NPL References**	
	TOTAL	**TOTAL**	**SHARE**	**TOTAL**	**SHARE**
Patents Granted 2010-2015:					
Toronto	2,152	520	24.2%	169	32.5%
Ottawa-Gatineau	1,405	357	25.4%	47	13.3%
Vancouver	1,437	459	31.9%	171	37.2%
Montreal	1,040	215	20.6%	81	38.0%
Kitchener–Cambridge–Waterloo	1,224	212	17.3%	48	22.5%
Patents Granted 2016-2021:					
Toronto	1,172	292	24.9%	112	38.2%
Ottawa-Gatineau	806	219	27.2%	38	17.3%
Vancouver	848	282	33.3%	131	46.4%
Montreal	655	153	23.4%	38	25.0%
Kitchener–Cambridge–Waterloo	399	153	38.4%	56	36.9%

Patents granted to Canadian resident inventors between 2010-2021, that were subsequently cited by future patents, received on average 3.2 citations; see **Table 8**. The citation premium to those cited patents that also contain a reference the scientific literature is +31%, whereas that premium to those patents that contain a regional NPL reference is +47% as shown previously in **Table 9**. A closer look at the distribution of the average number of received forward citations for cited patents pending on whether they have no, general, or regional NPL References, and also at the citation premium of those two latter categories of patents, indicates that significant regional variations exist. Substantial differences among the top 5 patenting CMAs are already present themselves in the overall sample of cited patents. For example, and also highlighted in **Table 12**, patents generated in the Toronto CMA between 2010-2021 and that were subsequently cited on average only received 2.76 citations, with their counterparts that were created in the Kitchener-Cambridge-Waterloo (KCW) CMA received 3.92 citations per forward cited patent. Considering the different types of patents, i.e., in terms of scientific foundations, those regional differences are even further amplified. For patents that refer to regional scientific inputs, the average number of received forward citations for cited patents range from a low of 2.48 for patents generated in the Montreal CMA to a high of 11.36 for patents developed in the KCW CMA.

Table 12 – Average Number of Received Forward Citations by Type of Patent, including citation premium for patents that contain NPL references

Census Metropolitan Area	Average Number of Received Forward Citations for Cited Patents				Premium versus Patents without NPL References	
	All Patents (2010-2021)	Patents without NPL Ref.	Patents with NPL Ref.	Pat. with Regional NPL Ref.	Patents with NPL Ref.	Pat. with Regional NPL Ref.
Toronto	2.76	2.55	3.39	3.12	33%	22%
Ottawa–Gatineau	2.77	2.74	2.87	2.55	5%	-7%
Vancouver	3.79	3.14	5.16	5.81	64%	85%
Montreal	3.31	3.39	2.99	2.48	-12%	-27%
Kitchener–Cambridge–Waterloo	3.92	3.06	6.89	11.36	125%	271%

In terms of the received forward citation premium enjoyed by patents that reference the scientific literature in general, or those that contain regional NPL References, even more significant differences among the observed 5 CMAs emerge. For example, patents that build on scientific inputs generated in the Montreal CMA on average receive less forward citations compared to patents that contain no NPL References at all. This is especially true for patents with references to regional scientific knowledge in this jurisdiction; these type of patents on average receive 27% fewer forward citations compared to patents without NPL References. On the other side of the spectrum, patents that were generated in the Kitchener-Cambridge-Waterloo CMA, and that contain regional NPL References, on average receive an additional 271% of citations compared to patents without any NPL References in this jurisdiction. Another notable example of a CMA that benefits from a forward citation premium for patents that contain regional scientific inputs is Vancouver, on average 85%, while in the Toronto CMA this premium is only 22%. On the other hand, patents with regional NPL References in the

Ottawa-Gatineau CMA, similar to Montreal, actually receive less forward citations (-7%) when they relied on regional scientific inputs in the development process.

The analysis pertaining to, a) patterns of regional science-technology (publications-patents) linkages, and b) the impact of regional science-technology knowledge spillovers as measured via forward citations received, can be summarised as follows:

- The regional analysis of the five largest patent producing Canadian metropolitan areas in terms of what impact their inventions have on future novel products and processes, and especially how established linkages to scientific inputs, in particular those that have a regional origin, generate extra premiums in that regard, reveals some interesting, and significantly divergent, results.
- For example, patents developed by inventors residing in the Vancouver CMA that relied on regional scientific knowledge in the development process receive on average about 63 percentage points more forward citations than patents without any NPL references when compared to those patents developed in the Toronto CMA.
- In actual terms, Vancouver patents that relied on any scientific inputs receive on average about 1.8 more citations than their equivalent Toronto patents, while those with regional NPL references receive an extra 2.7 citations.
- Among the top 5 technical knowledge producing Canadian CMAs, patents developed by Kitchener-Cambridge-Waterloo CMA based inventors that rely on scientific inputs (NPL References) receive on average the most forward citations; for KCW patents that contain regional NPL References, they receive on average 8 more citations per patent compared to the same reference group observed in the Toronto CMA.
- In contrast, patents developed by inventors residing in the Ottawa-Gatineau and Montreal CMAs do not receive additional forward citations if their inventions rely on regional scientific knowledge inputs in the development process. In fact, those type of patents receive on average fewer forward citations compared to patents that do not cite any scientific literature at all, i.e., -7% and -27%, respectively.

These stark variations beg further questions, and one rational explanation would be that underlying sectoral differences that exist across urban knowledge production systems might drive the establishment, and potential derived benefits, of regional science-technology linkages in the first place. In the whole spectrum of technological knowledge production there might be certain sectors that are naturally closer to a scientific base, e.g., chemicals, pharmaceuticals, biotechnology, electronics and ICT technologies, whereas other sectors, e.g., consumer goods, mechanical engineering, or transport and operation technologies, might be less reliant on scientific inputs, essentially less complex as the relevant literature proposes. While an in-depth analysis of patent technology classes, i.e., the CPC classes that were highlighted earlier in the knowledge space methodology, would unveil and confirm these and further assumptions in that regard, another possibility is to take a closer look at the assignees of patents that managed to establish science-technology linkages, especially localised ones. Thus, in the next chapter the focus shifts towards identifying the institutions and organisations that developed patented inventions that have benefited from regionally-produced scientific knowledge.

Institutions and Organisations that Drive Regional Science-Technology Linkages

The institutions and organisations that hold the property right to a patent are commonly referred to as patent assignee. Similarly, also a single individual or a group of people, i.e. an inventor or a group of co-inventors, can be named the assignee on a single patent document. In most cases, especially in a contemporary context, the vast majority of patents granted are assigned to institutions and organisations that employs the inventor(s). The assignee has the legal authority to enforce the patent rights, and it should be noted that this designation can possibly change over time. In light of the insights derived from the previous analysis in this section of the report the assignees that are behind establishing regional science-technology linkages now become the main interest. The case of Vancouver will serve as an example, while Appendix C will also highlight the detailed results for the four other CMAs that have been already investigated in detail previously.

Table 13 provides an overview of the assignees of patents that were generated in the Vancouver CMA (2016-2021) with regional scientific knowledge inputs, and subsequently cited by future patents. In addition, **Table 13** also highlights the share of regional NPL References out of all NPL References found in patents of a particular assignee, and the assignee type as determined and provided by the USPTO via the PatentsView data dissemination platform. The provided assignee type categories, which for example only differentiate between "US Company or Corporation" and "Foreign Company or Corporation", or "US Government" and "Foreign Government", were adjusted when it was obvious, e.g. universities in **Table 13** were relabelled "Higher-Ed Institution". Further it should be noted that the type of "Foreign comp/corp" listed in **Table 13** refers to 'non-US' entities and thus could refer to Canadian organisations, but also those that have their origin in countries other than in the United States.

The assignees that have established regional science-technology linkages in the Vancouver CMA via patents that refer to regional scientific inputs is led by the University of British Columbia (UBC). Recognised as one of the top public universities globally, Innovation UBC highlights its strong drive and engagement towards commercialising science and research outputs by declaring that: "Commercialisation and technology transfer help UBC research discoveries reach their maximum potential. UBC currently has more than 450 licensing agreements for its technologies. Our research is the foundation of more than 235 spin-off companies, and is at the heart of products, services, and treatments that have generated an estimated $11.5 billion in sales" (Innovation UBC website, n.d.). UBC generated over 19 patents between 2016-2021 that contained regional NPL References, whereas the share of regional to non-regional NPL References across those patents was over 90%. UBS accounted for almost 15% of all Vancouver CMA patents granted from 2016-2021 that contained a regional science-technology link.

UBC is followed by two Vancouver-based companies operating in the biotechnology and specialty medical devices sectors, Zymeworks Inc. and Neovasc Inc., which operates as a subsidiary of Shockwave Medical Inc. Next in the ranking is General Fusion Inc., again a Vancouver-based company that focuses on developing fusion power technology in the quest to create a clean, safe, and abundant source of electricity that is efficient and addresses global energy needs. Combined, the 4 top-ranked assignees listed in **Table 13** account for almost

40% of all patents that contain a regional NPL Reference generated in the Vancouver CMA and granted between 2016-2021. One notable observation across all assignees listed in **Table 13** is that most of them heavily rely on regional scientific knowledge inputs compared to scientific knowledge that might have its origin elsewhere as indicated by the high shares, i.e., in many cases 100%, of regional NPL References.

Table 13 – Cited Vancouver CMA patents (2016-2021) that contain regional scientific foundations by assignee name and type

Rank	Assignee Name	Patents with Regional NPL References	Share of Regional NPL References	Total Patents with NPL References	Assignee Type (USPTO & Adjusted)
1	The University of British Columbia	19.24	91	21.24	Higher-Ed Insitution
2	Zymeworks Inc.	11.48	85	13.48	Foreign comp/corp
3	Neovasc Tiara Inc.	10.50	100	10.50	Foreign comp/corp
4	General Fusion Inc.	9.00	100	9.00	Foreign comp/corp
5	Acuitas Therapeutics, Inc.	5.00	100	5.00	Foreign comp/corp
6	D-Wave Systems Inc.	4.98	73	6.78	Foreign comp/corp
7	Genentech, Inc.	4.84	100	4.84	US comp/corp
8	Protiva Biotherapeutics, Inc.	4.35	100	4.35	Foreign comp/corp
9	Genomedx Biosciences Inc.	3.50	100	3.50	Foreign comp/corp
10	Bioasis Technologies, Inc.	3.00	100	3.00	Foreign comp/corp
11	Xenon Pharmaceuticals Inc.	2.83	100	2.83	Foreign comp/corp
12	British Columbia Cancer Agency Branch	2.78	100	2.78	Foreign comp/corp
13	Novadaq Technologies, Inc.	2.67	100	2.67	Foreign comp/corp
14	Clearink Displays, Inc.	2.50	100	2.50	US comp/corp
15	Individual Assignees	2.50	33	7.50	Individual Assignees
16	Simon Fraser University	2.40	34	7.00	Higher-Ed Insitution
17	Ignis Innovation Inc.	2.38	100	2.38	Foreign comp/corp
18	Nono Inc.	2.17	46	4.67	Foreign comp/corp
19	0903608 B.C. Ltd.	2.00	100	2.00	Foreign comp/corp
20	Stryker European Operations Holdings Llc	2.00	100	2.00	US comp/corp
21	Switch Materials, Inc.	2.00	29	7.00	Foreign comp/corp
22	Novadaq Technologies Ulc	2.00	40	5.00	Foreign comp/corp
23	Quantum-Si Incorporated	2.00	100	2.00	US comp/corp
24	Arbutus Biopharma Corporation	1.67	100	1.67	Foreign comp/corp
25	Celator Pharmaceuticals, Inc.	1.63	66	2.49	US comp/corp
26	1Qb Information Technologies Inc.	1.00	33	3.00	Foreign comp/corp
27	Delta-Q Technologies Corp.	1.00	100	1.00	Foreign comp/corp
28	Neovac Tiara Inc.	1.00	100	1.00	Foreign comp/corp
29	Novelion Therapeutics Inc.	1.00	100	1.00	Foreign comp/corp
30	Qing Bile Therapeutics Inc.	1.00	100	1.00	Foreign comp/corp
	Total	**130.85**	**46**	**282.23**	

Note: Patent counts are sums of fractionally allocated inventor counts as highlighted previously.

While the Vancouver CMA case study about patent assignees that managed to utilise locally produced science in their respective technological advancements only provides one, albeit significant, aspect in terms of relevant factors that might determine regional science-technology linkages, there are a number of essential findings that are also corroborated via the information that can be derived from the same analysis across the other 5 Canadian CMAs that is featured in **Appendix C**. It appears that local universities, public and federal research institutions, along with organisations that operate in specific technology fields, e.g., health, pharma, biotech, and information and telecommunication technologies more broadly, are the entities that significantly contribute to establishing regional science-technology linkages. This might not come as a surprise given the diverse benefits that enable and support the establishment and growth of technology-based firms when they are located in an innovative cluster environment (Maine et al., 2010).

Concluding Remarks

The primary objective of the presented investigation was to provide, for the first time, a detailed evaluation of how locally produced scientific knowledge might feature as an important knowledge input in the development of novel products and processes of economic value in the context of the Canadian economy and its major inventive urban centres. Effective regional science-technology knowledge linkages, in particular in regional innovation systems with the objective to generate increased competitive advantages, are becoming increasingly important given the growing reliance of technological advancements (patents) on scientific knowledge inputs (publications) over time (Narin et al., 1997; Jefferson et al., 2018), and the insight that this also matters for the actual impact (Ahmadpoor & Jones, 2017) and value of patents (Poege et al., 2019; Li et al., 2017). Further, grounded in theories concerning recombinant knowledge production (Schumpeter, 1911), and the localised nature of knowledge production and spillover processes as highlighted in the Geography of Innovation literature (Feldman and Kogler, 2010), all emphasise the need to recognise, capture, and analyse regional science-technology linkages in order to derive at insights that could inform, and potentially enhance, future national and regional STI policy initiatives.

The overall result that Canadian patents that utilised regionally produced scientific knowledge on average also receive more forward citations, i.e., by 12% percentage points, compared to those patents that only build on science that was produced elsewhere, corroborate findings from another recent study that employed a similar methodological approach by Shin, Kogler & Kim (2024) titled: "The relevance of scientific knowledge externalities for technological change and resulting inventions across European metropolitan areas". This study already highlighted, albeit in a European regional context, that "regions with a higher reliance on their internal scientific resources tend to generate inventions with higher technological impact, and that a strong connection between science and technology is even more effective in advanced industrial regions" (p. 194). Following the same approach that connects science (publications) with technology (patents) via non-patent literature citation data, and subsequently evaluating the localisation and impact of local vs. non-local knowledge externalities towards impact as measured by received forward citations, the present investigation derives at the same overall finding that "regions that hold competitiveness in both science and technology can accomplish higher technological advancements, which stresses the importance of scientific foundation for developing technological capabilities" (Shin et al., 2024: 203).

Unlike in the study by Shin, Kogler & Kim (2024) the analysis of regional science-technology linkages in the regional Canadian context presented here was taken one step further as it also includes a detailed regional investigation that highlights the relative strength and impact of such linkages across specific urban economies, as well as a detailed overview of the various entities that actually have established those linkages in the first place. The results of this further analysis as it pertains to the five largest patent producing Canadian Census Metropolitan Areas (CMAs) highlights the strong regional variations that exist in terms of the reliance on locally produced science in technological oriented R&D activities, but further also the heterogeneity of impact such linkages may exert on future patented inventions. Specifically, while certain CMAs enjoy a significant forward citation premium on patents that utilised regional scientific knowledge inputs, such as the Vancouver and Kitchener-Cambridge-Waterloo CMAs, other regional economies do not benefit from this to the same extent, if at all. A more in-depth analysis of the institutions and organisations that drive regional science-technology linkages offers further insights in this regard, especially concerning the relevance of certain entities, e.g., universities, or particular technology sectors, e.g., biotechnology, to establish regional science-technology linkages in the first place.

Building on the present investigation there are numerous potential avenues for further research, especially in the context of the latter results highlighted here, but also in terms of informing STI policy making. For example, dedicated mechanisms that establish stronger localised networks between actors involved in scientific and technological knowledge production activities, or initiatives that enable and support more effective, and timely, knowledge dissemination processes within a regional innovation system, could provide good starting points where STI policy could intervene efficiently. The results of this study provide some important indicators where STI policy priorities should be directed in a regional but also sectoral context, and also offer the opportunity to further investigate identified key actors and their approaches to learn more about potential best-practices towards establishing regional science-technology linkages. Following these steps could prove to be highly relevant in terms of securing Canada's position in a global competitive innovation system that seems to increasingly rely on scientific advancements as key inputs into the development of innovative solutions with high impact.

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Appendix

A. Regional Knowledge Space Indicators

The knowledge space methodology is based on a co-occurrence matrix determined by the recombination of technology classes listed on single patented inventions and as documented in patent publications. The networked representation of technology classes, i.e., knowledge domains, illustrates the configuration of regional knowledge production in a knowledge recombination context. The relative proximity between nodes (technology classes) indicates how frequently two knowledge domains are listed together on individual patent documents. The size of the nodes shows how frequently a knowledge domain serves for the development of inventions in general. There are about 650 possible technology classes and they are grouped into 8 overarching technology sectors as highlighted in the example (**Figure A1**) below which displays the knowledge space of the Toronto CMA based on patents applied for at the USPTO between 2016 to 2019, and that were developed by inventors who resided in that jurisdiction at the time of invention.

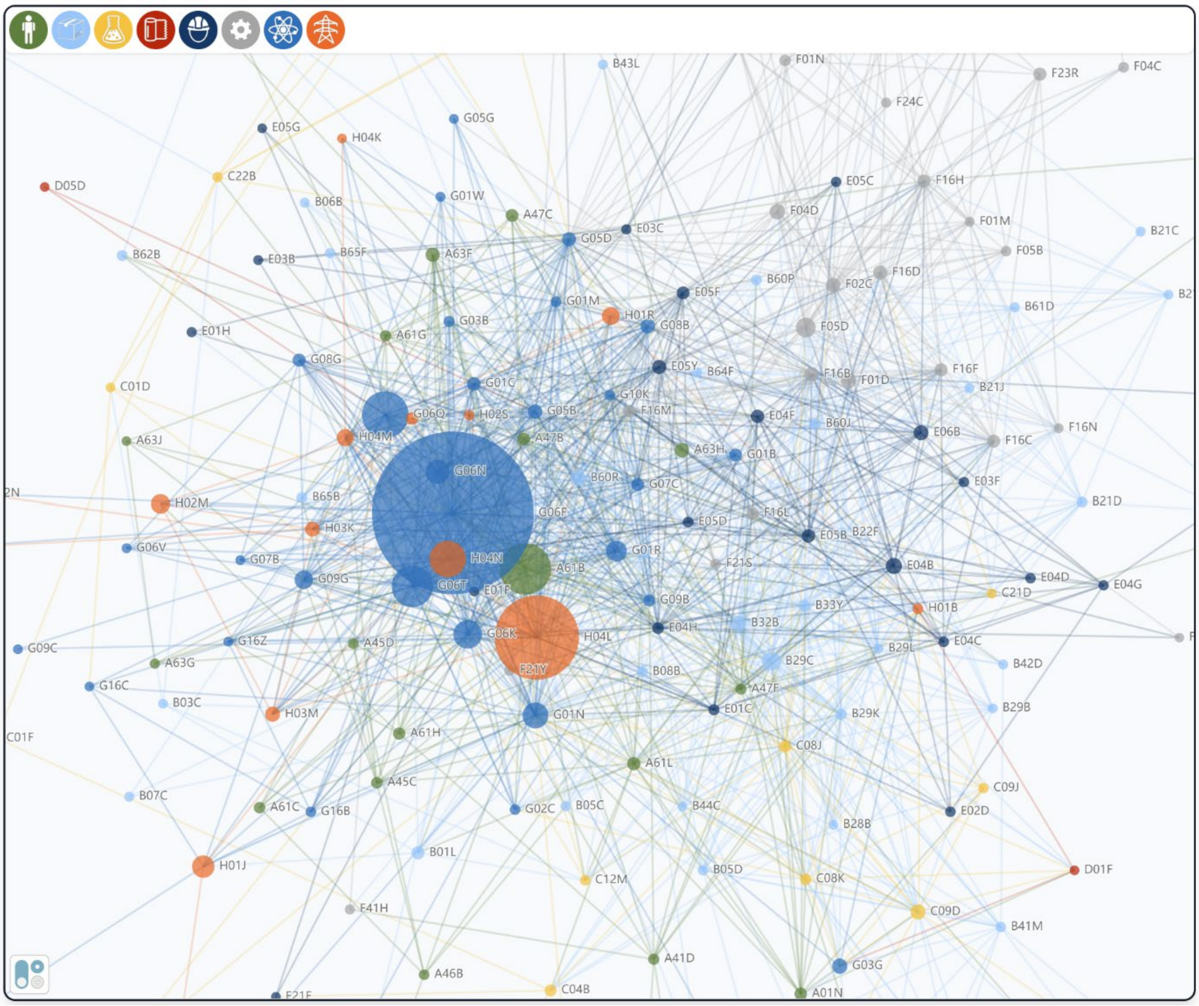

Figure A1 – The Toronto CMA Knowledge Space

Source: https://www.rknowledge.org/dashboard/northamerica/535

The Knowledge Space methodology is capable of delivering a number of fundamental metrics concerning the state and evolution of a regional knowledge production system. It has been utilised in a number of relevant studies, including: a) in the evaluation of European regional knowledge spaces in terms of their potential for future technological change and growth; b) in exercises that evaluate as well as offer planning and design tools for effective and tangible Science-Technology-Innovation (STI) policy initiatives, e.g., in the context of European Smart Specialisation Strategies, or concerning European Research & Innovation (R&I) policy initiatives that aim to enhance potential learning opportunities to ensure cohesive long-term development patterns.

The rKnowledge website offers additional insights concerning the various measures that have been tested and applied in a variety of published studies, while a short introductory video provides further guidance on how to use the rKnowledge Dashboard that offers a visualisation of all Canadian regional knowledge spaces along four specific Knowledge Space dimensions, which include the following:

Revealed Comparative Advantage (RCA) indicates how "specialised" a knowledge domain is in the regional knowledge space. An RCA=1 indicates that the regional share (i.e., CMA/CA) of a technology class is equal to the share of that particular class in the entire Canadian space. Thus, an RCA=2 implies that the share of said class in the regional knowledge space is double of that which is observed in the portfolio of the entire Canadian knowledge space. Similar, an RCA ≤1 signals that a technology class is less prominent in the region than it is in the overall Canadian portfolio. Knowledge domains that are close to an RCA=1, and that are well embedded in the regional knowledge space provide ample opportunities for future regional specialisation.

Relatedness Density indicates how embedded a particular class is via connections to other already specialised (RCA > 1) knowledge domains in the regional space. The notion is that a class that is not specialised yet (RCA ≤1), but is connected to already present specialisations, is more likely to transition to a regional specialised knowledge domain in the future. Investments into classes that are less frequently combined with other classes, especially non specialised classes, are more likely to fail than investing into nearly specialised and well-connected classes.

Betweenness and Weighted Degree Centrality

Building on established network analysis methods, these two measures indicate the level of embeddedness of a specific knowledge domain in the regional knowledge space, but also if a domain serves as a broker between various clusters of classes in the space. Specifically, a high value on the Weighted Degree Centrality measure indicates that a knowledge domain is frequently recombined on a single invention with a diverse set of other classes and as such is a frequent ingredient in the knowledge production process. A high Betweenness Centrality measure indicates that a particular knowledge domain connects different clusters of classes and thus serves as a broker in the local knowledge space. A recent study that utilises these two network measures along with RCA and Relatedness Density indicators in order to investigate whether regional Smart Specialisation Strategies that are currently employed across Europe adequately match local knowledge capabilities demonstrates a practical example of how Knowledge Space metrics offer a STI policies design and implementation tool capable of bridging the vision of economic development ambitions with the reality of constraints in regional economies.

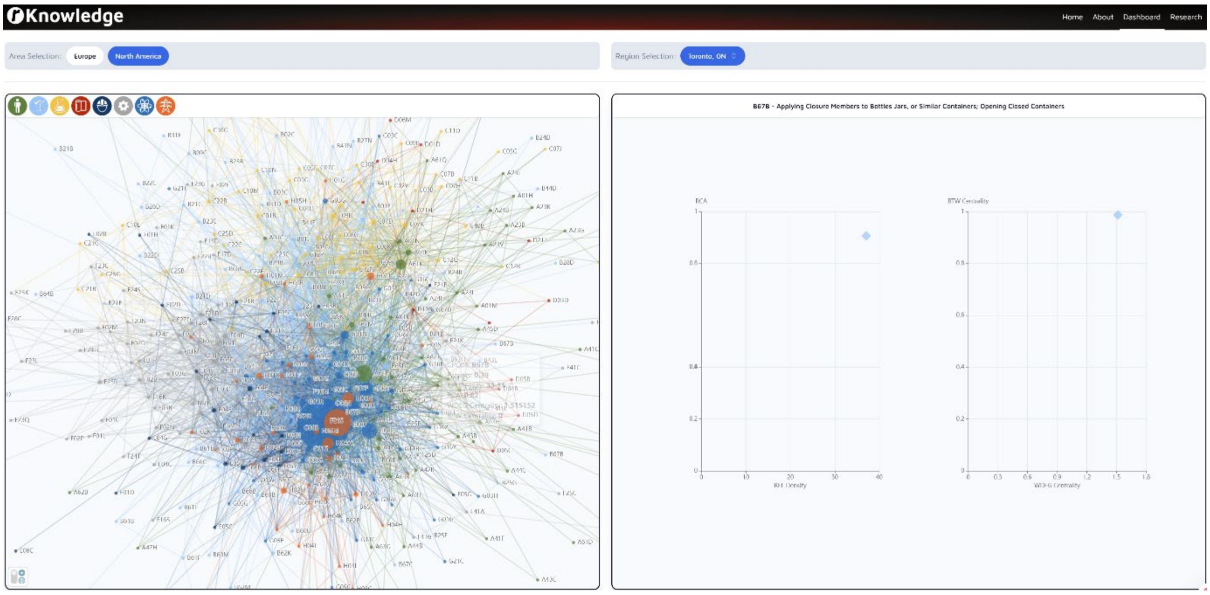

Figure A2 – rKnowledge Dashboard website snapshot of the Toronto CMA Knowledge Space and associated metrics.

Source: https://www.rknowledge.org/dashboard/northamerica/535

B. Regional Science-Technology Linkages

The following highlights the detailed tables that correspond to the "Science-Technology Linkages in Canadian Metropolitan Areas" discussion in this report. For each of the focal CMAs, the same set of tables are shown as described and analysed previously in the main "Science-Technology Linkages" section that referred to the entire Canadian economy, and as these tables offer an opportunity to draw further comparisons and conclusions concerning how specific regional economies have managed to establish linkages between their local scientific and technology knowledge production systems.

Table B1 – Toronto CMA; patents granted in 2010-2015 & 2016-2021

Number of patents by grant period that subsequently received forward citations

PERIOD	Patents	Not Cited	Cited	Cited Ratio
2010-2015	7,499	5,347	2,152	29%
2016-2021	8,689	7,518	1,172	13%
TOTAL	16,189	12,865	3,324	21%

Number of cited patents considering general and regional scientific foundations

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	2,152	1,632	520	169
2016-2021	1,172	880	292	112
TOTAL	3,324	2,511	813	281

Number of avg. forward citations received by type of cited patent

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NLP Ref.
2010-2015	6,848	4,747	2,101	633
2016-2021	2,314	1,663	652	244
TOTAL	9,162	6,410	2,752	877

Average number of received forward citations for cited patents

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	3.18	2.91	4.04	3.74
2016-2021	1.97	1.89	2.23	2.19
TOTAL	2.76	2.55	3.39	3.12

Additional citation premium of patents with NPL References, and for those with regional NPL References when compared to patents without NPL References

PERIOD	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	39%	29%
2016-2021	18%	16%
TOTAL	33%	22%

Table B2 – Ottawa-Gatineau CMA; patents granted in 2010-2015 & 2016-2021

Number of patents by grant period that subsequently received forward citations

PERIOD	Patents	Not Cited	Cited	Cited Ratio
2010-2015	4,921	3,516	1,405	29%
2016-2021	5,254	4,448	806	15%
TOTAL	10,175	7,964	2,211	22%

Number of cited patents considering general and regional scientific foundations

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	1,405	1,048	357	47
2016-2021	806	587	219	38
TOTAL	2,211	1,635	576	85

Number of avg. forward citations received by type of cited patent

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NLP Ref.
2010-2015	4,386	3,229	1,157	135
2016-2021	1,743	1,247	496	83
TOTAL	6,129	4,476	1,653	218

Average number of received forward citations for cited patents

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	3.12	3.08	3.24	2.86
2016-2021	2.16	2.13	2.27	2.18
TOTAL	2.77	2.74	2.87	2.55

Additional citation premium of patents with NPL References, and for those with regional NPL References when compared to patents without NPL References

PERIOD	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	5%	-7%
2016-2021	7%	2%
TOTAL	5%	-7%

Table B3 – Vancouver CMA; patents granted in 2010-2015 & 2016-2021

Number of patents by grant period that subsequently received forward citations

PERIOD	Patents	Not Cited	Cited	Cited Ratio
2010-2015	3,945	2,508	1,437	36%
2016-2021	5,060	4,212	848	17%
TOTAL	9,005	6,720	2,285	25%

Number of cited patents considering general and regional scientific foundations

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	1,437	978	459	171
2016-2021	848	566	282	131
TOTAL	2,285	1,544	741	302

Number of avg. forward citations received by type of cited patent

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NLP Ref.
2010-2015	6,415	3,567	2,848	1,338
2016-2021	2,257	1,280	977	415
TOTAL	8,673	4,847	3,825	1,753

Average number of received forward citations for cited patents

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	4.46	3.65	6.20	7.82
2016-2021	2.66	2.26	3.46	3.17
TOTAL	3.79	3.14	5.16	5.81

Additional citation premium of patents with NPL References, and for those with regional NPL References when compared to patents without NPL References

PERIOD	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	70%	114%
2016-2021	53%	40%
TOTAL	64%	85%

Table B4 – Montreal CMA; patents granted in 2010-2015 & 2016-2021

Number of patents by grant period that subsequently received forward citations

PERIOD	Patents	Not Cited	Cited	Cited Ratio
2010-2015	3,343	2,303	1,040	31%
2016-2021	4,783	4,128	655	14%
TOTAL	8,126	6,431	1,695	21%

Number of cited patents considering general and regional scientific foundations

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	1,040	825	215	81
2016-2021	655	501	153	38
TOTAL	1,695	1,326	368	120

Number of avg. forward citations received by type of cited patent

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NLP Ref.
2010-2015	4,159	3,382	777	225
2016-2021	1,442	1,119	323	72
TOTAL	5,601	4,500	1,100	297

Average number of received forward citations for cited patents

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	4.00	4.10	3.62	2.76
2016-2021	2.20	2.23	2.11	1.88
TOTAL	3.31	3.39	2.99	2.48

Additional citation premium of patents with NPL References, and for those with regional NPL References when compared to patents without NPL References

PERIOD	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	-12%	-33%
2016-2021	-6%	-16%
TOTAL	-12%	-27%

Table B5 – Kitchener-Cambridge-Waterloo CMA; patents granted in 2010-2015 & 2016-2021

Number of patents by grant period that subsequently received forward citations

PERIOD	Patents	Not Cited	Cited	Cited Ratio
2010-2015	4,091	2,866	1,224	30%
2016-2021	2,611	2,213	399	15%
TOTAL	6,702	5,079	1,623	24%

Number of cited patents considering general and regional scientific foundations

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	1,224	1,012	212	48
2016-2021	399	246	153	56
TOTAL	1,623	1,258	365	104

Number of avg. forward citations received by type of cited patent

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NLP Ref.
2010-2015	4,559	3,032	1,527	673
2016-2021	1,805	815	990	510
TOTAL	6,364	3,847	2,517	1,182

Average number of received forward citations for cited patents

PERIOD	All Patents	without NPL References	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	3.72	3.00	7.19	14.11
2016-2021	4.53	3.32	6.49	9.03
TOTAL	3.92	3.06	6.89	11.36

Additional citation premium of patents with NPL References, and for those with regional NPL References when compared to patents without NPL References

PERIOD	Patents with NPL References	Patents with Regional NPL Ref.
2010-2015	140%	371%
2016-2021	96%	173%
TOTAL	125%	271%

C. Utilisation of Regional Science Inputs for Invention by Assignees

The following highlights the detailed tables that correspond to the "Institutions and Organisations that Drive Regional Science-Technology Linkages" discussion in this report. For each of the focal CMAs, the same table is shown as described and analysed for the Vancouver CMA in that particular section of the report.

Table C1 – Cited Toronto CMA patents (2016-2021) that contain NPL References by assignee name and type

Cited Toronto CMA Patents (2016-2021) - Regional Scientific Foundations by Assignee

Rank	Assignee Name	Patents with Regional NPL References	Share of Regional NPL References	Total Patents with NPL References	Assignee Type (USPTO & Adjusted)
1	University Health Network	12.72	64	19.81	Foreign comp/corp
2	The Governing Council of the University of Toronto	11.32	80	14.21	Higher-Ed Insitution
3	Fluidigm Canada Inc.	4.67	100	4.67	Foreign comp/corp
4	Analog Devices Global Unlimited Company	4.21	100	4.21	Foreign comp/corp
5	The Hospital For Sick Children	3.83	100	3.83	Foreign comp/corp
6	Autodesk, Inc.	3.50	60	5.85	US comp/corp
7	Symbol Technologies, Llc	3.25	76	4.25	US comp/corp
8	Nono Inc.	2.83	100	2.83	Foreign comp/corp
9	Opko Ireland Global Holdings, Ltd.	2.57	100	2.57	Foreign comp/corp
10	Sunovion Pharmaceuticals Inc.	2.50	100	2.50	US comp/corp
11	McMaster University	2.30	100	2.30	Higher-Ed Insitution
12	Centre for Addiction and Mental Health	2.00	100	2.00	Foreign comp/corp
13	Microsoft Technology Licensing, Llc	2.00	100	2.00	US comp/corp
14	Individual Assignees	2.00	29	7.00	Individual Assignees
15	Interface Biologics, Inc.	2.00	100	2.00	Foreign comp/corp
16	Deep Genomics Incorporated	2.00	100	2.00	Foreign comp/corp
17	Quantum Dental Technologies Inc.	1.71	100	1.71	Foreign comp/corp
18	Hznp Limited	1.67	100	1.67	Foreign comp/corp
19	Qvella Corporation	1.67	100	1.67	Foreign comp/corp
20	Rockwell Automation Technologies, Inc.	1.60	100	1.60	US comp/corp
21	Fujifilm Sonosite, Inc.	1.50	100	1.50	US comp/corp
22	Novadaq Technologies, Inc.	3.00	86	3.50	Foreign comp/corp
23	Prothena Biosciences Limited	1.50	100	1.50	Foreign comp/corp
24	The University of British Columbia	1.40	100	1.40	Higher-Ed Insitution
25	Opko Renal, Llc	1.39	100	1.39	US comp/corp
26	Schweitzer Engineering Laboratories, Inc.	1.38	91	1.52	US comp/corp
27	Regeneron Pharmaceuticals, Inc.	1.33	100	1.33	US comp/corp
28	Altera Corporation	1.00	31	3.25	US comp/corp
29	D5Pharma Inc.	1.00	100	1.00	Foreign comp/corp
30	E-Zn Inc.	1.00	100	1.00	Foreign comp/corp
	Total	**111.65**	**38**	**292.22**	

Table C2 – Cited Ottawa-Gatineau CMA patents (2016-2021) that contain NPL References by assignee name and type

Cited Ottawa-Gatineau CMA Patents (2016-2021) - Regional Scientific Foundations by Assignee

Rank	Assignee Name	Patents with Regional NPL References	Share of Regional NPL References	Total Patents with NPL References	Assignee Type (USPTO & Adjusted)
1	Ciena Corporation	10.75	26	41.01	US comp/corp
2	Huawei Technologies Co., Ltd.	6.70	14	49.42	Foreign comp/corp
3	National Research Council of Canada	4.80	100	4.80	Foreign Government
4	Gan Systems Inc.	2.00	31	6.35	Foreign comp/corp
5	University Of Ottawa	1.50	60	2.50	Higher-Ed Insitution
6	Individual Assignees	1.33	31	4.33	Individual Assignees
7	HMQ, Minister Of Industry	1.00	100	1.00	Foreign Government
8	Dna Genotek, Inc.	1.00	100	1.00	Foreign comp/corp
9	Geneohm Sciences Canada, Inc.	1.00	100	1.00	Foreign comp/corp
10	Iogen Corporation	1.00	25	4.00	Foreign comp/corp
11	Techinsights Inc.	1.00	100	1.00	Foreign comp/corp
12	Analytics For Life Inc.	0.80	43	1.86	Foreign comp/corp
13	Iogen Energy Corporation	0.67	25	2.67	Foreign comp/corp
14	Membrane Distillation Desalination Ltd., Co.	0.67	100	0.67	Foreign comp/corp
15	One Media, Llc	0.67	100	0.67	US comp/corp
16	Ottawa Hospital Research Institute	0.67	100	0.67	Foreign comp/corp
17	Turnstone Limited Partnership	0.50	100	0.50	Foreign comp/corp
18	Variation Biotechnologies Inc.	0.50	100	0.50	Foreign comp/corp
19	Telefonaktiebolaget Lm Ericsson (Publ)	0.40	5	8.47	Foreign comp/corp
20	Coherent Logix, Incorporated	0.33	50	0.67	US comp/corp
21	The Brigham And Women'S Hospital, Inc.	0.25	100	0.25	US comp/corp
22	The Regents of the University of California	0.17	100	0.17	Higher-Ed Insitution
23	International Business Machines Corporation	0.14	2	9.40	US comp/corp
24	Cbn Nano Technologies Inc.	0.11	100	0.11	Foreign comp/corp
25	Abbott Point Of Care Inc.			11.80	US comp/corp
26	Apple Inc.			8.48	US comp/corp
27	Skyworks Solutions, Inc.			5.43	US comp/corp
28	Open Text Sa Ulc			4.00	Foreign comp/corp
29	Dell Software Inc.			3.89	US comp/corp
30	Lumentum Operations Llc			3.79	US comp/corp
	Total	**37.95**	**17**	**218.91**	

Table C3 – Cited Vancouver CMA patents (2016-2021) that contain NPL References by assignee name and type

Cited Vancouver CMA Patents (2016-2021) - Regional Scientific Foundations by Assignee

Rank	Assignee Name	Patents with Regional NPL References	Share of Regional NPL References	Total Patents with NPL References	Assignee Type (USPTO & Adjusted)
1	The University of British Columbia	19.24	91	21.24	Higher-Ed Insitution
2	Zymeworks Inc.	11.48	85	13.48	Foreign comp/corp
3	Neovasc Tiara Inc.	10.50	100	10.50	Foreign comp/corp
4	General Fusion Inc.	9.00	100	9.00	Foreign comp/corp
5	Acuitas Therapeutics, Inc.	5.00	100	5.00	Foreign comp/corp
6	D-Wave Systems Inc.	4.98	73	6.78	Foreign comp/corp
7	Genentech, Inc.	4.84	100	4.84	US comp/corp
8	Protiva Biotherapeutics, Inc.	4.35	100	4.35	Foreign comp/corp
9	Genomedx Biosciences Inc.	3.50	100	3.50	Foreign comp/corp
10	Bioasis Technologies, Inc.	3.00	100	3.00	Foreign comp/corp
11	Xenon Pharmaceuticals Inc.	2.83	100	2.83	Foreign comp/corp
12	British Columbia Cancer Agency Branch	2.78	100	2.78	Foreign comp/corp
13	Novadaq Technologies, Inc.	2.67	100	2.67	Foreign comp/corp
14	Clearink Displays, Inc.	2.50	100	2.50	US comp/corp
15	Individual Assignees	2.50	33	7.50	Individual Assignees
16	Simon Fraser University	2.40	34	7.00	Higher-Ed Insitution
17	Ignis Innovation Inc.	2.38	100	2.38	Foreign comp/corp
18	Nono Inc.	2.17	46	4.67	Foreign comp/corp
19	0903608 B.C. Ltd.	2.00	100	2.00	Foreign comp/corp
20	Stryker European Operations Holdings Llc	2.00	100	2.00	US comp/corp
21	Switch Materials, Inc.	2.00	29	7.00	Foreign comp/corp
22	Novadaq Technologies Ulc	2.00	40	5.00	Foreign comp/corp
23	Quantum-Si Incorporated	2.00	100	2.00	US comp/corp
24	Arbutus Biopharma Corporation	1.67	100	1.67	Foreign comp/corp
25	Celator Pharmaceuticals, Inc.	1.63	66	2.49	US comp/corp
26	1Qb Information Technologies Inc.	1.00	33	3.00	Foreign comp/corp
27	Delta-Q Technologies Corp.	1.00	100	1.00	Foreign comp/corp
28	Neovac Tiara Inc.	1.00	100	1.00	Foreign comp/corp
29	Novelion Therapeutics Inc.	1.00	100	1.00	Foreign comp/corp
30	Qing Bile Therapeutics Inc.	1.00	100	1.00	Foreign comp/corp
	Total	**130.85**	**46**	**282.23**	

Table C4 – Cited Montreal CMA patents (2016-2021) that contain NPL References by assignee name and type

Cited Montreal CMA Patents (2016-2021) - Regional Scientific Foundations by Assignee

Rank	Assignee Name	Patents with Regional NPL References	Share of Regional NPL References	Total Patents with NPL References	Assignee Type (USPTO & Adjusted)
1	Bioasis Technologies, Inc.	3.00	100	3.00	Foreign comp/corp
2	The Royal Institution For The Adv. of Learning /McGill University	3.00	100	3.00	Higher-Ed Insitution
3	Genesis Technologies Limited	2.00	100	2.00	Foreign comp/corp
4	Carboncure Technologies Inc.	1.81	100	1.81	Foreign comp/corp
5	Hoffmann-La Roche Inc.	1.50	100	1.50	US comp/corp
6	Huawei Technologies Co., Ltd.	1.50	100	1.50	Foreign comp/corp
7	Mayo Foundation for Medical Education and Research	1.50	100	1.50	US comp/corp
8	Individual Assignees	1.00	10	10.00	Individual Assignees
9	National Research Council of Canada	1.00	50	2.00	Foreign Government
10	Universite De Montreal	1.00	50	2.00	Foreign comp/corp
11	Ecole De Technologie Superieure	1.00	75	1.33	Foreign comp/corp
12	Adc Therapeutics Sa	1.00	100	1.00	Foreign comp/corp
13	Alethia Biotherapeutics Inc.	1.00	100	1.00	Foreign comp/corp
14	Dassault Systemes Americas Corp.	1.00	100	1.00	US comp/corp
15	Everest Networks, Inc.	1.00	100	1.00	US comp/corp
16	Fpinnovations	1.00	100	1.00	Foreign comp/corp
17	Neomed Institute	1.00	100	1.00	Foreign comp/corp
18	Aeromics, Inc.	1.00	100	1.00	US comp/corp
19	Bellus Health Inc.	0.90	100	0.90	Foreign comp/corp
20	Bhi Co., Ltd.	0.90	100	0.90	Foreign comp/corp
21	Duchesnay Inc.	0.80	100	0.80	Foreign comp/corp
22	Johnson Controls Technology Company	0.75	21	3.50	US comp/corp
23	Hydro-Quebec	0.75	100	0.75	Foreign comp/corp
24	Redhill Biopharma Ltd.	0.75	100	0.75	Foreign comp/corp
25	Syros Pharmaceuticals, Inc.	0.71	100	0.71	US comp/corp
26	Caprion Proteomics Inc.	0.67	100	0.67	Foreign comp/corp
27	Valorbec, Sec	0.67	100	0.67	Foreign comp/corp
28	Genentech, Inc.	0.57	100	0.57	US comp/corp
29	Microsoft Technology Licensing, Llc	0.50	60	0.83	US comp/corp
30	Merck Sharp & Dohme Llc	0.50	100	0.50	US comp/corp
	Total	**38.33**	**25**	**153.37**	

Table C5 – Cited Kitchener-Cambridge-Waterloo CMA patents (2016-2021) that contain NPL References by assignee name and type

Cited Kitchener-Cambridge-Waterloo CMA Patents (2016-2021) - Regional Scientific Foundations by Assignee

Rank	Assignee Name	Patents with Regional NPL References	Share of Regional NPL References	Total Patents with NPL References	Assignee Type (USPTO & Adjusted)
1	Ignis Innovation Inc.	44.81	100	44.81	Foreign comp/corp
2	Rockwell Automation Technologies, Inc.	2.60	84	3.10	US comp/corp
3	Quantum Valley Investment Fund Lp	2.50	71	3.50	Foreign comp/corp
4	Individual Assignees	1.00	40	2.50	Individual Assignees
5	Quantum Benchmark, Inc.	1.00	100	1.00	Foreign comp/corp
6	Applied Brain Research Inc.	0.86	100	0.86	Foreign comp/corp
7	Positec Power Tools (Suzhou) Co., Ltd.	0.83	31	2.67	Foreign comp/corp
8	Huawei Technologies Co., Ltd.	0.80	100	0.80	Foreign comp/corp
9	Primal Fusion Inc.	0.50	5	10.50	Foreign comp/corp
10	Ciena Corporation	0.50	71	0.70	US comp/corp
11	Zymeworks Inc.	0.33	100	0.33	Foreign comp/corp
12	Natrix Separations Inc.	0.25	100	0.25	Foreign comp/corp
13	Symbol Technologies, Llc	0.25	100	0.25	US comp/corp
14	The Governing Council of the University of Toronto	0.17	50	0.33	Higher-Ed Insitution
15	Cognitive Systems Corp.			17.86	Foreign comp/corp
16	North Inc.			11.67	Foreign comp/corp
17	Thalmic Labs Inc.			10.08	Foreign comp/corp
18	Blackberry Limited			8.25	Foreign comp/corp
19	Open Text Sa Ulc			6.67	Foreign comp/corp
20	Isara Corporation			3.67	Foreign comp/corp
21	Dejero Labs Inc.			3.55	Foreign comp/corp
22	Quantum Valley Ideas Laboratories			3.00	Foreign comp/corp
23	Ctrl-Labs Corporation			2.00	US comp/corp
24	Aeryon Labs Inc.			1.00	Foreign comp/corp
25	Christie Digital Systems Usa, Inc.			1.00	US comp/corp
26	D2L Corporation			1.00	Foreign comp/corp
27	Lakes Environmental Research Inc.			1.00	Foreign comp/corp
28	Rsvp Technologies Inc.			1.00	Foreign comp/corp
29	Tetechs Inc.			1.00	Foreign comp/corp
30	Trilliant Networks, Inc.			1.00	US comp/corp
	Total	**56.40**	**37**	**152.70**	