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CANADA'S ADVANCED INDUSTRIES

A Path to Prosperity

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CANADA'S ADVANCED INDUSTRIES

A Path to Prosperity

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Table of Contents

Executive Summary

Canada is having a moment.

In a world where talent is mobile and technology central, Canada stands out more than ever with its vibrant democracy, growing tech clusters, and unparalleled openness to the world's migrants.

Yet there is a problem: Despite the nation's many strengths, Canada's economy faces serious structural challenges, including from an aging population and slowing output growth. Even more important, the nation needs to ask urgently whether it possesses the right mix of industries performing at a high enough level to allow for new levels of prosperity.

And here, the nation, its provinces, and its local economies need to focus anew on expanding a particular high-value subset of "advanced industries."

As defined by Brookings, advanced industries—which include industries as diverse as auto and aerospace production, oil and gas extraction, and information technology—are the high-value innovation and technology application industries that inordinately drive regional and national prosperity. As such, advanced industries matter because they generate disproportionate shares of the nation's output, exports, and research and development.

And yet, for all that, questions surround the state of Canada's advanced sector.

True, the sector is in many respects well-positioned to compete for market share in the global scrimmage to create value. And yet the fact remains that, at least in comparison with its American counterpart, Canada's advanced industries are not realizing their full potential, with ramifications that promise slower growth and a declining standard of living for Canadians.

Which is where this report comes in: Intended to help leaders focus their efforts on what matters most in their drive to improve the long-term prospects of the Canadian economy, the following pages provide a framework for targeting ongoing work to build a more dynamic advanced economy that works for all. Along these lines, the report advances three major findings:

1. **Canada possesses a diverse, widely distributed, and quite promising advanced industry sector**
   An analysis of the size, geography, and growth of the Canadian advanced industry sector shows that:

   - **Canada's advanced industry sector anchors the nation's high-value economy.** High R&D, high-STEM advanced industries are the bedrock of Canada's high-value economy. About 1.9 million Canadians worked in advanced industries in 2015, good for about 11 percent of the nation's employment. From this relatively small share of jobs, however, advanced industries generated 17 percent of Canada's GDP, 61 percent of national exports, and 78 percent of research and development. These outsized shares reflect that the average value-added per employee in advanced industries was 34 percent higher than in the economy overall. High productivity within the sector ensures that the average worker employed in an advanced industry earned a yearly wage nearly 50 percent higher than the average Canadian worker.

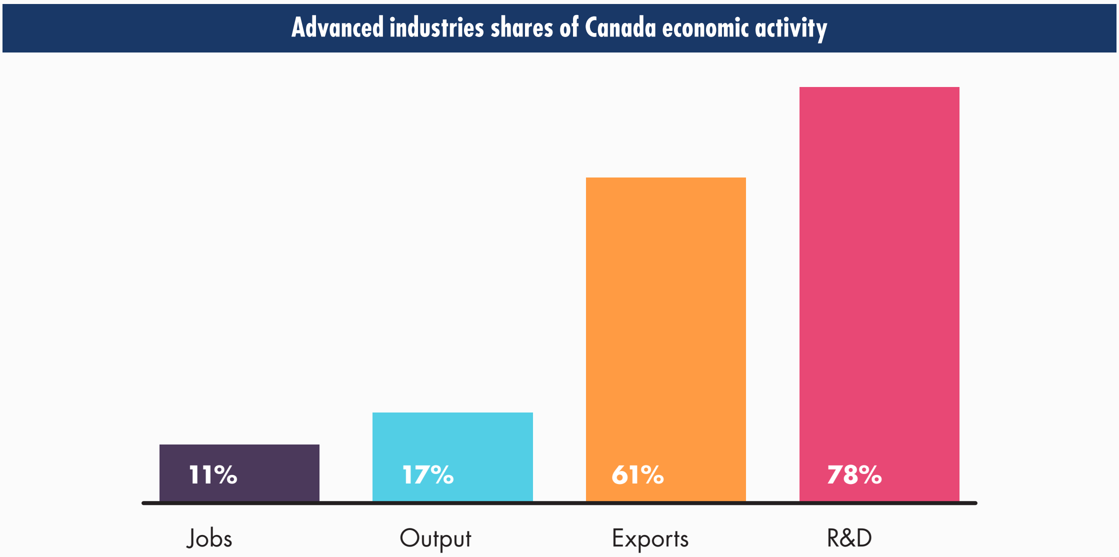


Figure 1: Advanced industries anchor Canada's high-value economy

- **Canada's advanced industry mix is quite diverse—and changing.** As of 2015, the 50 advanced industries in Canada employed nearly 1.9 million workers and generated $247 billion in output. As such, the sector has notable specializations. In terms of employment, services account for just over half of the Canadian advanced industry worker base (51 percent), followed by manufacturing (36 percent) and energy (13 percent). The impact of the Canadian energy industry, however, becomes apparent in the output statistics. The three advanced energy industries account for 42 percent of national output, led by $67 billion generated by oil and gas extraction alone. Advanced services and manufacturing, meanwhile, each account for 29 percent of national output. In terms of both output and employment, then, Canada's advanced industry mix skews toward energy when compared to the United States.

With that said, Canada's advanced industry base has undergone a notable transition since 1996. In that year, advanced manufacturing accounted for over half (52 percent) of the nation's advanced industry employment while services employed only about 34 percent of advanced industry workers. Incredibly, those shares essentially switched between 1996 and 2015. Tremendous growth in advanced services employment and a slight decline in advanced manufacturing employment fueled this transition.

- **Canadian provinces and metropolitan regions vary significantly in the scale, intensity, and diversity of their advanced industry sectors, which in some ways compare favorably to that of the United States.** Every part of Canada can lay some claim to the nation's advanced industry economy, albeit at varying scales and intensities. Not surprisingly, **Ontario**, **Quebec**, **Alberta**, and **British Columbia** loom large, together accounting for 91 percent of Canada's advanced industry employment.

  Ontario alone accounts for 43 percent of the sector's footprint nationally with over 800,000 advanced industry jobs. As context, Ontario houses the largest concentration of advanced industries employment in North America outside of California and Texas, the respective homes of the United States' largest technology and energy clusters.

  Diving below the provincial level reveals further notable geographic patterns. Not unexpectedly, Canada's largest Census Metropolitan Areas (CMAs) contain the largest number of advanced industry jobs. **Toronto** leads the nation with 384,000 workers in advanced industries, followed by **Montreal** (260,000), **Calgary** (138,000), and **Vancouver** (134,000). Together, these four CMAs account for nearly half (49 percent) of Canadian advanced industries employment.

  Canada's most advanced industries-intensive CMAs rival the highest employment shares in the United States. As the home of Silicon Valley, no metro area in North America has a greater share of employment in advanced industries than San Jose (31.4 percent). But notably, the next four metros are Canadian, led by **Calgary**, **Windsor**, **Kitchener-Waterloo**, and **Saguenay**.

  In terms of growth and change, nearly every Canadian CMA added advanced industries employment between 1996 and 2015, with the exception of **St. Catharine's-Niagara**, **Greater Sudbury**, and **Thunder**

All Canadian provinces contain significant advanced industries employment

Province	Total	Manufacturing	Services	Energy
Ontario	805,823	344,838	402,267	58,717
Quebec	431,971	177,435	219,418	35,118
Alberta	283,809	49,198	135,213	99,398
British Columbia	197,038	46,122	131,577	19,339
Manitoba	50,601	24,314	15,941	10,346
Saskatchewan	40,321	11,696	16,452	12,172
Nova Scotia	29,496	7,738	18,139	3,619
New Brunswick	22,930	5,877	11,773	5,280
Newfoundland and Labrador	18,309	1,558	7,984	8,767
Prince Edward Island	4,373	1,766	2,276	330
Canada	**1,884,671**	**670,541**	**961,042**	**253,088**

Table 1: Advanced industry employment, by province, 2015

Bay. Western and eastern CMAs have experienced the fastest advanced industries growth since 1996. Partly driven by the investments in energy, and energy-related manufacturing, metro economies like **St. John's** (4.2 percent annualized growth), **Saint John** (3.6 percent), **Moncton** (3.4 percent), and **Calgary** (3.4 percent) experienced the fastest annualized yearly growth in advanced industries employment, albeit several of those from a small base.

But even as local economies added advanced industry jobs on net, the erosion of manufacturing employment took a toll. Ontario metro areas like **Oshawa**, **Hamilton**, and **Greater Sudbury** all saw their share of employment in advanced industries plummet by 20 to 25 percent.

Even with these declines, however, Southern Ontario remains a hub of advanced industry employment, notable for its diversity. We gauge advanced industry diversity by measuring the number of advanced industries in which a metro area has a greater concentration of jobs in a particular industry than the nation as a whole.

By this metric we observe a diversity of advanced industries—particularly in the advanced manufacturing segment—in several Canadian metro areas, led by **Kitchener-Waterloo** (specialized in 31 of 50 advanced industries), **Montreal** (26), **Toronto** (26), **Brantford** (25), and **Hamilton** (23). This diversity compares favorably with that in the most diversified advanced industries bases in the United States, like Charlotte (25), San Francisco (24), Chattanooga (24), San Jose (23), and Chicago (23). In all of these places the convergence of digital, genetic, and analog enterprise holds out the possibility of especially valuable new innovations.

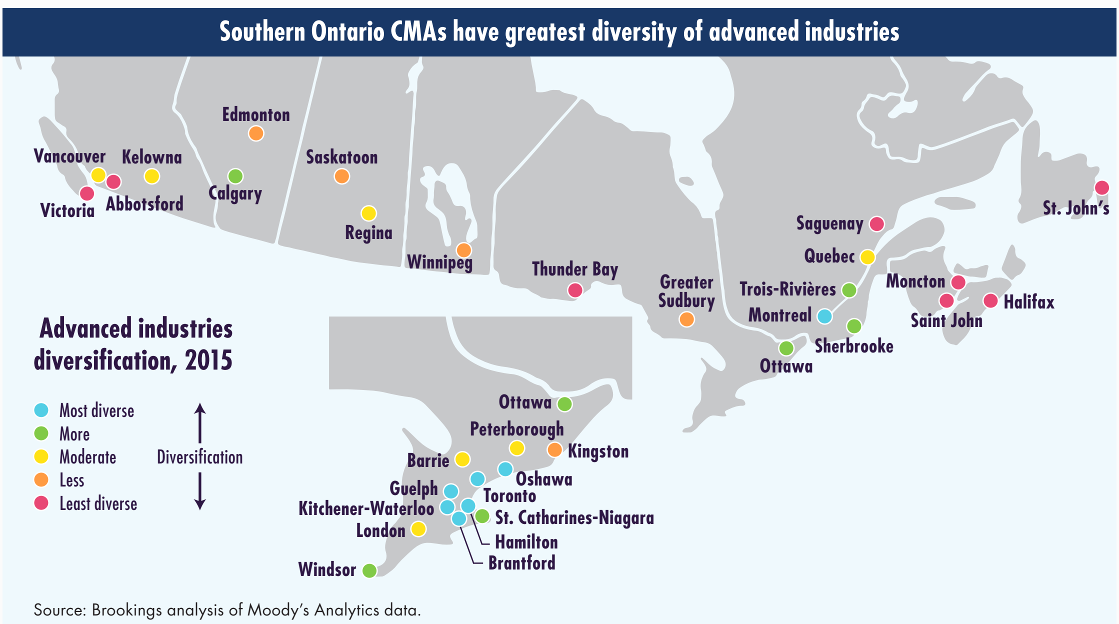


Figure 2: Advanced industry diversity, by CMA

2. Advanced sector productivity and productivity growth are much lower in Canadian metro areas than U.S. metro areas

And yet, while Canada's advanced industries sector compares favorably to its American counterpart, such a comparative lens also reveals a serious problem: Advanced industries in Canada are much less productive than in the United States, with major implications for the nation's future. Several takeaways arise:

- **Canadian advanced industry productivity growth has been seriously lagging.** Above all, it is clear that the Canadian advanced sector has failed to respond to the global productivity challenge, at least relative to the U.S. sector. To see this, consider that between 1996 and 2015, U.S. average annual value added per worker growth in advanced industries averaged 3.2 percent per year, while Canadian productivity growth in these industries averaged 0.3 percent. Or, to put it another way: In 1996, the productivity differential between the average Canadian worker in a metro area and the average U.S. worker in a metro area was about 17 percent. By 2015, that gap had grown to 100 percent. In non-advanced industries, meanwhile, Canadian productivity converged with the U.S. between 1996 and 2015.

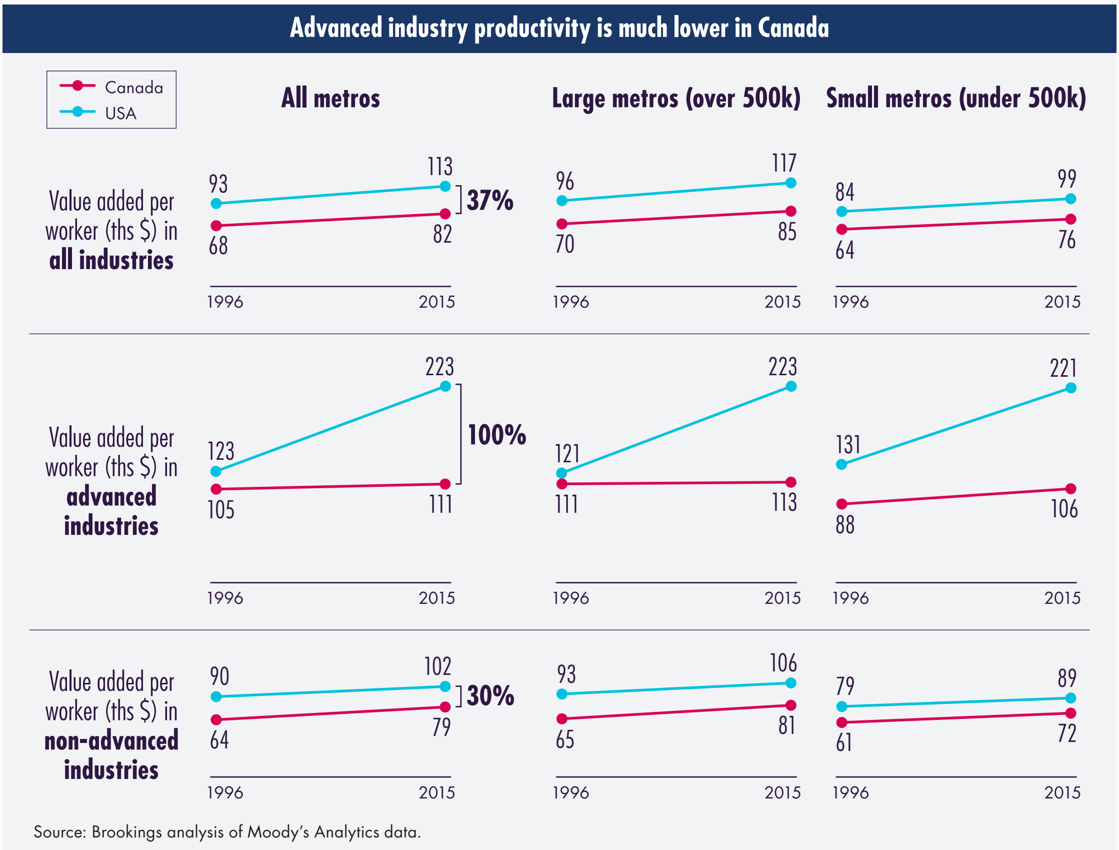


Figure 3: Canada-USA productivity gaps, by metro size

- **Thanks to its productivity shortfalls, Canada's advanced industry sector is depressing the overall productivity of the nation's regions.** The average value added per worker of all workers in Canadian metro areas is about $82,000, 37 percent lower than the $113,000 per worker figure in the United States. However, given that advanced industry value added per worker languishes at just half the level in Canadian metros as in U.S. ones, it's clear that advanced industries are inordinately contributing to the nation's regional productivity deficit.
- **Behind these trends lie authentic productivity deficits rather than differences of industry structure.** In this regard, the deterioration of Canada's per-worker advanced sector output since 1996 extends across the vast majority of advanced manufacturing, services, and energy industries. The productivity gap in advanced industries did not arise, then, because Canada's employment shifted into lower productivity industries. Rather, the differences in productivity growth between Canadian and U.S. metro areas result from advanced industry productivity having grown three times faster in U.S. metro areas. In other words, the differences in productivity between the two countries do not stem from different industrial structures.

Advanced industry value added per worker has grown much faster in the U.S. than in Canada in recent years

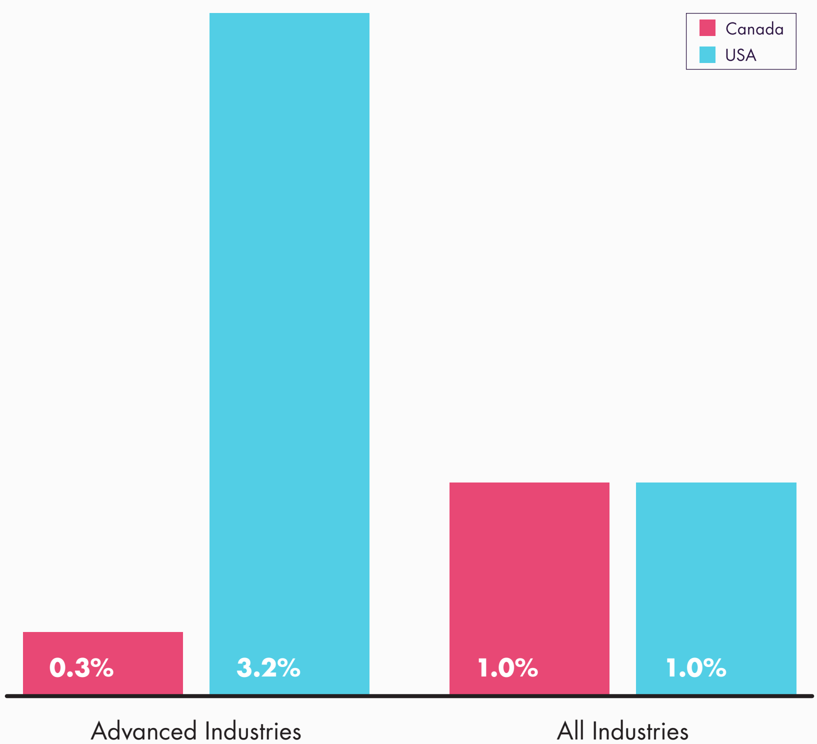


Figure 4: Value added per worker growth, 1996–2015, annualized, all metro areas

3. **Canada should commit to addressing four particular sources of its deficient advanced-sector productivity growth, including issues involving the nation's capital availability, competition levels, connectivity, and technological complexity (the four "Cs")**

Given the sector's combination of critical importance and lagging productivity, then, Canadian leaders should focus urgently on leading explanations of that lag and seek to address them.

Along those lines, this report—without trying to be comprehensive—assesses four potential causes of Canada's advanced sector productivity gap, at varying levels of detail, and suggests for each high-level strategic priorities for driving the Canadian advanced sector onto a higher growth path. In keeping with that, Canadian government and business leaders should:

Commit to capital deepening: Significant previous research has documented that Canada makes do with substantially lower capital intensities across its economy than the United States. This gap depresses productivity growth. Specifically, Canadian firms appear to invest much less than American companies in physical and knowledge capital, such as information and communications technology (ICT), and young Canadian companies enjoy much spottier access to risk capital for innovation and growth. In view of this, public- and private-sector leaders should expand ongoing efforts or develop new initiatives to:

- Promote digital adoption by building awareness of under-investment, especially in ICT, as a competitive problem
- Incentivize greater risk capital investment by helping increase the number of top-performing venture capital funds
- Develop a public-private Canadian Matching Fund and an entirely private Business Growth Fund to provide capital to, take equity stakes in, or provide loans to high-promise small- and medium-sized enterprises

Commit to expanding competition: Competition, in this regard, remains a critical spur to innovation and productivity growth. However, many of Canada's largest sectors (such as finance and telecommunications) remain highly regulated and more shielded from global competition than firms in the United States. Meanwhile, the nation's top managers are often trained in those same sectors: strong industries with blue-chip companies that are also highly sheltered. All of which makes it critical for the nation to embrace competition as a source of productivity gains. In this fashion, policymakers should:

- Allow greater market competition in Canada's highly regulated network sectors
- Promote a business culture of risk-taking by emphasizing entrepreneurship in training and education

Commit to connectivity: In addition, new evidence presented in this report adds to concerns that Canada contends with a dearth of large, successful, and globally networked companies in the advanced sector. With too few of these global champions, the nation lacks access to key sources of knowledge, best practice exchange, organizational capacity, and power—all deficiencies that align with its productivity lag. And so the nation should strive to build more globally competitive advanced industry firms in Canada as a way to alter its current branch-plant identity. To that end, leaders should:

- Make scaling up domestic companies a focus of the innovation ecosystem
- Promote foreign direct investment

- Invest in globally connecting infrastructure—especially major international airports
- Support globally relevant institutions such as major research universities

Commit to complexity: With new research pointing to the association of local economic variety with growth, Canada and its regions should experiment with "complexity analysis" and "smart specialization" as tools for identifying local technological trajectories and projecting smart development strategies. Because technological complexity improves the potential for new innovation, assessing the complexity of local innovation patterns allows for regions and nations to forecast promising developments and then focus and align interventions. In keeping with that, regional economic development leaders—in league with their provincial and federal partners—should adopt smart specialization as a useful strategic framework for improving the efficiency of innovation and the productivity of Canadian regions. To that end, policymakers and business people should:

- Build up data and analytics capabilities that inform policy making at the local level
- Identify regional strengths and align policies and investment that enhance them
- Test network-building policies such as the "supercluster" initiative and expand where appropriate

Introduction

Canada is having a moment.

In a world where talent is mobile and technology-based growth central, Canada stands out more than ever with its vibrant democracy, growing tech clusters, and unparalleled openness to the world's migrants.

Seemingly a world apart from the paroxysms of Brexit and Donald Trump, the nation—anchored by its major regional economies—seems poised to capitalize.

Yet there is a problem: Despite Canada's many strengths, the nation's economy faces serious structural challenges, including from an aging population and slowing output growth to questions about the long-term viability of its resource sector. Most disconcertingly, Canada needs to ask urgently whether it possesses the right mix of industries performing at a high enough level to allow the nation to prosper as a small open economy adjacent to an America in the midst of tumultuous arguments and policy changes involving taxes, trade, and talent.

And here there is no way around it: Canada, its provinces, and its communities need to focus anew on expanding the nation's highest-value "advanced industries."

As defined by Brookings, advanced industries, which include industries as diverse as auto and aerospace production, oil and gas, and information technology, are the high-value innovation and technology application industries that inordinately drive regional and national prosperity.

Advanced industries matter because companies in the sector—ranging from Magna in auto parts and Bombardier in aerospace and transportation to TransCanada in energy and tech standouts like CGI—generate disproportionate shares of the nation's output, jobs, and exports. Likewise, advanced sector firms, whether in pharmaceutical manufacturing, oil and gas extraction, or digital services like computer system design, matter intensely because they encompass a huge piece of the technology enterprise that contributes most heavily to Canadian innovation, good job creation, and high living standards.

However, for all that, questions both new and old surround the state of Canada's advanced industries—the most important determinant of the nation's future prosperity.

To be sure, the nation's advanced sector is in many respects well-positioned to compete for market share in the global scrimmage to create value. Sizable and varied advanced industries are, in this connection, widely distributed across the nation's regions and enjoy easy access to a highly educated workforce not always available in the United States. And yet the fact remains that, at least in comparison with its American counterpart, the Canadian sector is not tapping its full productive potential.

Specifically, as this brief will show, the advanced industry sector in Canada has failed to respond to the global productivity challenge, and today has lost significant ground on productivity growth to the American sector, which itself has been slowing. Similar issues are posed by the recent corporate tax reform in the U.S., which, although imperfect, could alter the continent's competitive landscape. The result of these challenges, if they are not responded to urgently, will almost certainly be materially slower growth and a declining standard of living for Canadians.

For that reason, Canada's leaders—facing a world of hyper-intense competition and disruption—need to take aggressive and immediate action to expand the nation's advanced sector and call forth its full productive potential.

Hence this report: Intended to help Canadian leaders focus their efforts on what matters most in their drive to improve the long-term prospects of the Canadian economy, the report provides a framework for targeting ongoing work to push the Canadian enterprise onto a more productive path conducive to building an advanced economy that works for all.

As such, the brief complements the work of the Minister of Finance's Advisory Council on Economic Growth and other bodies by introducing the concept of the advanced industry sector, assembling and analyzing significant new data on its progress and geography, and considering the nation's competitive position, especially as it results from the advanced sector vitality of its 33 Census Metropolitan Areas (CMAs).

In that fashion, the following section of the report discusses what advanced industries are and why they matter. After that, a second section benchmarks the size, distribution, variety, and productivity of the Canadian advanced industry sector, both nationally and as it occurs in the nation's CMAs. A third and final section reviews four possible explanations of the middling performance of Canada's advanced industries and suggests high-level strategic priorities for intervention. Given the more programmatic recommendations of the Advisory Council on Economic Growth, the suggestions presented here represent more a high-level strategic framework for motivating concerted action.

In this regard, the current moment presents Canada with both sizable challenges and real opportunities. While success at catalyzing advanced and inclusive growth will require a new mindset among all concerned, the urgency of government and industry leaders to reset the Canadian economy is palpable. For that reason these pages represent a bet on success.

1. Canada's Advanced Industries: What They Are, Why They Matter

The Canadian economy is experiencing relentless technological change, the blurring distinction between manufacturing and services, and the infiltration of digital software into every sort of production, including heavy industry. Advanced industries—those industries that disproportionately rely on research and development and STEM workers—are at the heart of this transition, and therefore key to the future of Canadian prosperity.

What are advanced industries?

We define advanced industries as those that conduct large amounts of research and development (R&D) and employ a disproportionate share of science, technology, engineering, and mathematics (STEM) workers. Specifically, the advanced sector encompasses 50 industries across manufacturing, services, and energy that meet the following criterion:

> **R & D spending** that exceeds $450 per worker, above the 80th percentile of U.S. industry intensity
>
> **STEM worker** share of industry exceeds U.S. industry average (21 percent)

These industries include advanced manufacturing industries such as pharmaceuticals, motor vehicles, aerospace, and machinery; energy industries such as oil and gas extraction and electric power generation; and services including software design, telecommunications, and scientific and technical services. These industries have birthed some of Canada's most iconic companies, whether aerospace giant Bombardier, the major e-commerce software publisher Shopify, or the erstwhile smartphone manufacturer Blackberry. Originally an American-based construct, the advanced industries selected using U.S. data overwhelmingly align with the most R&D-intensive industries in Canada.

Why do advanced industries matter?

Advanced industries are the bedrock of Canada's high-value economy. About 1.9 million Canadians worked in advanced industries in 2015, or about 11 percent of national employment. From this relatively small share of jobs, advanced industries generated 17 percent of Canada's GDP, 61 percent of national exports, and 78 percent of research and development. In 2015, the average value added per employee in advanced industries was 34 percent higher than in the economy overall.

The positive impact of these industries radiates across the rest of the economy in two different ways. For starters, the advanced industries tend to have long supply chains. Capital-intensive sectors like automotive, aerospace, and energy extraction require second- and third-tier suppliers that provide the components and equipment needed to make these industries function.

Second, advanced industries seed new technologies and innovations that help drive productivity growth throughout the rest of the economy. These industries are where Canadians' highest impact inventions, from the pager to the Walkie Talkie to the motorized wheelchair, have all been developed. The most prominent example is information and communication technology, a platform technology that has pervaded manufacturing and is poised to revolutionize industries outside of our definition, like financial services, healthcare, and education as well. Indeed, many businesses within industries outside of our definition are intense users of technology and a technically skilled workforce, including

Defining and measuring advanced industries

The framework for advanced industries relies on two concepts central to the innovation economy at its broadest. The first factor—R&D spending—signals that innovation through the advent of new technologies, products, and processes is central to an industry. An industry's STEM worker intensity, the second factor of our definition, indicates that the industry is employing a workforce that can apply R&D discoveries to commercialize new products and services. Both are critical components of how new innovations translate to commerce and economic growth.[1] This definition yield the 50 industries listed in Table 2.

We measure advanced industries using Moody's Analytics data on value-added and employment for four-digit NAICS industries for Canadian Census Metropolitan Areas (CMAs) and provinces and American Metropolitan Statistical Areas (MSAs) and states. This time series dataset goes from 1996 to 2015, which we utilize to measure growth in advanced industries employment, value-added, and productivity (value-added per worker) at the local level.

NAICS CODE	INDUSTRY TITLE	EMPLOYMENT	OUTPUT (MILLIONS)
	ENERGY		
2111	Oil and gas extraction	100,200	$67,295
2122	Metal ore mining	48,300	$11,066
2211	Electric power generation, transmission and distribution	104,400	$25,045
	MANUFACTURING		
3241	Petroleum and coal products manufacturing	21,000	$6,015
3251	Basic chemical manufacturing	17,700	$3,244
3252	Resin, synthetic rubber, and artificial synthetic fibers and filaments manufacturing	4,300	$2,307
3253	Pesticide, fertilizer, and other agricultural chemical manufacturing	8,300	$1,004
3254	Pharmaceutical and medicine manufacturing	32,000	$4,283
3259	Other chemical product and preparation manufacturing	12,400	$1,577
3271	Clay product and refractory manufacturing	2,400	$198
3279	Other nonmetallic mineral product manufacturing	9,900	$795
3311	Iron and steel mills and ferroalloy manufacturing	28,800	$2,521
3313	Alumina and aluminum production and processing	12,200	$2,462
3315	Foundries	11,400	$744
3331	Agriculture, construction, and mining machinery manufacturing	28,100	$2,642
3332	Industrial machinery manufacturing	15,200	$1,336
3333	Commercial and service industry machinery manufacturing	14,500	$1,749
3336	Engine, turbine, and power transmission equipment manufacturing	5,700	$649
3339	Other general purpose machinery manufacturing	30,400	$3,395
3341	Computer and peripheral equipment manufacturing	8,500	$568
3342	Communications equipment manufacturing	19,000	$1,586
3343	Audio and video equipment manufacturing	1,300	$130
3344	Semiconductor and other electronic component manufacturing	17,200	$929
3345	Navigational, measuring, electromedical, and control instruments manufacturing	22,200	$2,195
3346	Manufacturing and reproducing magnetic and optical media	1,600	$161
3351	Electric lighting equipment manufacturing	5,900	$444
3352	Household appliance manufacturing	2,500	$153
3353	Electrical equipment manufacturing	15,900	$1,627
3359	Other electrical equipment and component manufacturing	11,600	$1,026
3361	Motor vehicle manufacturing	60,400	$7,156
3362	Motor vehicle body and trailer manufacturing	14,800	$759
3363	Motor vehicle parts manufacturing	84,000	$7,866
3364	Aerospace product and parts manufacturing	59,100	$6,525
3365	Railroad rolling stock manufacturing	5,000	$738
3366	Ship and boat building	9,100	$579
3369	Other transportation equipment manufacturing	6,500	$1,272
3391	Medical equipment and supplies manufacturing	19,000	$1,209
3399	Other miscellaneous manufacturing	50,900	$2,703
	SERVICES		
5112	Software publishers	35,100	$4,477
5152	Catble and other subscription programming	2,300	$1,266
5172	Wireless telecommunications carriers (except satellite)	28,300	$5,076
5174	Satellite telecommunications	3,700	$666
5179	Other telecommunications	7,700	$1,390
5182	Data processing, hosting, and related services	11,600	$1,566
5191	Other information services	48,400	$2,134
5413	Architectural, engineering, and related services	272,900	$17,226
5415	Computer systems design and related services	288,000	$21,060
5416	Management, scientific, and technical consulting services	163,600	$10,358
5417	Scientific research and development services	63,000	$4,172
6215	Medical and diagnostic laboratories	35,900	$1,522

Table 2: Employment and Output in Canada's 50 Advanced Industries

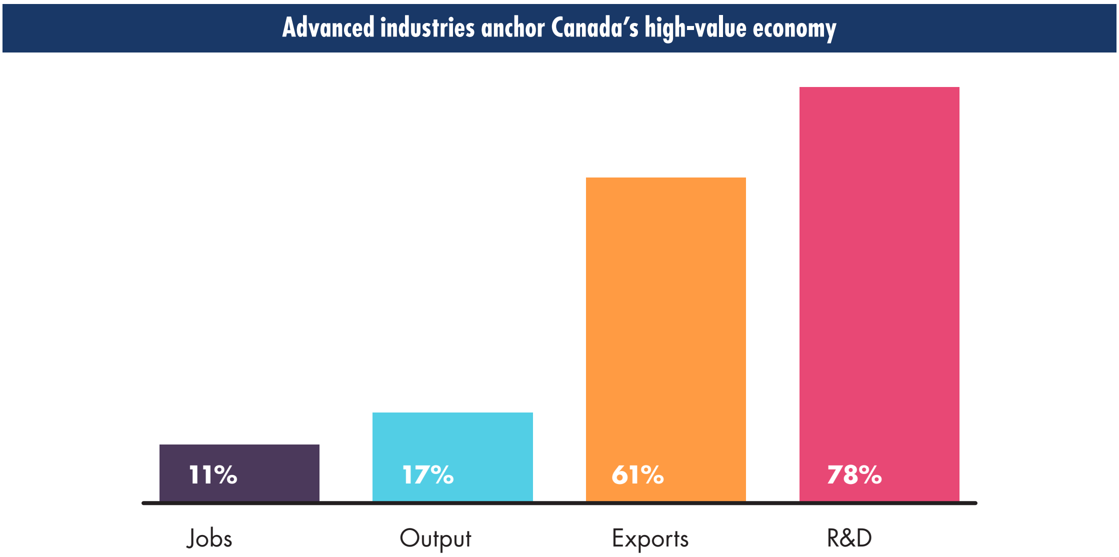


Figure 5: Advanced industries anchor Canada's high-value economy

finance and other creative industries such as media. And while these industries are not included in our definition, they employ tens of thousands of workers, most predominately in Greater Toronto, and will remain an important segment of the economy in terms of technology adoption and diffusion in the coming years.

Given their relatively high productivity, advanced industries are fundamental to the future of Canadian prosperity. The average worker employed in an advanced industry earned a yearly wage of nearly $60,000, 50 percent higher than the average Canadian worker ($39,000) did. In other words, advanced industries are a critical part of advancing broad-based wage growth.

In short, as Canada aims to build a future-oriented economy that provides broad-based income growth, advanced industries will be essential.

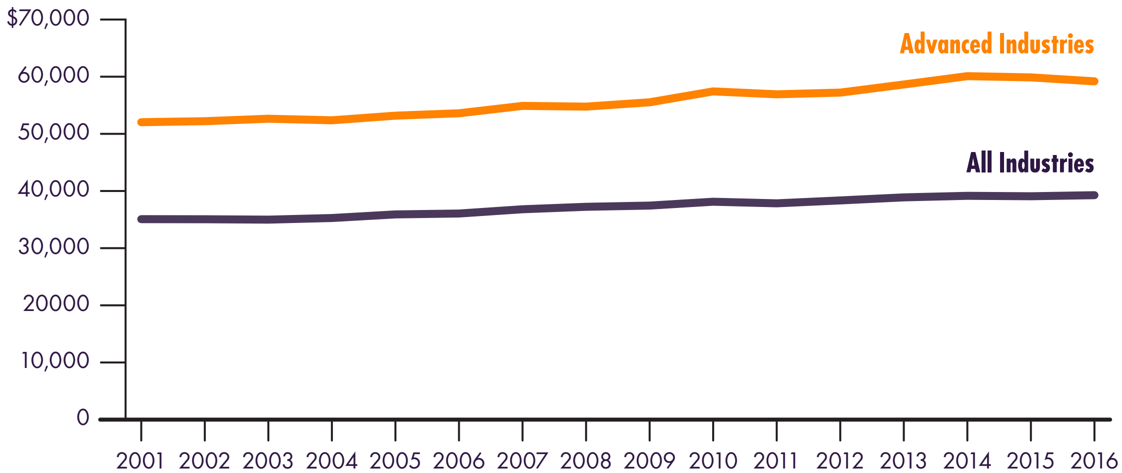


Figure 6: Average annual earnings, $CAD

2. Findings: Benchmarking Canada's Advanced Industries

An analysis of the 50 advanced industries in Canadian regions and provinces, including comparisons with U.S. metro areas and states, finds that:

Canada boasts a diverse base of advanced industries, which together account for 11 percent of national employment and 17 percent of national GDP

As of 2015, the 50 advanced industries in Canada employed nearly 1.9 million workers, or 11 percent of the national total. That this base generated $247 billion in output, or 17 percent of the national total, indicates the advanced sector's superior productivity to the rest of the economy. By comparison, the United States' advanced industry base supports about 9 percent of the workforce and 18 percent of national output.

The Canadian economy has notable specializations within advanced industries. In terms of employment, services account for just over half of the Canadian advanced industry worker base (51 percent), followed by manufacturing (36 percent) and energy (13 percent). The impact of the Canadian energy industry is even more apparent in the output statistics. The three advanced energy industries account for 42 percent of national advanced industry output, led by $67 billion generated by oil and gas extraction alone (see sidebar). Advanced services and manufacturing each account for 29 percent of national output. In terms of both output and employment, Canada's advanced industry mix skews toward energy when compared to the United States.

How the energy industry influences Canadian advanced industries

This report applies an advanced industries definition developed in a previous analysis of the United States. While this provides the benefits of consistent comparative benchmarking across the two nations—a significant contribution of this report—it does require acknowledging how the inclusion of key energy industries such as oil and gas extraction will have unique consequences for a resources-intensive economy like Canada that may not be as significant in the United States.

There are three aspects related to the energy industry to keep in mind while reading this report. First, energy has a much larger impact on value added than on employment. As of 2015, the energy industry accounted for 42 percent of advanced industry output but only 13 percent of employment. So statistics measuring the share of value added in advanced industries will be much larger for CMAs and provinces with a foothold in energy than their share of employment, although these two statistics do tend to run together.

Second, and relatedly, the energy industry will significantly influence the trend line for advanced industry output growth and productivity growth. We examine this dynamic later in the report, but CMAs and provinces with large presences in the energy industry generally display higher volatility in these statistics than the rest of the country. As a result, we examine advanced industry productivity trends both including and excluding energy.

Third, over the two decades this report uses as its analysis window, oil and gas prices did fluctuate. Even with this long time horizon, there are invariably cyclical trends related to energy that do influence regional, provincial, and national economic movements. That noted, the energy industries included in our advanced industries definition do undertake significant levels of research and development and demand pools of STEM workers, and therefore remain notable contributors to national innovation and prosperity. While acknowledging these caveats about cyclicality unique to these industries and how that influences sub-national trends related to advanced industries, energy remains an important component of the Canadian advanced industries landscape.

The profile of advanced industry activity varies across the two countries

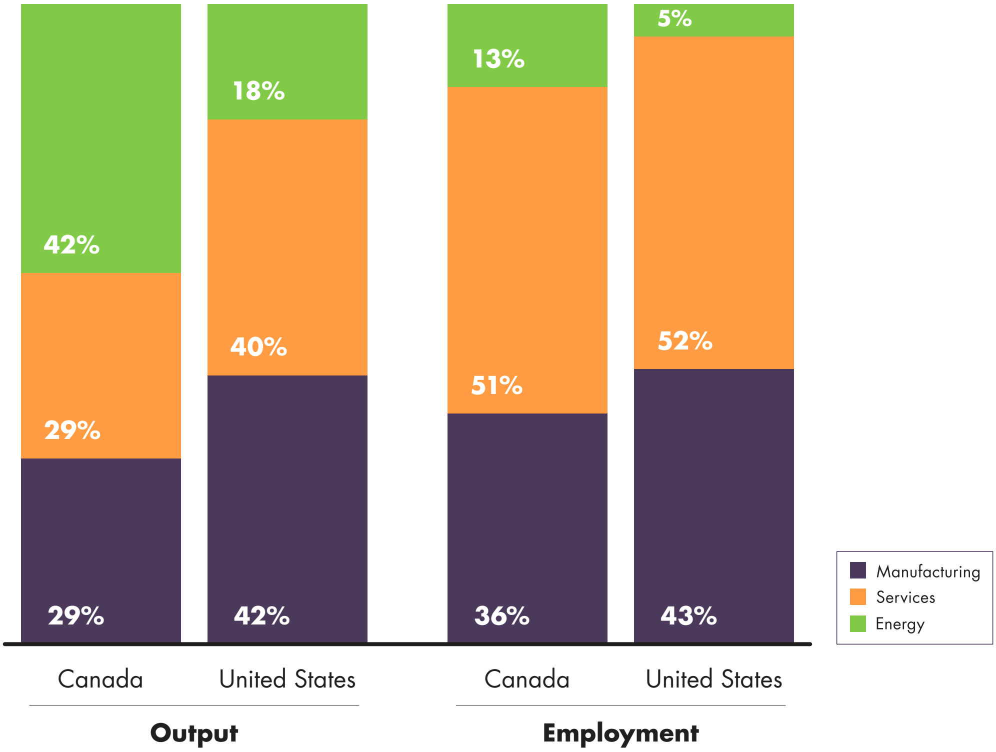


Figure 7: Share of total advanced industry activity, by sub-sector, 2015

Since 1996, Canada's advanced industry base has undergone a notable transition. In that year, advanced manufacturing accounted for over half (52 percent) of the nation's advanced industry employment while services employed only about 34 percent of advanced industry workers. Incredibly, those shares essentially switched between 1996 and 2015.

Tremendous growth in advanced services employment and a slight decline in advanced manufacturing employment fueled this transition. Emblematically, computer systems design and related services added 188,000 jobs, nearly tripling its base between 1996 and 2015. Meanwhile, the three industries that constitute motor vehicle production lost 27,000 jobs over those twenty years.

Canadian provinces and metropolitan regions vary significantly in the scale, intensity, and diversity of their advanced industry production

Every part of Canada can lay some claim to the nation's advanced industry economy, albeit at varying scales and intensities. Not surprisingly, **Ontario**, **Quebec**, **Alberta**, and **British Columbia** have the largest number of advanced industry jobs. Together those four provinces account for 91 percent of Canada's advanced industry employment.

Ontario alone accounts for 43 percent of the sector's footprint nationally, with over 800,000 advanced industry jobs. As context, Ontario houses the largest concentration of

All Canadian provinces contain significant advanced industries employment				
Province	**Total**	**Manufacturing**	**Services**	**Energy**
Ontario	805,823	344,838	402,267	58,717
Quebec	431,971	177,435	219,418	35,118
Alberta	283,809	49,198	135,213	99,398
British Columbia	197,038	46,122	131,577	19,339
Manitoba	50,601	24,314	15,941	10,346
Saskatchewan	40,321	11,696	16,452	12,172
Nova Scotia	29,496	7,738	18,139	3,619
New Brunswick	22,930	5,877	11,773	5,280
Newfoundland and Labrador	18,309	1,558	7,984	8,767
Prince Edward Island	4,373	1,766	2,276	330
Canada	**1,884,671**	**670,541**	**961,042**	**253,088**

Table 3: Advanced industry employment, by province, 2015

advanced industries employment in North America outside of California and Texas, the respective homes of the United States' largest technology and energy clusters.

In Ontario, advanced industries accounted for 11.7 percent of all provincial jobs in 2015, and ranked just behind Alberta (12.4 percent) for the highest share and slightly ahead of Quebec (10.6 percent). British Columbia and Manitoba also have over 8 percent of their local workforce employed in advanced industries. These provincial shares resemble advanced industry intensities in U.S. states like California, Indiana, Massachusetts, Virginia, and Washington.

Diving below the provincial level reveals further notable geographic patterns. Not unexpectedly, Canada's largest Census Metropolitan Areas (CMAs) contain the largest number of advanced industry jobs. **Toronto** leads the nation with 384,000 workers in advanced industries, followed by **Montreal** (260,000), **Calgary** (138,000), and **Vancouver** (134,000). Together, these four CMAs account for nearly half (49 percent) of Canadian advanced industries employment.

Calgary's advanced sector ranks as proportionately the largest, with 17.0 percent of workers employed in the sector. **Windsor** follows closely behind with 16.9 percent of jobs in advanced industries. **Guelph** (16.6 percent), **Kitchener-Waterloo** (16.2 percent), **Saguenay** (13.4 percent), and **Oshawa** (12.9 percent) follow that. In total, Ontario houses seven of the 10 highest ranked Canadian CMAs on this measure, reflecting the province's centrality in the nation's advanced industry economy. Advanced industries account for 12.9 percent of employment in **Montreal** and 12.1 percent in **Toronto**.

On the flip side, the CMAs with the lowest shares of local employment in advanced industries include **Abbotsford** (5.3 percent), **Moncton** (5.6 percent), **Kingston** (6.9 percent), and **Kelowna** (7.4 percent).

Canada's most advanced industry-intensive CMAs rival the highest employment shares in the United States. As the home of Silicon Valley, no metro area in North America has a greater share of employment in advanced industries than San Jose (31.4 percent). But notably, the next four metros are Canadian, led by Cal-

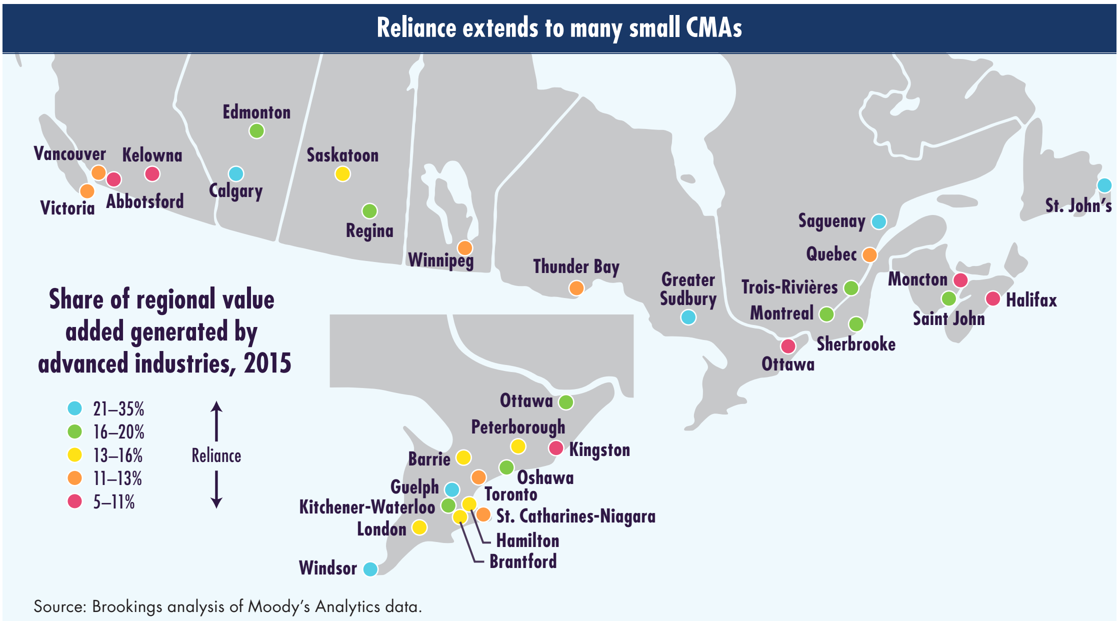


Figure 8: Share of regional value-added generated by advanced industries, 2015

gary. U.S. metro areas specialized in advanced manufacturing and technology services follow those four Canadian CMAs: Seattle, Wichita, Detroit, and San Francisco.

As a measure of reliance on advanced industries, the share of local value-added generated in local economies by these 50 industries reveals a slightly different map of CMAs. By this metric, the prominence of Canada's oil and gas sector reveals itself. **Calgary** (34.2 percent), **St. John's** (31.0 percent), **Saguenay** (28.8 percent), and **Windsor** (23.1 percent) have the greatest shares of their local value-added driven by advanced industries. In Calgary and St. John's, oil and gas extraction accounts for 69 and 83 percent, respectively, of advanced industry value-added. Meanwhile, Windsor's motor vehicle manufacturing cluster accounts for 57 percent of local value added. While subject to the fluctuations of oil and gas prices, Canada's unique stake in the global energy industry implicates a geographically diverse set of eastern and western CMAs.

Nearly every Canadian CMA added advanced industries employment between 1996 and 2015, with the exception of **St. Catharine's-Niagara**, **Greater Sudbury**, and **Thunder Bay**. Eight CMAs added more than 10,000 advanced industry jobs during this period, led by the nation's largest CMAs.

Western and eastern CMAs experienced the fastest advanced industries growth since 1996. Partly driven by the investments in energy, and energy-related manufacturing, metro economies like **St. John's** (4.2 percent annualized

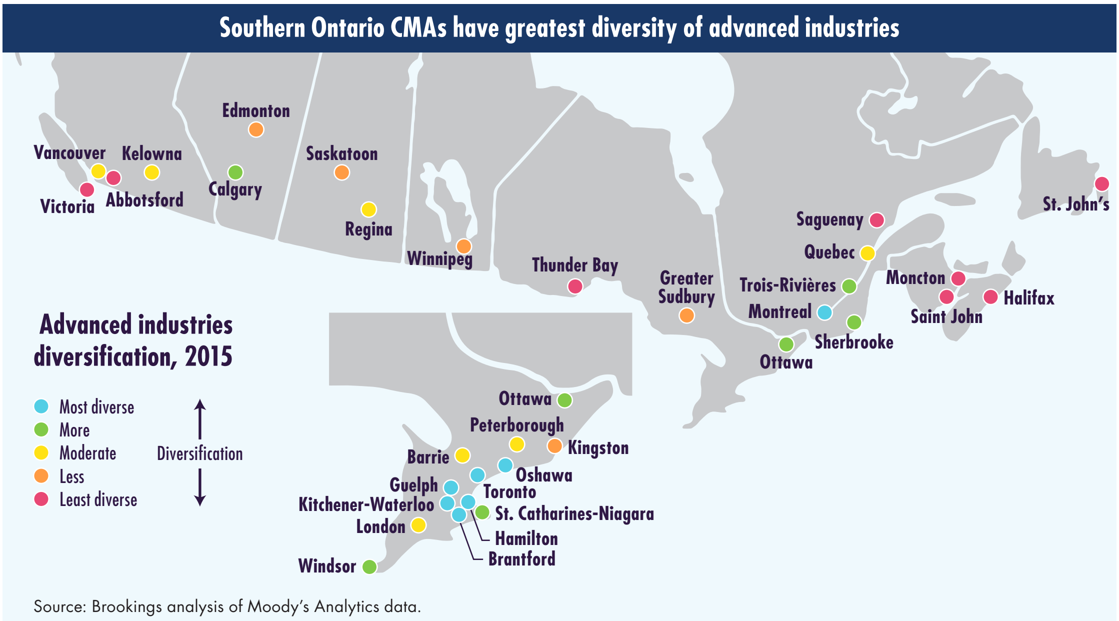


Figure 9: Advanced industry diversity, by CMA

growth), **Saint John** (3.6 percent), **Moncton** (3.4 percent), and **Calgary** (3.4 percent) experienced the fastest annualized yearly growth in advanced industries employment, albeit several of those from a small base.

But even as local economies added advanced industry jobs on net, the erosion of manufacturing employment took a toll. Ontario metro areas like **Oshawa**, **Hamilton**, and **Greater Sudbury** saw their share of employment in advanced industries plummet by 20 to 25 percent. Toronto also experienced a slight decline in its advanced industry job share.

Even with these declines, Southern Ontario remains a hub of advanced industry employment, notable for its diversity. We gauge advanced industry diversity by measuring the number of advanced industries in which a metro area has a specialization. We measure specialization by whether the metro area has a greater concentration of jobs in a particular industry than the nation as a whole.

By this metric we observe a diversity of advanced industries—particularly in the advanced manufacturing segment—in several Canadian metro areas, led by **Kitchener-Waterloo** (specialized in 31 of 50 advanced industries), **Montreal** (26), **Toronto** (26), **Brantford** (25), and **Hamilton** (23). This diversity compares favorably with that in the most diversified advanced industries bases in the United States: Charlotte (25), San Francisco (24), Chattanooga (24), San Jose (23), and Chicago (23).

Numerous Canadian regions boast more than 10 advanced industries with elevated local concentrations

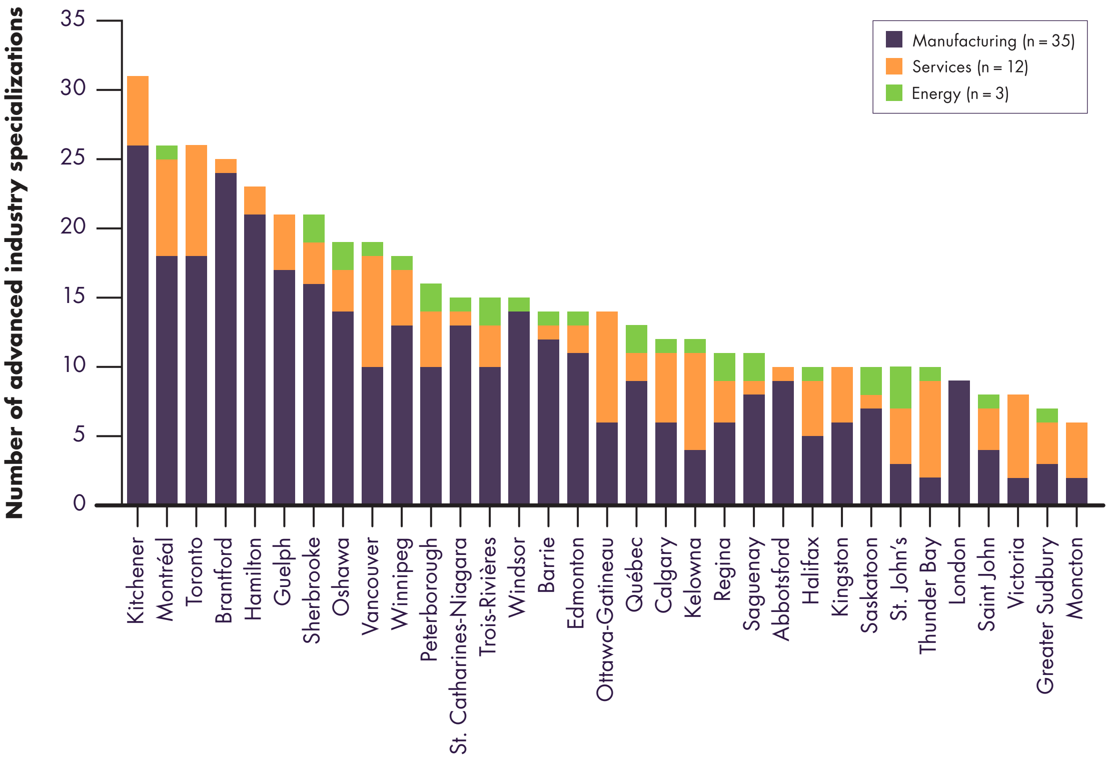


Figure 10: Number of advanced industries with Location Quotient > 1, 2015, by CMA

Advanced sector productivity is much lower in Canadian metro areas than U.S. metro areas

The previous finding reveals that Canada's metro economies boast a key set of valuable advanced industries cutting across manufacturing, services, and energy. These industries exist locally at an intensity, density, and diversity that rivals or exceeds U.S. advanced industry clusters, especially in advanced manufacturing. These facts ensure that the sector compares favorably to its American counterpart by at least several important measures.

And yet, with that said, this comparative lens also reveals a challenge: Advanced industries in Canada are much less productive than in the United States. Nationally, the OECD reports that Canada's GDP per hour worked is about 30 percent lower than in the United States. Productivity is notoriously difficult to measure below the level of the nation, and the only statistic available at the regional scale—the amount of economic output per worker—is admittedly crude. Nevertheless, the evidence is clear: An examination of the local productivity of the nation's advanced sector concentrations confirms the existence of a serious productivity shortfall in Canada's core industry sector.

The average value added per worker in Canadian metro areas is about $82,000, 37 percent lower than the $113,000 per worker in the United States. In 1996, this gap was about 36 percent. Productivity gaps across the en-

Figure 11: Canada-USA productivity gaps, by metro size

tire economy hold across both large and small metro areas.

Advanced industries are a key source of the overall productivity gap between U.S. metro areas and Canadian metro areas. In 1996, the productivity differential between the average Canadian worker in metro areas and the average U.S. worker in metro areas was about 17 percent. By 2015, that gap had expanded to 100 percent. In other words, advanced industry value added per worker is nearly twice as high in U.S. metro areas as in Canadian metro areas.

Put another way, average annual value added per worker growth was about 1 percent per year in both Canadian and U.S. metro areas. But advanced industries productivity growth in U.S. metros averaged 3.2 percent per year, while Canadian productivity growth in these industries averaged 0.3 percent per year.

Fluctuations in the energy industry partly account for this stark trend, as the amount of value generated by the oil and gas sector depends on fluctuations in the commodity markets. However, even after removing energy from the advanced industries definition, Canadian advanced industry productivity growth significantly lags behind the United States. Between 1996 and 2015, productivity growth in the manufacturing and services portions of advanced industries grew at about 0.8 percent per year in Canada.

Advanced industry productivity growth did

Advanced industry value added per worker has grown much faster in the U.S. than in Canada in recent years

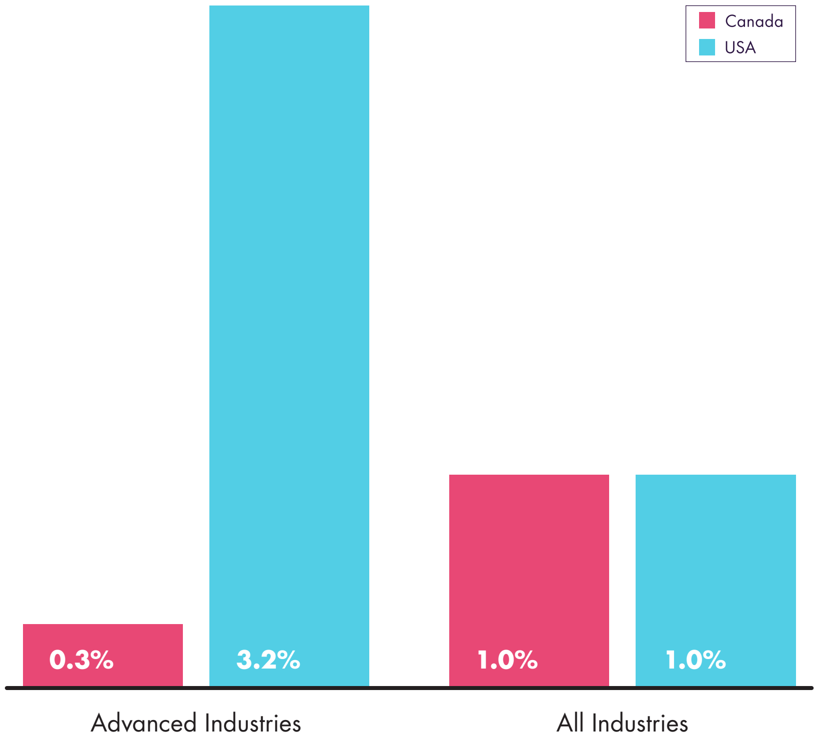


Figure 12: Value added per worker growth, 1996–2015, annualized, all metro areas

Annualized value added per worker growth varies widely across province and across time

	1996–2015		2010–2015	
Province	**Advanced industries**	**Advanced industries, excluding energy industries**	**Advanced industries**	**Advanced industries, excluding energy industries**
Alberta	-1.67%	-0.19%	0.67%	-0.38%
British Columbia	0.56%	1.16%	0.48%	1.56%
Manitoba	0.09%	0.28%	1.56%	2.44%
New Brunswick	-1.71%	-0.10%	-2.09%	-2.21%
Newfoundland and Labrador	3.78%	-0.56%	-9.80%	-3.95%
Nova Scotia	0.19%	0.91%	-4.90%	-4.14%
Ontario	0.74%	0.95%	1.08%	1.18%
Prince Edward Island	0.97%	1.22%	0.78%	1.66%
Quebec	0.20%	0.34%	1.58%	1.12%
Saskatchewan	-1.17%	1.92%	1.74%	2.17%
Canada	**0.28%**	**0.75%**	**0.94%**	**0.91%**

Table 4: Value added per worker growth, 1996–2015, annualized, by province

vary across Canadian provinces. Eastern geographies such as **Newfoundland and Labrador** and **Prince Edward Island** displayed strong productivity growth, albeit from a lower base. Beyond those small, energy-intensive provinces, **Ontario** and **British Columbia** were the only other two provinces to exceed Canada's 0.3 percent advanced industries productivity growth rate. *Table 4* reveals the significant presence of energy in many Canadian provinces and how that industry influences productivity trends during this period.

While exceptions exist, the productivity advantage in the United States holds across the vast majority of advanced manufacturing, services, and energy industries. Indeed, key advanced manufacturing industries such as motor vehicles production, aerospace manufacturing, and even oil and gas extraction display significantly lower productivity levels in Canada than in the United States. The productivity gap in advanced industries did not arise because Canada moved employment into lower productivity industries. Rather, the differences in productivity growth between Canadian and U.S. metro areas resulted from advanced industries growing three times faster in U.S. metro areas.

In other words, the differences in productivity between the two countries do not stem from different industrial structures. Consider this thought experiment: If Canadian metro areas were to adopt the same industrial structure as U.S. metro areas (as measured by the employment share of four-digit NAICs industries), then Canadian GDP would be $37 billion greater in 2015, about 2.5 percent larger than it is now. Yet, if Canadian metro areas were to adopt the productivity levels of U.S. metro areas, Canadian GDP would be about $781 billion larger in 2015, or a massive 52 percent larger.[2]

In sum, while Canada's sizable advanced sector compares favorably with America's for its size and density, the sector suffers from a significant productivity gap that undercuts its global competitiveness and ability to increase its share of the global advanced economy.

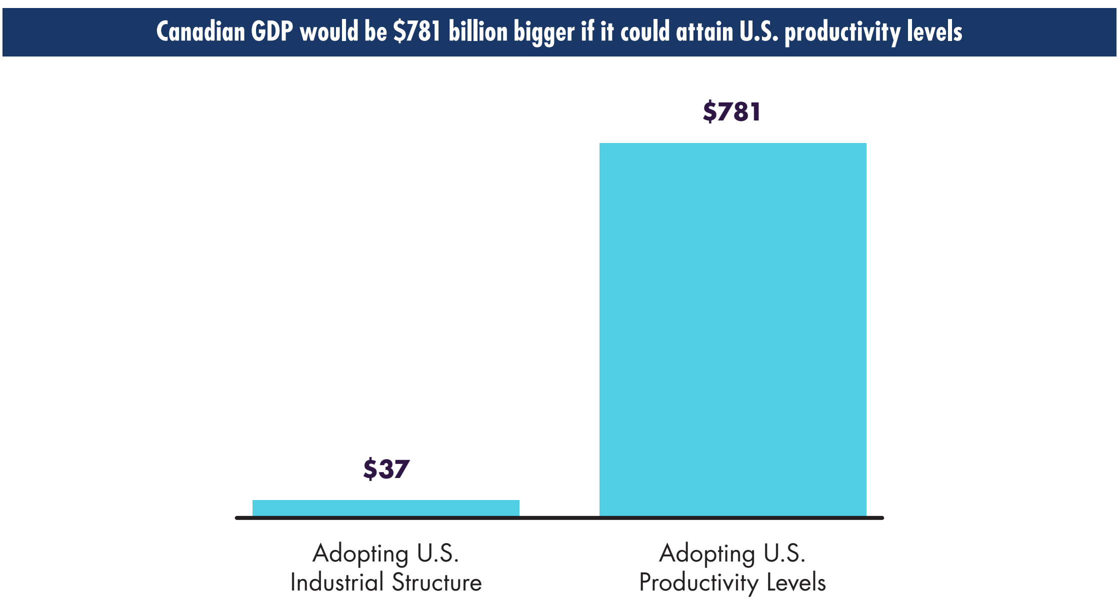


Figure 13: Additions to 2015 Canadian GDP should scenario unfold...

3. Discussion and Strategies

Sizing and tracking the progress and geography of Canada's advanced industries is important because local and national advanced clusters power prosperity.

Given that, it is encouraging that Canadian metro areas have a presence in many high-value advanced industries and that in some cases Canada's clusters compare favorably to those in U.S. metropolitan areas. It is clear that advanced industries, and the well-paying jobs they generate, represent a significant opportunity for Canadian workers and metropolitan communities.

And yet, the fact remains that in Canada these industries, and the Canadian economy as a whole, are not tapping their full productive potential, at least as compared to the United States.

This is a problem because while productivity may not be "everything," it is "almost everything," as economist Paul Krugman has insisted, when it comes to a country's ability to improve its standard of living. For that reason, it is a matter of some urgency to consider what factors may be depressing the productivity of Canada's sizable advanced sector.

Which is why it is welcome that the productivity gap between the two countries—and the metro areas that power them—has resulted in a substantial body of rigorous inquiry relevant to policymakers.

Literally dozens of factors influence productivity and have become subjects of analysis, such as questions about the business environment established by government competition, investment, tax, and trade policy; the skill and technical capabilities of the workforce; and innovation enhancement through research and development, technology adoption, and management strategy. More recently, new perspectives from fields such as network theory, economic geography, and evolutionary economics have begun to surface in the discussion.

In view of the voluminousness of this work, then, parsing the particular contributions of these varied influences remains beyond the scope of this analysis. Therefore, we do not endeavor here to offer new analysis related to every aspect of the productivity gap nor claim conclusive evidence about its causes. Rather, we will in the following pages explore four leading potential drivers of the gap, at varying levels of detail: capital, competition, connectivity, and complexity ("the four Cs"). To the first two (relatively well-understood) influences on Canadian productivity, we propose to speak briefly. To the latter two more recently recognized factors, we will speak in more detail, including by offering new analysis. Altogether, the discussion will endeavor to highlight several critical issues for federal and provincial attention and suggest high-level strategic priorities.

Here we begin with a look at several heavily interrelated capital and competition factors:

Capital and competition

The first "C" is *capital*, specifically the propensity of the economy to 1) invest in *physical capital*, such as machinery and equipment, and *knowledge capital*, such as information and technology systems, and 2) provide risk capital to fuel entrepreneurship and firm growth. and 2) provide *risk capital* to fuel entrepreneurship and firm growth.

For centuries, physical investments in factories, machines, and other forms of equipment have enhanced the productivity of workers, businesses, and regional economies. As such, previous literature suggests that Canada's relatively low capital intensity—the amount of fixed capital relative to other factors of production—may be depressing advanced sector productivity.

As of the early 2000s, Andrew Sharpe found that "the lower capital intensity of economic activity in Canada, [was] estimated to account for around one fifth of the [labor productivity] gap" between the two countries.[3] Then Rao and Wang (2004) found that the capital intensity gap accounts for 30 percent of the labor productivity gap in the service sector and half of the manufacturing productivity gap.[4] A few years later Deloitte concluded that the amount of machinery and equipment stock per worker in Canada was less than half that of the United States in 2009, down from 62 percent in 1990.[5] And in the wake of the recession, the Conference Board found that Canadian investment in machinery and equipment had not kept pace with depreciation.[6]

In short, part of the productivity gap seems to be that Canada-based companies are investing less than U.S.-based companies in general, and in a particularly important component specifically: information and communication technology (ICT). The contribution of the computer and electronics sector to productivity growth in the United States during the 1990s and 2000s has been well-documented. By contrast, Harchaoui and Tarkhani (2004) found that the adoption of information technology contributed modestly to Canada's productivity growth in the late 1990s, but its contribution is not as strong as in the United States.[7] This gap continues into the present: Deloitte found that Canada's ICT stock per worker—a metric of knowledge capital investment—was also only about half that of the United States in 2009.[8]

Lower investments in information technology may be related to a second hypothesized capital deficiency: risk capital. In most economies, a relatively small share of young, fast-growing companies end up driving job creation and productivity growth.[9] These young firms are oftentimes technology-reliant and replenish the dynamism of local and national economies.

Notwithstanding their critical function, most young firms fail, which makes funding their growth a higher risk proposition. For its part, risk capital—the bundle of investment vehicles that include private equity, venture capital, and angel investing—provides speculative funding to these types of companies. However, many indicators of the depth and availability of Canadian risk capital, such as friends, family, and angel investment, are well below U.S. levels. Companies with promising, productivity-enhancing ideas may not be able to secure financing. In 2013, a Deloitte report noted the challenge:

> **Compared to other countries, more of Canadian startups slow down or simply disappear in part because many of our business leaders are not investing in the activities required to sustain growth.[10]**

More recently, and in parallel, a recent survey of dozens of Ontario business people and technologists by the Institute for Competitiveness and Prosperity concluded that only 35 percent said capital commitment to innovation was a moderate or strong advantage for the province.[11]

These risk capital shortages connect to a difficult-to-measure but widely held belief that Canadian executives have a lower risk tolerance than their American counterparts. For instance, the Ontario CEO survey highlighted "risk-taking culture" as the province's most significant challenge, while a prior survey of 900 North American business leaders also found that Canadian executives tended to be less tolerant of risk than their American counterparts.[12]

Aversion to risk may also derive from the unique competitive landscape in which major Canadian industries and firms operate. *Competition*, in this regard, remains a critical spur to innovation and productivity growth, yet many of Canada's largest sectors (e.g., finance, telecommunications, etc.) remain highly regulated and more shielded from global competition than firms in the United States.

Several studies have proposed that greater market competition could lead to improvements in Canadian productivity. For instance, Kellison (2004) argued that the construction sector has a surprisingly high productivity level compared to that of the United States due to its cadre of small firms that compete vigorously with one another for market share.[13] Souare (2013) concluded that the Canada-U.S. productivity gap is partly attributable to deficits in competition intensity. Overall, sectors with less market competition were less productive, partly because they invested in lower amounts of R&D and machinery and equipment.[14]

Together, the capital gap and the competition gap may reinforce lower productivity through another mechanism: the traits of Canadian management talent. Canada's top managers are often trained in the nation's banking, energy, or telecommunications sectors: strong industries with blue-chip companies that are also sheltered. Without the continued demands of global competition, one hypothesis is that these firms and industries are less likely to seed in their young managers an appetite for risky investments in the new technologies needed to power productivity growth.

In sum, Canadian industries' lower exposure to intense competition may well be interacting with its capital gaps to significantly depress the nation's competitiveness. While Canada's strong commitment to education and its open immigration system have ensured it a strong talent base, its high-end advanced-sector managers—those business leaders that can uniquely combine business and technology into high-growth ventures—seem less likely to invest in the gambles necessary to generate and commercialize big productivity enhancing breakthroughs. Likewise, while Canada's more sheltered industrial landscape undoubtedly helped it avoid the worst finanacial crisis from 2007 to 2008, it may now be limiting Canadian firms' ability to gain global market share in key technologies and industries.

How should Canada's policy environment and private sector respond to spur capital investment, competition, and business dynamism?

The capital investment gap has been widely documented and there are no shortage of proposed solutions to address it. In a series of reports, Deloitte has argued that firm-level deficiencies in capital investment may derive from an "overconfidence" among those companies. In short, approximately one-third of Canadian firms are not aware they are underinvesting, and that timely firm-and-industry-level information will help business leaders reality check their competitive position. As they write, "to help close the productivity gap, close the perception gap."[15]

There are also public policy reforms that could incentivize greater capital investment, particularly addressing the market failures that curtail risk capital investment. Much is already being done nationally in this space. For starters, BDC Capital, the investment arm of the Business Development Bank of Canada, has prioritized closing financing gaps by increasing the number of top-performing venture capital funds providing late-stage financing and engaging more large corporates in growth capital investment.[16]

New public, private, or public-private funds may be needed to seed larger growth capital pools. Along these lines, the national government's Advisory Council on Economic Growth has proposed two structures for such a fund. The first is the development of a Canadian Matching Fund to provide a mix of public and private capital to high-potential firms. The second is an entirely private sector-led Business Growth Fund that would either take equity stakes or provide loans to small and medium-sized enterprises.[17] Historically, government venture capital has underperformed private venture capital in Canada, so instruments that allow for private management of capital investment are likely to yield better results.[18]

In regards to market competition policy, one set of potential reforms would allow for greater market competition in Canada's highly-regulated network sectors. The OECD has identified several policy reforms that would stimulate product market competition in electricity, telecommunications, and air transportation. These reforms, which include easing foreign ownership restrictions in key sectors, aim to enhance the efficiency of inputs and boost productivity.[19]

Inducing greater competition may also ease risk aversion in the Canadian economy, a notable trait that has been documented across a range of publications. No one policy influences a country's business culture, of course. Rather a suite of policies—incentives for capital investment, the laws that regulate competition in key sectors, and the education and training provided to future entrepreneurs and business leaders—offers a combinatorial impact on the culture of risk-taking within Canada's key regional economies.

* * * * *

Looking beyond the well-recognized issues of Canadian capital and competition deficits, the following two sections will explore two additional influences on productivity: the global connectedness of Canadian firms and regions and those regions' technological complexity (a key factor of smart specialization and regional growth). Less analyzed to date than capital and competition issues, these issues of connectivity and complexity merit more extensive discussion, including with the introduction of new information and analysis. In each case a few high-level strategy priorities are identified:

Connectivity

The third "C" behind the productivity gap in Canadian advanced clusters involves the nation's insufficient large-firm *connectivity*—the degree to which especially Canada's biggest corporations participate in global value chains.

Large global corporations in the advanced industry sector have been key drivers of productivity gains over the past 20 years.[20] In part this owes to the fact that these firms developed the efficient internal processes required to maintain complex global networks of local branches and subsidiaries.[21] Given this, it is concerning that Canada has a dearth of large, successful, and globally networked companies within the advanced industry sector. With too few heavily networked large corporations, it may be that the nation lacks access to key sources of global knowledge exchange, best practices, and value creation. In this vein, the geographic structure of these establishments and their connections to regional and global headquarters can tell us a great deal about spatial inequalities across the economy.

To investigate these patterns, we have employed a globally comprehensive dataset of large firms from Dun & Bradstreet and mapped those significant firms to metro areas around the world. To this end, the largest 500 advanced industry firms are identified by their 2016 revenue (see *Appendix A*). The dataset provides the addresses of all establishments, the specific function at each subsidiary, and the reporting hierarchy between locations. These addresses are then mapped onto a standard set of metro areas including 35 Census Metropolitan Areas (CMAs) for Canada, 388 Metropolitan Statistical Areas (MSAs) for the U.S., and 1,540 metro areas of at least 300,000 for the rest of the world as defined by the UN Population Division. This data allows us to assess the degree to which a metro area is central or peripheral to global corporate networks.[22]

What do these data show? To begin with, we find that Canada has a relative shortage of top firms in advanced industries. Only 14 of the largest 500 corporations in the database are based in Canada. Five of these are in energy and mining, three are in telecommunications, two in auto manufacturing, and one each in transportation manufacturing, chemicals, digital services, and life sciences. Furthermore, these firms reside at the smaller end of the revenue and employment spectrum (see *Figure 14*).

These 14 companies situate their headquarters in just five metro areas: Montreal and Calgary each have four, followed by Toronto (3), Vancouver (2), and Guelph (1) (see *Figure 15*). In contrast, U.S. firms account for 162 of the global top 500 and are spread across 58 different

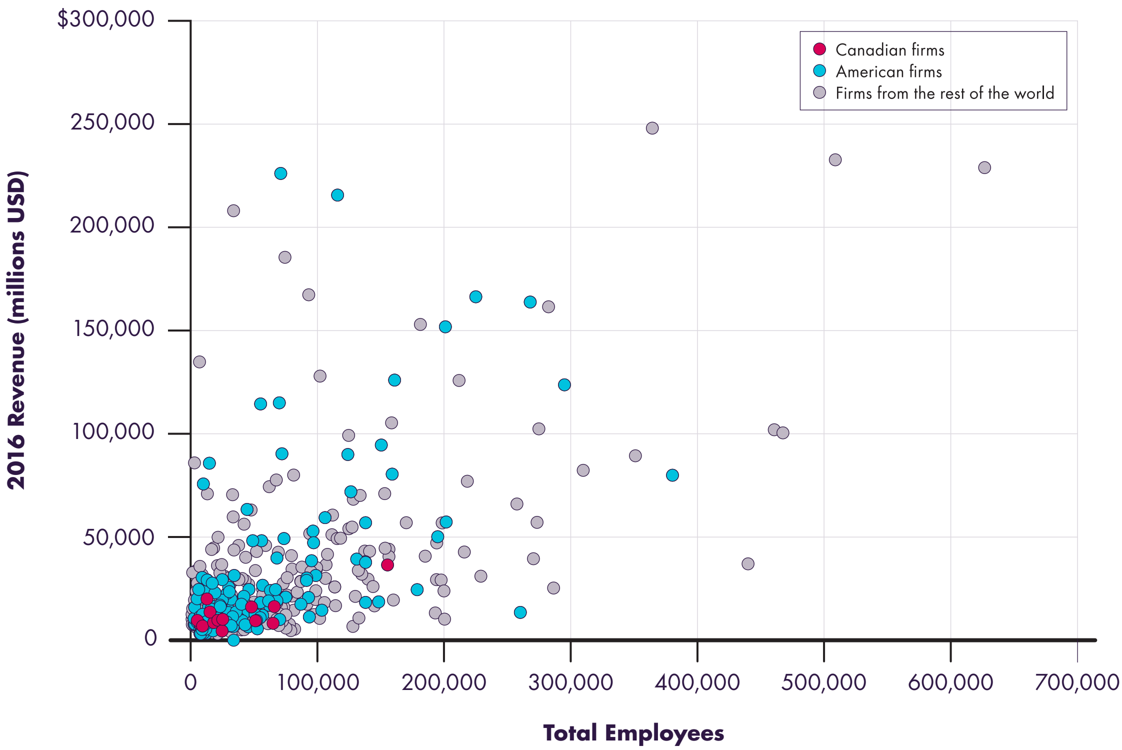


Figure 14: Global top 500 firms by employment and revenue

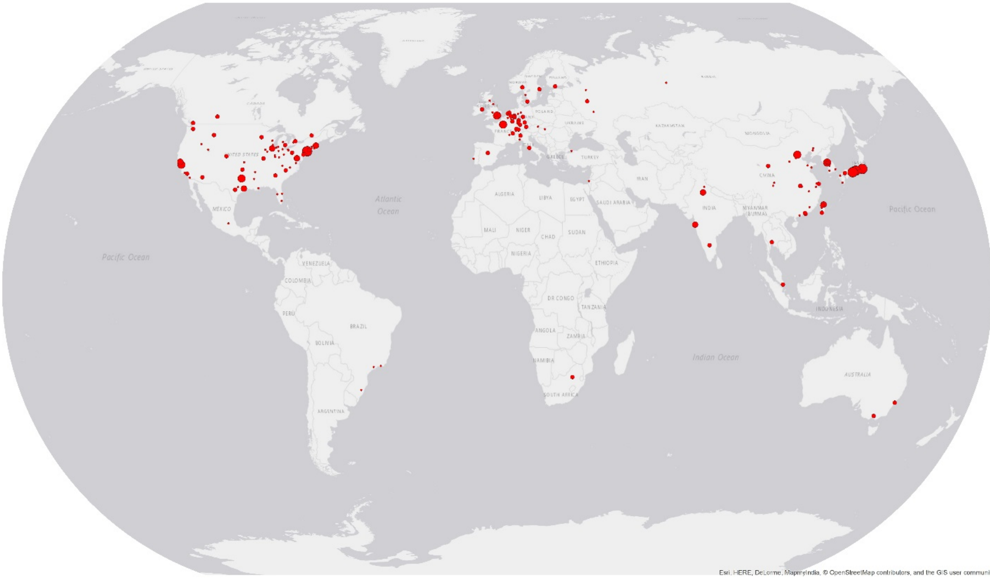


Figure 15: Advanced industry headquarter count by metro (top 500 companies)

metros. New York is the most common headquarter location with 21, followed by San Jose (13), Dallas (11), Houston (10), and Chicago (9).

Looking more broadly at corporate networks, the majority of establishments (68 percent) in Canada belong to a foreign-owned entity, affirming Canada's status as predominantly a branch-plant economy. A large share of Canadian-owned establishments are subsidiaries of the three large telecoms companies. When these are removed from the total, a mere 11 percent of advanced industry establishments are domestic. In comparison, 63 percent of U.S. establishments are American-controlled.

The branch-plant characteristic of the Canadian economy is further reinforced by the function of these establishments. Only 38 percent of establishments are performing core advanced industry functions (e.g., R&D, direct production, etc.), with the remainder conducting lower value-added activities, such as sales, marketing, maintenance, and logistics. By comparison, 54 percent of large-firm establishments in the United States perform core advanced industry functions. This emphasis on lower value-added activities may explain why Canada has maintained an advanced industry employment base while its advanced industry productivity growth has been dismal.

In addition to being more productive, meanwhile, large firms tend to export more and act as the main conduits of global networks and knowledge flows. Accordingly, large firms and their global connections may significantly influence the broader productivity of their home nations. On this front, the global footprint of large Canadian corporations in the advanced industries is heavily skewed towards the United States (see *Figure 16*). Large Canadian companies enjoy a moderate degree of presence in Western and Northern Europe but have a light footprint in all other major regions of the world. The lack of penetration into Asia is particularly notable and worrisome as it is the largest and fastest growing market and an increasing source of innovation, business models, and investment. There are also many Asia-

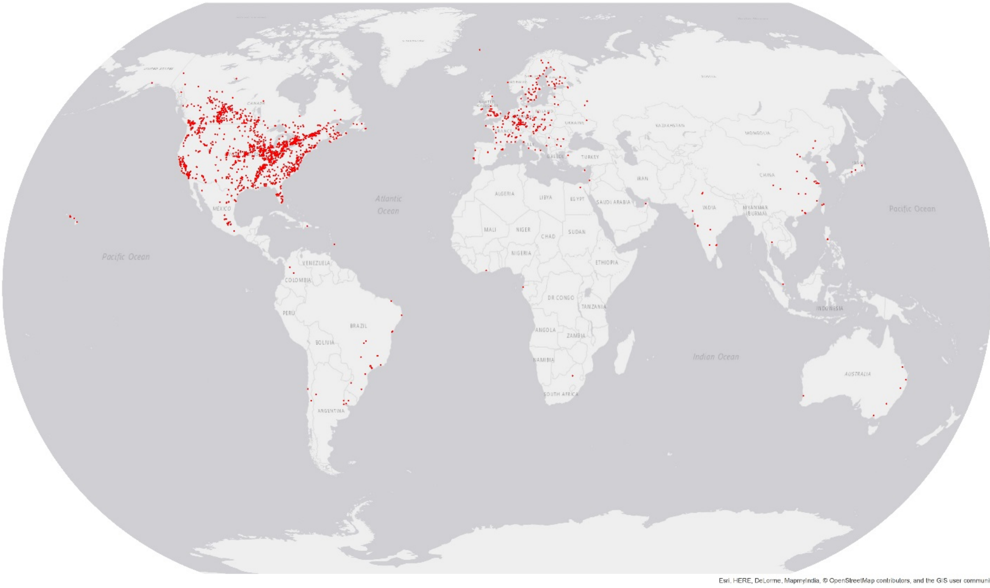


Figure 16: Location of establishments of Canada's top advanced industry companies

based companies with a significant presence in Canada, which highlights an imbalance in the advanced industries.

Figure 17 visually displays how the corporate networks of the world's 500 largest advanced industry firms concentrate in relatively few global hubs. Canada benefits from being situated within this global network, in contrast to the many places in the world that are almost entirely bypassed. Its network skews towards a few relatively strong connections to key U.S. regions, but only a few intercontinental linkages exist. It is clear that Canada does not occupy a central position in these global value chains.

Looking more closely at these patterns, Toronto is clearly the central node in the Canadian advanced industry network and the nation's main international hub. *Table 5* exhibits the metro pairings with the most number of parent-subsidiary business connections. Toronto retains by far the most connections. Furthermore, the majority of Toronto-based businesses are the parent establishment. The connection between Calgary and Edmonton is also strong, with the former being the dominant partner. Similarly, Montreal and Vancouver share many connections, with Montreal being primary.

A significant share of large firm connections in Canada never go beyond the border. Fully 82 percent of parent-subsidiary linkages occur between Canadian cities. Connections with Mexican and U.S. city-regions account for another 12 percent of linkages, leaving only 6 percent with intercontinental partners. Within the NAFTA region, Toronto has the most pairings with North American metros, led by New York, Boston, San Jose, Detroit, and Los Angeles. Overwhelmingly, the parent company is located in the U.S. metro, and the subsidiary is in Toronto. In all 49 parent-subsidiary linkages between companies in New York and Toronto, the parent resides in New York. This highlights the power imbalance between U.S. and Canadian metros and reinforces the message that Canada is largely a branch-plant economy.

There is a similar pattern with intercontinental connections. Nagoya-Toronto, Paris-Montreal, and London (UK)-Calgary are the top three intercity links. In each case the foreign metro is dominant.

The overall pattern of the top 500 global advanced industry corporations highlights the relatively weak position of Canadian metros in comparison to their U.S. peers. A geographic power imbalance leaves Canadian metros with a branch-plant identity characterized by low value-added activities. The small number and size of world-leading Canadian firms, in this regard, puts the country and its cities at a dis-

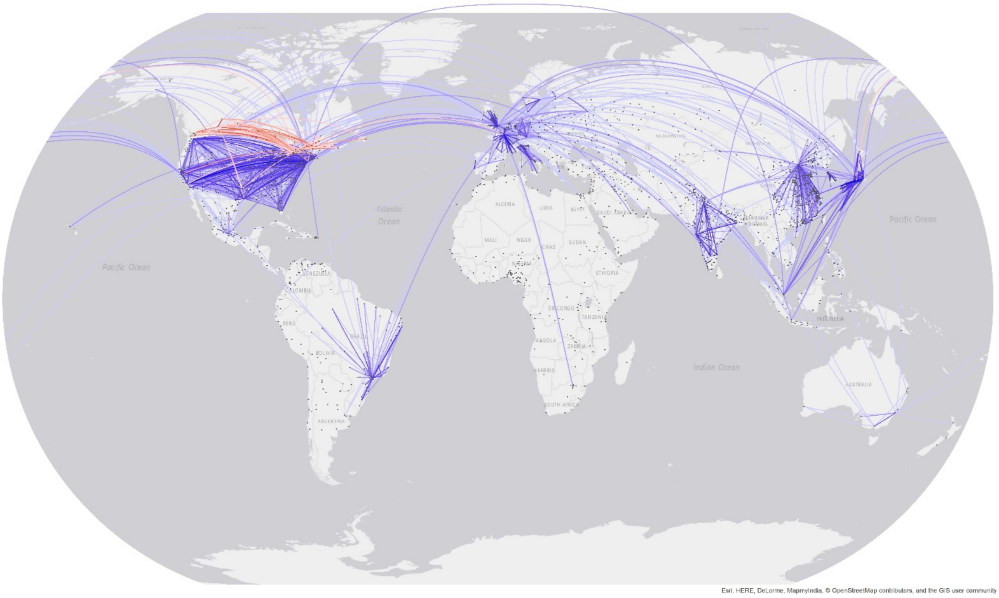


Figure 17: Global network of top 500 firms highlighting Canada

Top 10 Domestic Connections			Top 10 Continental Connections			Top 10 Intercontinental Connections		
#	Primary-Secondary	+/−	#	Primary-Secondary	+/−	#	Primary-Secondary	+/−
339	Toronto-Montreal	+85	49	New York-Toronto	+49	11	Nagoya-Toronto	+9
248	Toronto-Vancouver	+116	37	Boston-Toronto	+35	10	Paris-Montreal	+10
242	Toronto-Calgary	+8	23	San Jose-Toronto	+21	9	London (UK)-Calgary	+5
131	Toronto-Ottawa-Gat.	+105	20	Detroit-Toronto	+10	9	London (UK)-Toronto	+5
105	Calgary-Edmonton	+89	20	Los Angeles-Toronto	+20	8	Dublin-Toronto	+2
98	Barrie-Toronto	+58	19	Houston-Calgary	+11	8	Osaka-Toronto	+6
88	Toronto-Edmonton	+86	15	New York-Montreal	+3	8	London (UK)-Winnipeg	+6
77	Montreal-Vancouver	+37	14	Chicago-Toronto	+14	7	Montreal-Zurich	+1
73	Toronto-London (ON)	+69	13	Dallas-Calgary	+13	7	London (UK)-Montreal	+3
72	Toronto-Hamilton	+54	10	Dallas-Toronto	+8	7	Paris-Toronto	+7

Table 5: Top city pairings

Note: The +/- figures refer to the balance of companies' parent-subsidiary relationships. The dominant metro is listed first.

advantage in terms of their investment levels, organizational capacity, scale, power, and access to information. In that sense, the nation's paucity of large and dominant firms with global reach likely explains a portion of the nation's productivity lag.

Creating, building, and sustaining globally competitive advanced industry firms in Canada would therefore do a great deal to reverse these negative trends. In the next section we turn to the critical role of local innovation ecosystems in seeding these types of firms, but several important strategies exist for promoting greater scale and connectivity.

At the national level, a connectivity agenda will naturally implicate policies related to trade and foreign direct investment. As we discussed earlier, maintaining an open, competitive economy forces Canadian firms to up their game to compete with the world's best companies. Trade liberalization and trade enforcement are critical. Ottawa's participation in the ongoing renegotiation of the North American Free Trade Agreement (NAFTA) looms particularly large, given the significant reliance on the United States within advanced industry supply chains. Trade policies can also tap new opportunities for Canadian firms in less well-connected markets, especially Asia.

Large firms are an additional key source of global connectivity. While it is desirable for such firms to be homegrown and headquartered locally, foreign firms should also be welcomed. Closing off such opportunities also shuts down potential linkages that bring important knowledge and expertise to a region. Fear and avoidance of competition does not tend to lead to higher levels of productivity. Large firms in the advanced industries not only bring a pipeline of STEM knowledge, but are also sources of good management practices that have the potential to spill over into the local ecosystem.

Local and regional governments (especially small- to medium-sized metros) have limited resources and capacity to directly affect international relations. They often need to work with higher levels of government to impact any policy changes such as trade agreements, corporate tax rates, and the development of essential infrastructure such as airports. Another way is to work with local anchor institutions that have global reach. Top research universities are one type of anchor that can act as a conduit for global knowledge flows, which are necessary for keeping local advanced industry systems refreshed and at the leading edge.

Complexity and smart specialization

The previous section reveals that Canada needs to develop more globally connected advanced industry firms to power productivity growth and prosperity.

For firms to grow into large global champions they must master the technological complexity of the modern economy. To achieve this mastery, firms rely on the technological capabilities embedded in their surroundings. This is somewhat counterintuitive considering the advances in information and communication technologies that theoretically make working from anywhere possible, but evidence suggests that personal relationships, institutional anchors, and connective infrastructure continue to concentrate expertise and capabilities in specific locations.

Innovation does not occur just anywhere—rather there is a strong geography of knowledge. Patenting rates, one rich metric of technological inventiveness (see *Appendix B*), vary widely across different metropolitan regions (*Figure 18*). This reflects the fact that there is a geography to knowledge and innovation that favors places with strong talent pools, a range of companies, effective institutions, and efficient infrastructure.[23] The number of patents are highly correlated with the number of people working in advanced industries, as the sector is responsible for the vast majority of technological innovation. Most Canadian metros are below the trend line, meaning that on a per capita basis technological innovation occurs at significantly lower rates. To give another idea of the scale of technological innovation in the U.S. compared to Canada, from 2011 to 2015, San Francisco and San Jose combined to produce 71,000 patents, while during the same period, all 33 Canadian metros together generated just 17,000 patents.

The simple volume of patenting activity, however, does not tell the whole story of a region's innovative capacity Some technologies are more valuable than others. Some combinations of technologies are more fruitful than others. Some patents are more common than others in the overall North American system. So if a region possesses technological strengths in areas that are relatively rare, it has an advantage over others that tend to possess more average profiles. Not only does such a region have additional strengths, but it will likely be in a position to produce new combinations of technologies using local assets that most of its peers lack.

A regional economy's technological "complexity," in this respect, takes into account the range of innovation in each metro by capturing the relative rarity of the types of patents being produced. Metro areas that have the ability to produce more novel combinations can be said to possess more technological complexity than metros with relatively few or common strengths, with the implication being that technological complexity stands as an important characteristic of high-potential economies.

Figure 19 outlines a practical example of these concepts. The diagram on the left show three categories of technology: biotechnology, information technology, and nanotechnology. A region that has existing strengths in biotech-

Figure 18: Patents counts (2011–2015) and advanced industry employment

nology and information technology is in a good position to combine both to participate in the field of "applied bio systems genomics," whereas regions that do not have such existing assets are unlikely to be competitive in this emerging field. In like fashion, the center of the diagram is labeled "genechip," representing a combination of all three areas of technology. This demonstrates that by possessing more technological strengths that can be combined in novel ways, an economy enjoys an exponentially greater number of potential development pathways.

The diagram in the panel on the right, meanwhile, begins to illustrate how the technological complexity of regions can be measured through what Kogler, Rigby, and Tucker have called the "knowledge space."[24] As patents are classified according to technology type like biotechnology, information technology, and nanotechnology, the number of patents per category gives us an understanding as to which technologies are more common than others. The first step in crafting a knowledge space, therefore, involves producing patent counts by technology type for all of North America (*Figure 20*).

Figure 20 tracks the overall technological evolution of the North American knowledge space in five-year intervals from 1981 to 1985 up to 2011 to 2015. Each disc represents a specific category of technology as defined by the patent classification system. The size of the disc represents the number of patents in each category. The color displays the general category of technology. The relative position of each disc is based on how closely they are related to other technologies based on how often they appear as on individual patent records together. Using this information we can see that in the period from 1981 to 1985, there was a relative balance in the main categories of patents between electronics, instruments, chemistry, and industrial processes. There is a fairly similar pattern from from 1991 to 1995 before we start to see the beginning of significant change in the 2001 to 2005 period. By this time, electronics is becoming the dominant type of technology being invented, with instruments, drugs, and pharma also remaining key, while the other categories have fallen off in significance. This trend continues into the most recent period which sees electronics as the leading type of invention.

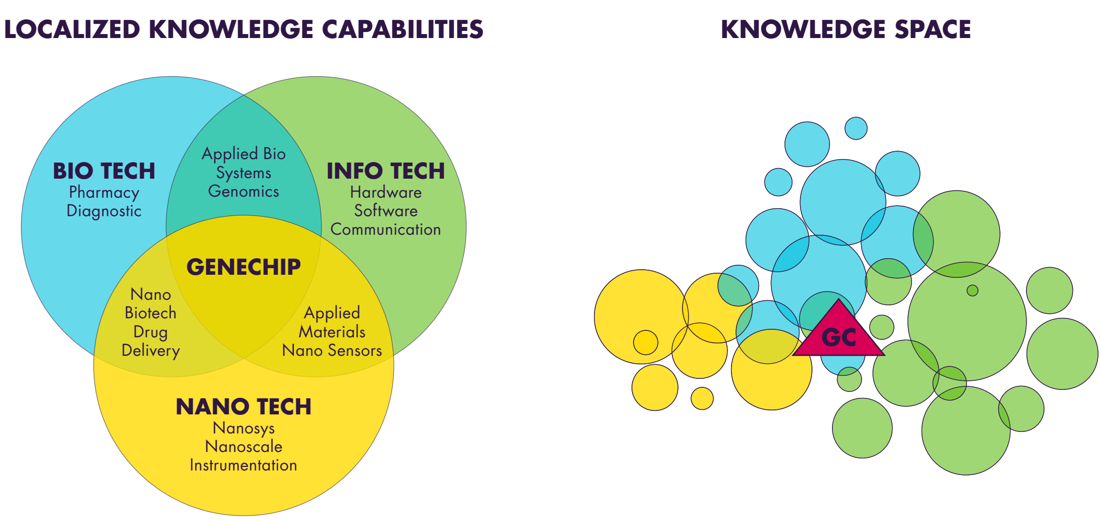


Figure 19: The knowledge space methodology

Source: Kogler D. F. & Tucker I. (2013) Mapping Knowledge Space and Technological Relatedness in US Cities, European Planning Studies

This overall profile is then used as a benchmark to compare metro-level technological capabilities. For example, if "Technology X" represents 2 percent of all North American patenting, but 4 percent of patents in "Metro A", then "Metro A" can be said to be relatively specialized in "Technology X". This is repeated for all technologies and all metros.

All metros will have areas of specialization within the "knowledge space," but the placement in the hierarchy will depend on both the quantity and quality of patents produced. Some technologies contribute more to others and therefore offer more potential value. Patents that received a large number of co-classifications across a wider array of categories are taken into account when assessing the overall technological portfolio of a metro.

This combination of quantity and quality can be expressed through a knowledge complexity score. *Figure 21* ranks all of the Canadian and U.S. metros according to knowledge complexity. The larger graph highlights a subset of Canadian regions while the smaller one gives an indication as to the position of comparator U.S. metros. While the three largest Canadian metros (Toronto, Montreal, and Vancouver), score reasonably well, ranking in the 40s, it is the two smaller and more specialized regions, Ottawa-Gatineau and Kitchener-Waterloo, which stand out by placing in the top 10 among North American regions. This puts them in the upper echelon of North American metros, behind Silicon Valley and Austin but ahead of Boston and New York.

These two regions are known for having well-developed innovation ecosystems supported by strong local institutions. They are also the two regions that have produced the two most

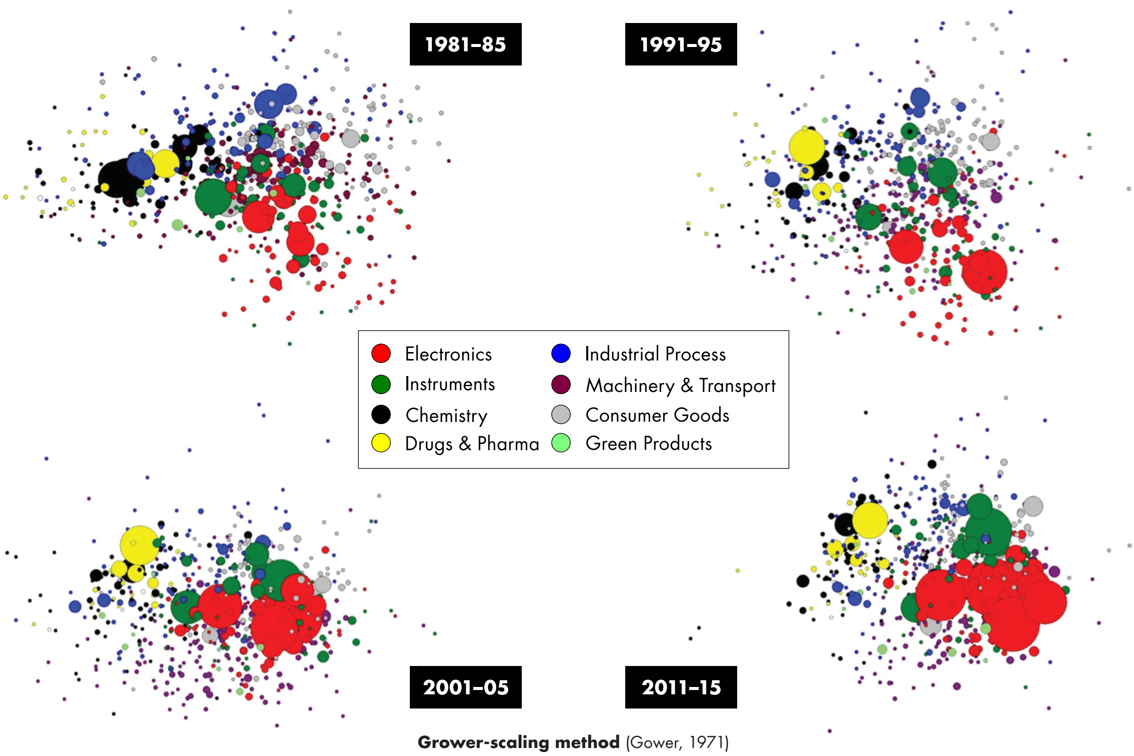


Figure 20: The evolution of the North American knowledge space

successful high-tech global firms, Nortel and Blackberry. While the former has gone bankrupt and the latter is a shadow of its former self, both ecosystems have displayed tremendous resilience. Ottawa-Gatineau possesses many global firms such as, Cisco, Ericsson, Alcatel Lucent, and Nokia, that have absorbed much of the talent and innovative capacity generated by Nortel. In Kitchener-Waterloo, the startup scene is robust and has produced many rising stars such as OpenText, D2L, and Thalmic Labs. It does beg the question, however, as to what might have been for these regions if both companies had continued to be world leaders. This analysis shows that Canadian metros can excel in producing knowledge, but continue to struggle to fully capitalize on their talents.

Beyond issuing an overall metric of complexity, the knowledge space methodology helps to identify areas of technological strength within local economies. And since a region's ability to create new technologies largely depends on its particular historical capabilities, it becomes possible to predict the types of technology that will be invented going forward in a region by taking stock of a region's current knowledge space. Which is why new work in economic geography and complexity studies opens important new perspectives—and actionable insights—for economic development in Canada.

To see how such a process may unfold, consider the changing knowledge spaces of Montreal, Vancouver, and Kitchener-Waterloo. *Figure 22* shows the technological evolution of the Montreal metropolitan region from the period 1991 to 1995 to the 2011 to 2015 period. The small black and white diagrams highlight (in black) the patent categories in which Montreal has a

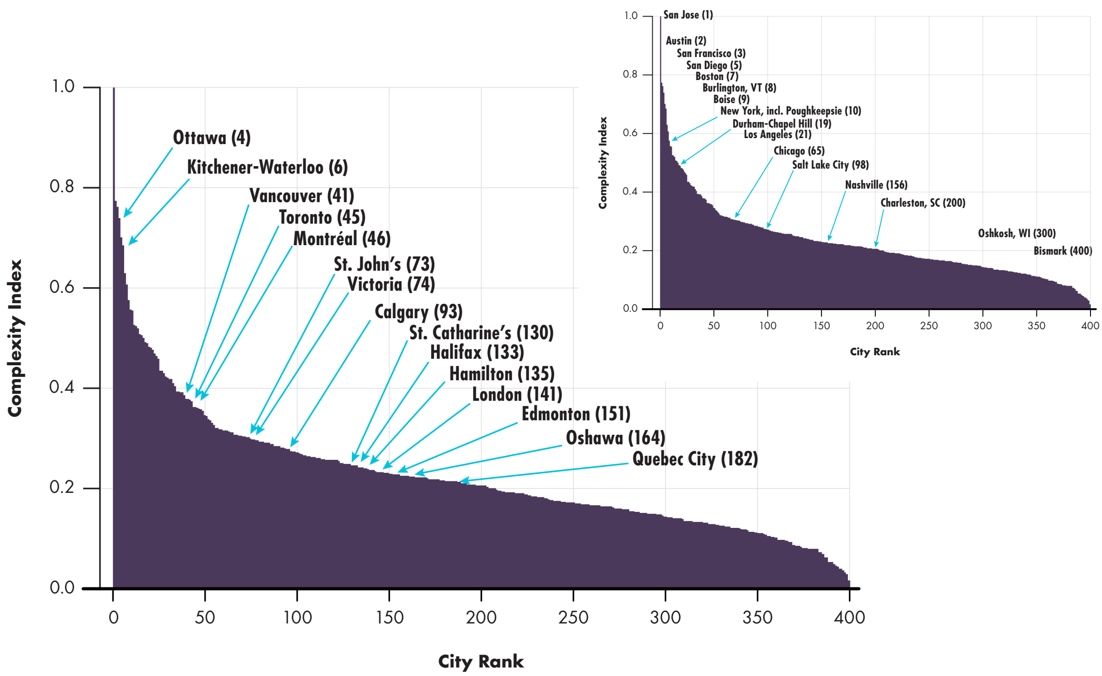
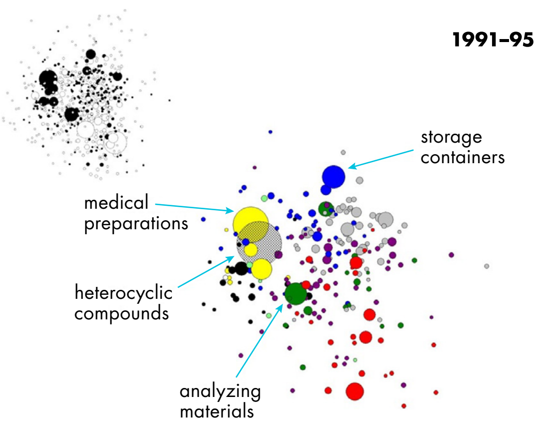


Figure 21: Metropolitan knowledge complexity, 2011–2015

relative advantage (greater prevalence locally than in North America as a whole). In the larger color diagrams, only these patent categories are displayed. In addition, the number of patents are represented by the size of the disc, while the color indicates the general technological category. The tables on the right show the top five categories of patents for Montreal for the two time periods.

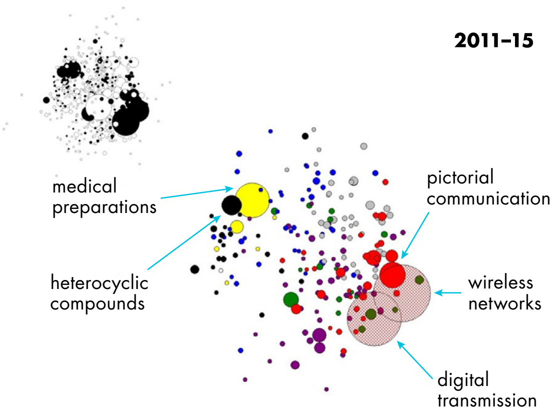
Much has changed. In the period from 1991 to 1995, Montreal's predominant science and technological specialization was in pharmaceuticals. There were also signs of strength in industrial processes, instruments, and electronics. Patenting rates were modest, with 30 to 80 patents for the top five categories. By the 2011 to 2015 period, the technological specialization of Montreal had evolved to see electronics become the predominant category of invention. Pharmaceuticals remained notable while other previous areas of strength diminished somewhat. Machinery and transport also witnessed a slight uptick, likely due to the development of the aerospace industry. Patenting rates for the top categories increased, but by no means dramatically so. This analysis demonstrates that in addition to areas of identified strength, there may be opportunities in Montreal to pursue innovation at the intersection between electronics and the life sciences.



Key Technology Classes in Montreal

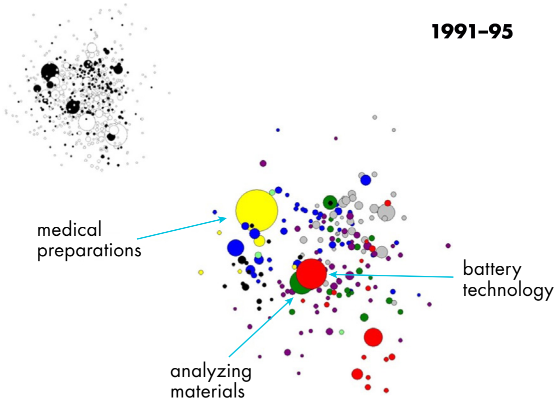
(where RCA > 1)

	1991–95	
CPC Code	**Name**	**# Patents**
C07D	heterocyclic compounds	80
A61K	medical preparations	63
B65D	storage containers	38
G01N	analyzing materials	36
C07K	peptides	34



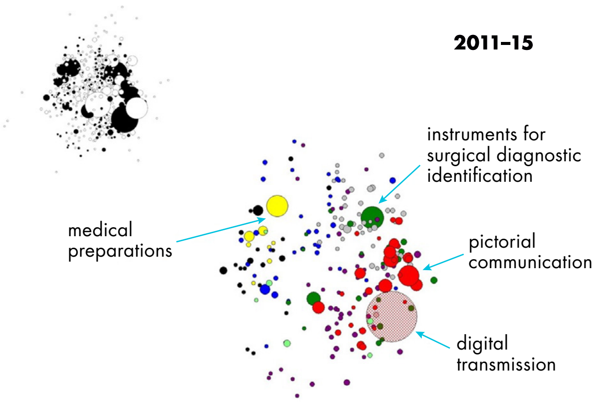
	2011–15	
CPC Code	**Name**	**# Patents**
H04W	wireless networks	147
H04L	digital transmission	137
A61K	medical preparations	84
H04N	pictorial communication	60
C07D	heterocyclic compounds	43

Figure 22: The evolution of Montreal's knowledge space



Key Technology Classes in Vancouver
(where RCA > 1)

	1991–95	
CPC Code	Name	# Patents
A61K	medical preparations	62
H01M	battery technology	44
G01N	analyzing materials	33
H04L	digital transmission	24
A63B	peptides	23



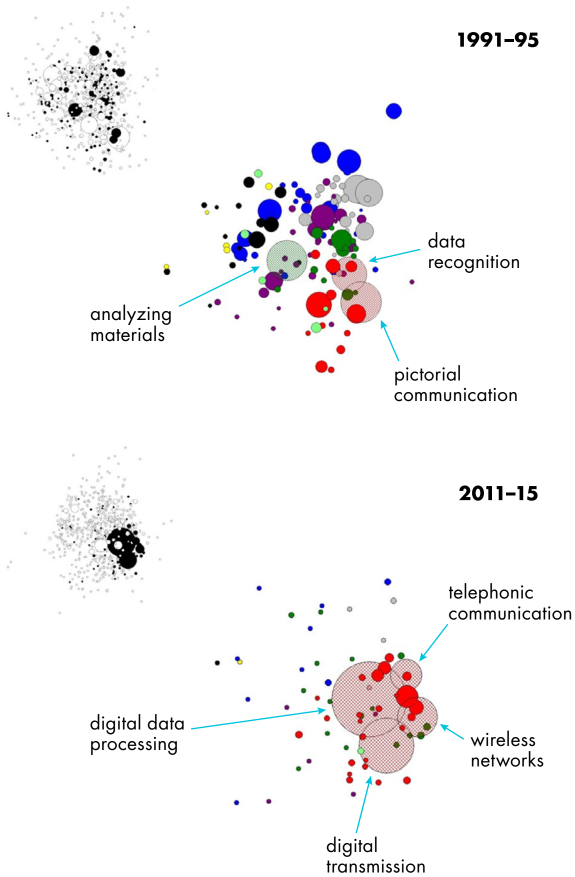
	2011–15	
CPC Code	Name	# Patents
H04L	digital transmission	182
A61B	surgical diagnostic identi-fication	72
A61K	medical preparations	67
H04N	pictorial communication	67
G06T	image data processing	42

Figure 23: The evolution of Vancouver's knowledge space

Vancouver, for its part, has historical strengths in life sciences, industrial processes, and digital technologies. Battery technology was the second most common technology category in the early 1990s, likely due to dynamism around fuel cells. While receiving a lot of attention at the time, it has not lived up to the previously ascribed promise. By the period from 2011 to 2015, most of the same broad strengths continued but with digital technologies taking over the top position. Surgical diagnostic identification emerges as the second ranked patent category, suggesting that there may already be some synergies between the life sciences and electronics industries. Patenting rates of the top categories have roughly doubled since the early 1990s, though this growth is uneven on a technology-specific basis.

The Kitchener-Waterloo region, finally, has experienced arguably the greatest amount of change over the past 25 years. The University of Waterloo is well-known for turning out top computer science graduates, many of whom have created successful companies. A less known fact about the region is that it historically had an extremely diverse economic base, ranging across many manufacturing industries such as automotive, machinery, and food processing. This is reflected in Kitchener-Water-

Key Technology Classes in Kitchener-Cambridge-Waterloo
(where RCA > 1)



	1991–95	
CPC Code	**Name**	**# Patents**
H04N	pictorial communication	12
G01N	analyzing materials	12
G06K	data recognition	10
A47C	vehicle seats	8
A63B	sports aparatus	8

	2011–15	
CPC Code	**Name**	**# Patents**
G06F	digital data processing	481
H04L	digital transmission	347
H04W	wireless networks	243
H04M	telephonic communication	183
H04N	pictorial communication	122

Figure 24: The evolution of Kitchener-Waterloo's knowledge space

loo's patent profile from the 1991 to 1995 period which shows a broad array of technologies as relative strengths, including vehicle seats and sports equipment. By 2011 to 2015 this changed considerably with an intense specialization in digital technologies. Patenting rates exploded in quantity with an overall growth of 353 percent. Much of this growth can be attributed to Blackberry (formerly RIM), which at its peak, was a true global champion in the telecommunications equipment industry. While still active, it is not turning out the same amount of innovation as it was in its prime. The region has continued to do well despite the challenges that Blackberry has faced, however. Much of this resiliency is due to targeted investments made that support the overall regional innovation ecosystem, especially ones relating to talent generation and incubation. This has led to a healthy amount of local startup activity as well as the attraction of globally significant firms. The current state of technological innovation involves a more specialized base, but a wider range of companies.

The Link Between Scale, Connectivity, and Complexity

The scale of a regional economy and the extent of its connectivity to the rest of the world has implications for its ability to produce new innovations. This dynamic bridges our discussions of scale, connectivity, and complexity.

When it comes to technological innovation in cities, scaling is not a just a function of the number of people and companies within metro areas, but a function of the number of possible combinations between them.[25] This reality exists because most technological innovation comes from combining existing technologies in new and valuable ways.[26] In practice, this means people with different but complementary skill sets interacting and learning from one another.

While regions such as Ottawa-Gatineau have relatively successful innovation ecosystems, Canadian metros typically lack the scale of their U.S. peers. *Figures 25* and *26*, along these lines, compare the inventor networks of San Jose and Ottawa-Gatineau. The first set of diagrams displays all of the inventors (red dots) in each region and all of the collaborative relationships between them (grey lines) as measured by instances of co-inventions. In most cases, instances of co-invention are a reflection of intra-firm networks. In other words, people tend to work together on technological innovations within firms rather than between them. Thus, the higher number of interconnections in the San Jose example relative to Ottawa-Gatineau is partially a reflection of the existence of more large companies that frame inventor networks.

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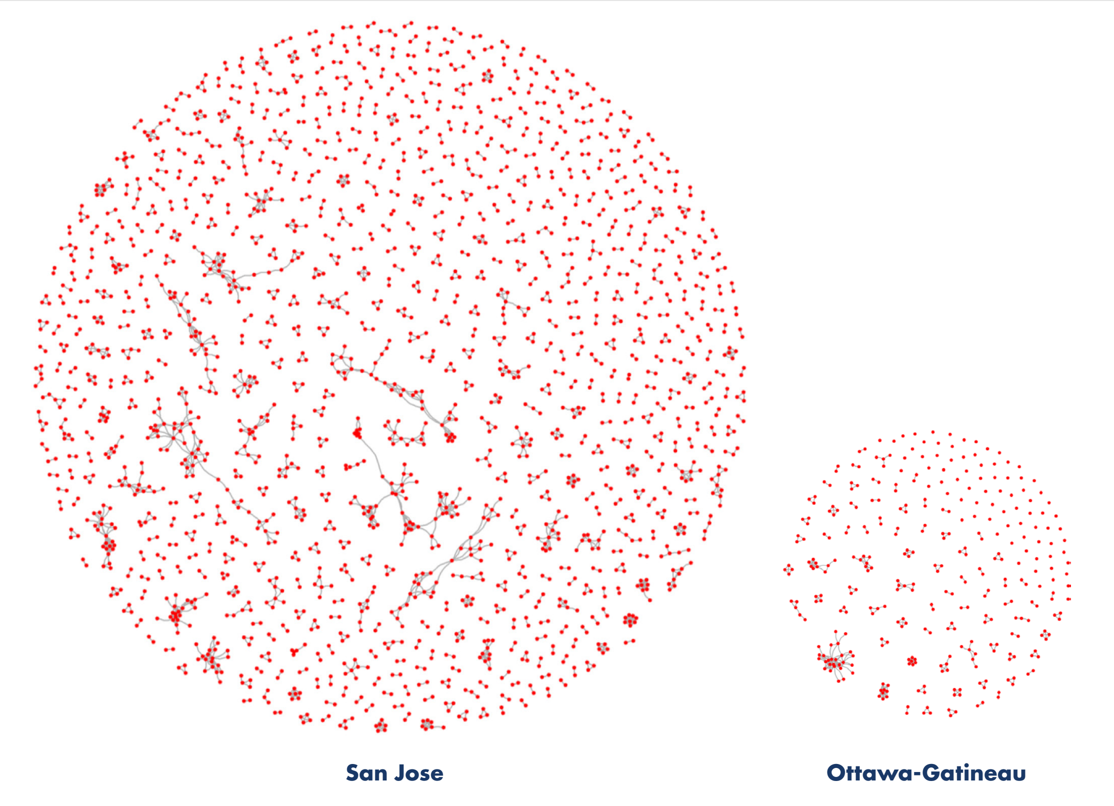


Figure 25: Intra-regional inventor networks of San Jose and Ottawa-Gatineau

Figure 26 builds on the previous diagram by including inter-regional inventor relationships. The red dots represent local inventors and the blue dots represent inventors in other metros that have a local collaborator. The grey lines represent instances of co-inventing on patents. This diagram gives insights into the non-location connections and the wider net that is cast. When searching for new and valuable information, looking elsewhere is often required as local places are specialized. For this reason, having more connections to other places becomes a significant advantage. The picture below shows that the San Jose metro, relative to Ottawa-Gatineau possesses, exponentially more inter-regional inventor relationships. As discussed previously, much of this is owed to the presence of large companies that are centered in Silicon Valley.

These static diagrams do not capture the full picture as people change companies and move locations. And when they do, they take their knowledge with them and create new combinatorial possibilities. These pictures do, however, give a sense of the robustness of the two regional ecosystems whereby San Jose is significantly stronger. The connections between metros are ultimately formed by the interaction and collaboration between individuals. In the case of inventors with advanced industries, these relationships are often organized within large global firms. There is evidence that suggests that as firms grow and expand globally, R&D functions remain close to the center of the network. For metros to lead in technological innovation, it is imperative that they have mechanisms that tap into global knowledge flows. Large advanced industry firms—with their extensive webs of connection—are a key component of this process.

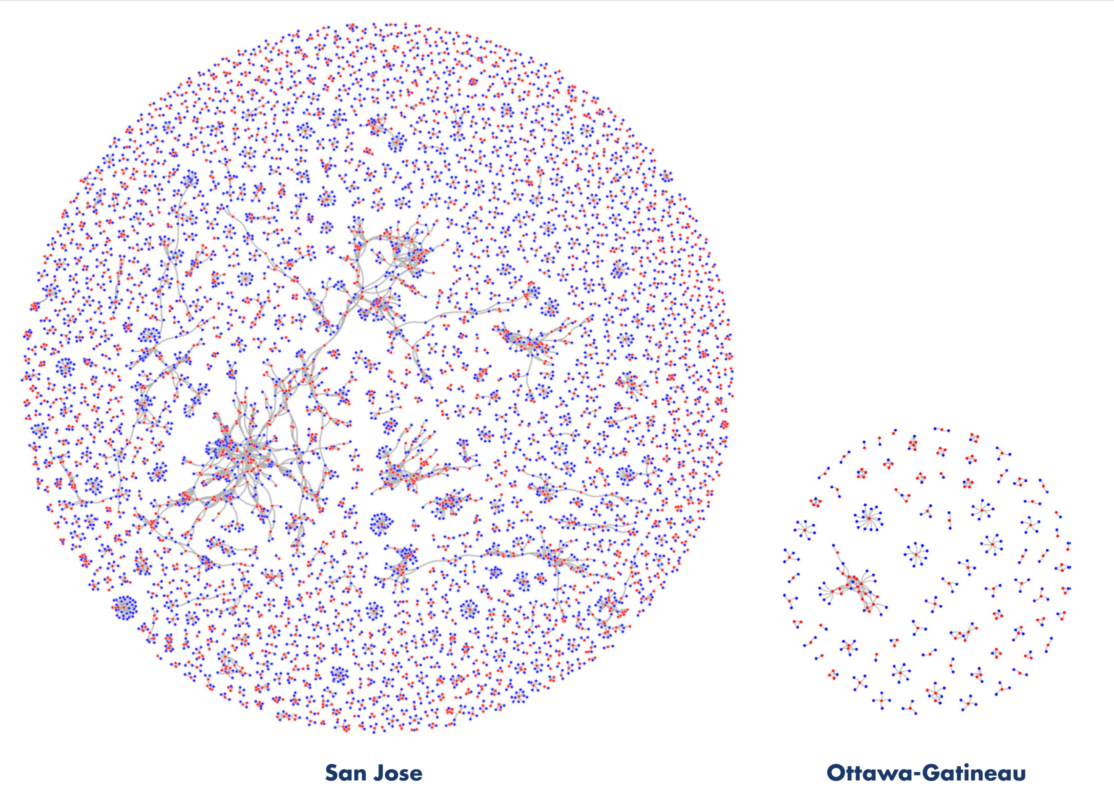


Figure 26: Inter-regional inventor networks of San Jose and Ottawa-Gatineau

The knowledge space approach to regional analysis points directly to “smart specialization”—the development of data-informed priorities for implementing focused economic development based on existing local capabilities.

Smart specialization is the current regional development model favored by the European Commission.[27] This strategy entails concentrating public investment based on identified areas of local strength. The knowledge space methodology, in this regard, is specifically designed to aid in the identification process. While many stock-taking regional profiling exercises have been used in this way in the past, the knowledge space methodology provides the advantage of offering predictive analytics that identify probable areas of future strength, based on data. In this regard, while there is general agreement on what makes for a robust ecosystem that supports the advanced industries—factors like a strong education system, top-ranked research universities, startup and scale-up incubators, venture capital, quality urban environments—none of these things come cheap, so it is important that they are done as efficiently as possible.

This is where smart specialization stands out as a useful strategic framework in its ability to focus and align the various elements of the ecosystem on the particular parts of the local economy that offer the greatest potential. In that fashion, smart specialization works as a methodology for maximizing a region’s chances of catalyzing high-value growth by orienting interventions toward the most promising and complex zones of economic activity.

In addition to regional and provincial strategy development related to innovative growth, smart specialization has the potential to inform federal efforts. For instance, the Canadian government’s “supercluster” initiative is soliciting a competitive bid process whereby consortia of large and small advanced industry businesses in addition to higher education institutions join together to commercialize a strategic area of technology. Smart specialization is one framework that could organize the coordination of these institutions around informed technological bets.

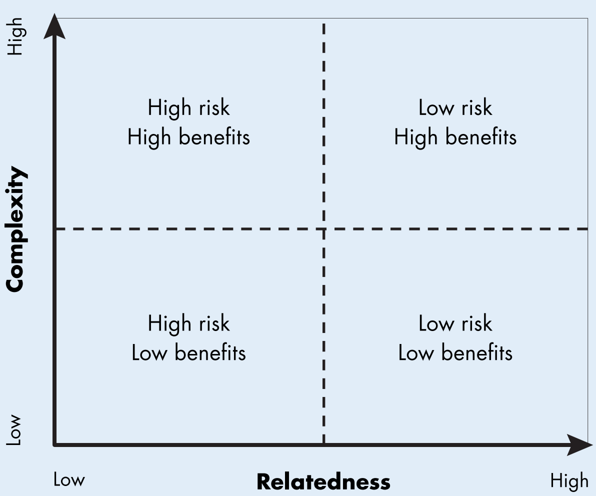
Canada is a highly regionalized country. National and provincial policies have varying impacts on regions depending on their local characteristics. A coordinated smart specialization program needs to start at the local level by identifying community-based strengths, before setting out to build on them. Crucially, the knowledge space methodology not only identifies local strengths, but also suggests possible synergies between them that offer the potential to create new pathways of development. The public sector can play a convening role between private sector players that may not be fully aware of the opportunities in the ecosystems that they inhabit. With new highly disaggregated sources of data in addition to advanced analytics, it is now possible to not only identify these broad structural opportunities but to identify and evaluate the strengths of firms and individual inventors. Governments need to be aggressively pursuing these new data and analytic tools in order to properly inform a complex set of regional development policies.

Smart Specialization and its applications to Canadian regions

Europe has focused more on tailoring regional development policies to local circumstances than have Canada and the U.S. Currently, Smart Specialization is one of the central features of such an approach within the European Union. Smart Specialization is fundamentally about building upon a region's strengths. In practice, this means identifying key industries and providing specific infrastructure, regulation, and additional supports that will help local companies compete in the global marketplace.

An important dimension of this strategy is using analytical tools to identify and evaluate potential areas of local expertise and specialization, particularly in science and technology domains. One approach uses patent data in order to detect the most promising areas of technology innovation that exist within regional economies. The rate and direction of technological progress is one of the best predictors of long-run economic prosperity. Patents are considered the best way to measure technological innovation, especially at the regional level.

Along these lines, Crespo and others (2017) have developed a methodology for using patent data for the purpose of developing regional Smart Specialization strategies. (See Appendix B for background on the advantages of employing patent data for this purpose.) This methodology analyzes patent data for regions on three dimensions: a) the amount of patenting by technology type; b) the complexity of technologies; and c) the relatedness of technologies within the local economy. The first aspect involves identifying local strengths based on what types of technologies are produced in greater amounts in the local economy relative to the overall economy. For Canadian purposes, this means assessing Canadian regions' specific technological strengths relative to all other regions in the U.S. and Canada. Once these strengths are identified, their overall economic potential is evaluated along the two dimensions of complexity and relatedness. Complexity refers to the extent to which a technology class is found to combine with other types of technologies. "Platform" technologies are ones that provide knowledge inputs to many additional technologies. Ones that have broad application across many sectors of the economy tend to have the most value. Thus, technologies that are more "complex" offer more potential benefit. Relatedness is a measure of how congruent a technology is with additional areas of local strength. The thinking behind this measure is that technologies that are most compatible with the local technological profile also have a better chance of succeeding. These dimensions are summarized in the figure below. The goal is to identify technologies that are found in the upper-right quadrant as they offer the greatest potential reward while facing lower levels of risk.



Source: Crespo, J., Balland, PA., Boschma, R. & Rigby, D. (2017) Regional Diversification Opportunities and Smart Specialization Strategies. *European Commission Directorate-General for Research and Innovation.* Brussels. doi: 10.2777/13373.

Turning from theory to practice, the key point is that patent data from the USPTO gives policymakers the ability to measure technological strength in Canadian metropolitan regions in relation to all others. This provides a way to assess the best opportunities to mount a local Smart Specialization approach in a particular region.

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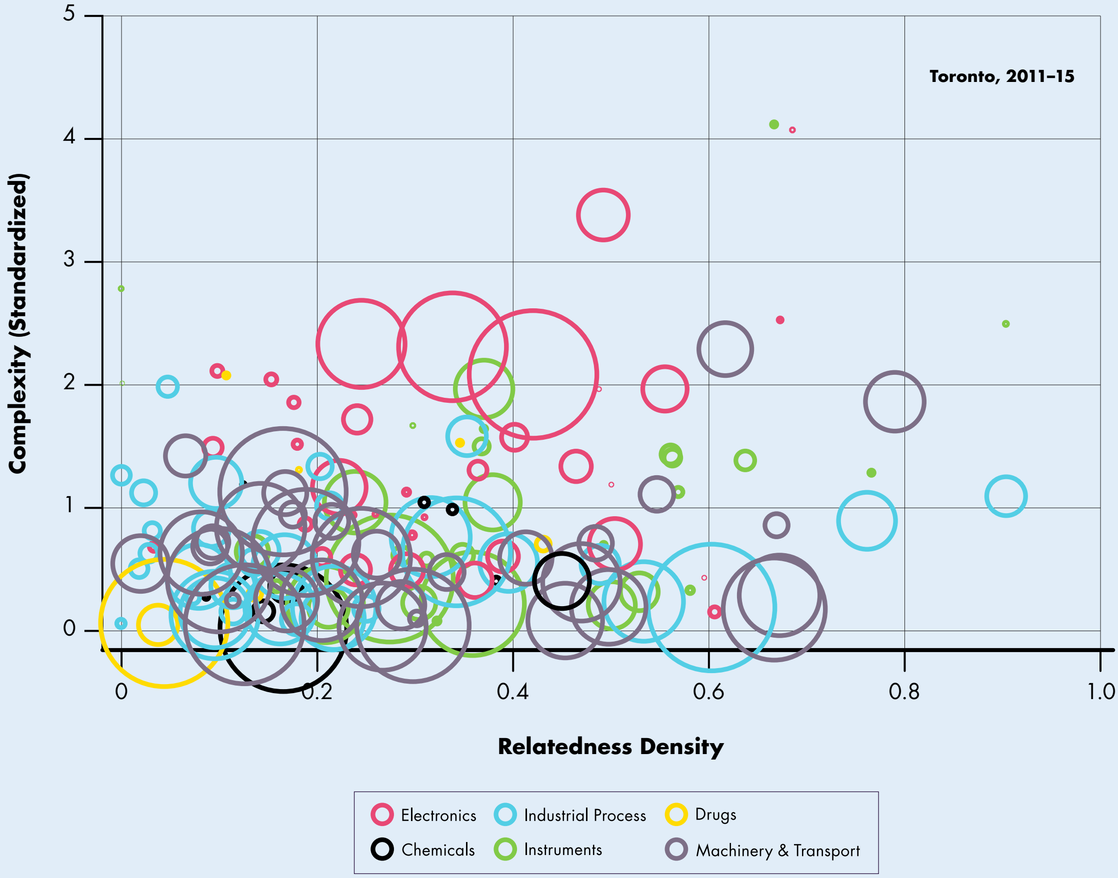
To see how this might work in Toronto, see the figure below, which highlights the technologies developed in the Toronto Census Metropolitan Area between 2011 and 2015. Each circle represents a specific technology class. The size displays the amount of patenting while the color indicates the general technology category. Complexity is measured on the y-axis, while relatedness is accounted for on the x-axis. Together the data suggests that there are particular areas of technological strength in Toronto within the region's electronic, machinery, and transport domains that have the greatest potential to generate further technological progress and innovation.

Specific technologies such as G04R, radio-controlled time-pieces; G06J, hybrid (part digital and part analogue) computing arrangements; G11C, static storage devices; and H03C, modulation, are highlighted examples that possess strong complexity values and are highly related to Toronto's existing capabilities, but are not yet large enough to be considered relative comparative advantages. These traits suggest that the named technologies offer the greatest growth opportunities within the region. As patent data is fully disaggregated in this way, it not only enables the identification of key technological trends in the region, but can also be used to highlight specific firms and key individuals that are most active in producing them. In this way, quite detailed Smart Specialization policies can be crafted in regions and applied to initiatives such as the federal "Supercluster" strategy in order to help evaluate and support top performers in local economies across the country.



Note: Miscellaneous & crossover categories omitted

* * * * *

Ultimately, this report argues that Canadian prosperity depends on boosting the productivity of the nation's regional and national advanced industry clusters.

In some regions, the sector is deep, vibrant, and quite competitive even with key U.S. concentrations; in others it is less so. In all places (and this is the core problem), the Canadian sector is struggling with subpar productivity, with ramifications that promise slower growth and a declining standard of living for Canadians in the absence of renewal.

Going forward, then, Canada's private, public, and civic sectors must work together in new ways to respond to fundamental deficiencies of the nation's advanced industry environment, including, as they pertain to the nation's competitive mindset, its limited power in global value chains and the thinness of many of its technology networks.

Canada's advanced industries are a critical anchor of national prosperity. To reverse the nation's declining standard of living, Canada needs to boost these industries' productivity in support of expanded prosperity.

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Appendix A

Top Advanced Industry Companies by Sub-Sector

ENERGY & MINING		**TRANSPORTATION EQUIPMENT**	
PetroChina	China	GE	United States
Exxon Mobil	United States	Boeing	United States
Oil & Natural Gas Corp.	India	Airbus Group	Netherlands
BP	England	United Technologies	United States
Glencore	England	Lockheed Martin	United States
METALS & MATERIALS		**ICT MANUFACTURING**	
ArcelorMittal	Luxembourg	Apple Inc.	United States
ThyssenKrupp	Germany	Samsung Electronics	South Korea
POSCO	South Korea	Hon Hai	Taiwan
Nippon Steel & Sumitomo Metal	Japan	Hitachi	Japan
Shougang Group	China	Intel	United States
CHEMICALS		**TELECOMMUNICATIONS**	
BASF SE	Germany	AT&T	United States
Dow Chemical	United States	Verizon	United States
ChemChina	China	NTT	Japan
Mitsubishi Chemical Holdings	Japan	China Mobile Communications	China
LyondellBasell	Netherlands	Comcast	United States
MACHINERY		**DIGITAL SERVICES**	
Caterpillar	United States	Alphabet Inc.	United States
Mitsubishi Heavy Industries	Japan	Microsoft	United States
CNH Industrial N.V.	United States	IBM	United States
Deere	United States	Sony	Japan
Komatsu	Japan	Hewlett Packard Enterprise	United States
ELECTRICAL EQUIPMENT		**LIFE SCIENCES**	
Mitsubishi Electric	Japan	Pfizer	United States
ABB	Switzerland	Roche	Switzerland
Schneider Electric	France	Novartis	Switzerland
Philips Electronics	Netherlands	Bayer AG	Germany
Whirlpool	United States	Merck	United States
AUTO MANUFACTURING		**STEM SERVICES**	
Toyota	Japan	SK Innovation	South Korea
Volkswagen	Germany	China Electronics Corporation	China
General Motors	United States	Fluor	United States
Daimler	Germany	AECOM	United States
Ford Motor	United States	Hyundai Engineering & Const.	South Korea

Appendix B
The Advantages of Patent Data

Patent data can provide a wealth of information about technology, people, companies, and places. As the data is public and fully disaggregated, it offers deep insights into how technological change occurs. Patents are classified according to the type of technology. Virtually all new technologies involve previous knowledge from existing technologies. This is reflected by citations to older patents. From this we can tell which technologies (and individual patents) have provided the foundation for current innovations. We can also know who is specifically responsible for the innovation as patent records are filed by individual inventors. Most patents have multiple inventors, which signals the cooperative relationships between inventors. Patent records also include information on which companies or research organizations (e.g., universities) inventors work for. Patent records also tell us where inventors reside. From this we can understand which technologies are invented where, and in the cases where co-inventors reside in difference places, we can gain an understanding of knowledge flows between locations. The entire local stock of patents in any given time period enables us to create a portrait of a region's technological capabilities. All patents records include date stamps that reflect when the patent was applied for and when it was granted, so we can track the evolution of technologies and the capabilities of places over time.

Endnotes

1 See Mark Muro and others. (2015). *America's Advanced Industries: What They Are, Where They Are, and Why They Matter.* Washington: The Brookings Institution. Methodology appendix available at www.brookings.edu/wp-content/uploads/2015/02/Advanced-Industries-Data-and-Methods-Appendix.pdf

2 This is not to say that industrial structure has zero impact on productivity. Indeed, in the post-2000 period the relatively greater decline in the Canadian manufacturing base compared to the United States helped widen the labor productivity gap between the two countries. See Tang, J. (2017). Industrial structure change and the widening Canada-U.S. labor productivity gap in the post-2000 period. *Industrial and Corporate Change, 26*(2), 259–78.

3 Sharpe, A. (2003). Why are Americans more productive than Canadians? (No. 2003-03). Centre for the Study of Living Standards. Sharp (2003) also identified lower R&D expenditures, lags in technological diffusion, and limited economies of scale and scope as significant contributors to the observed Canada-U.S. productivity gap.

4 Rao, S., Tang, J., and Wang, W. (2004). Measuring the Canada-US productivity gap: Industry dimensions. *International Productivity Monitor, 9,* 3–14. Industries in which Canada had a capital intensity advantage vis-à-vis the U.S. were likewise found to be those in which it also had a labor productivity advantage.

5 Currie, B., Scott, L. W., and Dunn, A. W. (2011). The future of productivity: An eight-step game plan for Canada. Future of Canada. Deloitte.

6 Kirby, J. (2016, December 12). *75* charts every Canadian should watch in 2017. *Maclean's*. Retrieved from www.macleans.ca/economy/economicanalysis/75-charts-every-canadian-should-watch-in-2017/

7 Harchaoui, T. M., and Tarkhani, F. (2004). Whatever Happened to Canada-US Economic Growth and Productivity Performance in the Information Age? Statistics Canada.

8 Currie, B., Scott, L. W., and Dunn, A. W. (2011). The future of productivity: An eight-step game plan for Canada. Future of Canada. Deloitte.

9 Decker, R.A. et al. (2016). Where Has All the Skewness Gone? The decline in high-growth (young) firms in the U.S. *European Economic Review, 86,* 4–23. Speculating on the causes underlying the declining contribution of young firms to employment growth in the US, the authors suggest as possibilities credit constraints due to imperfect information about new firms' productivity and greater insulation from competitive pressures.

10 Currie, B. and Scott, L.W. (2013). The future of productivity: A wake-up call for Canadian companies. Future of Canada. Deloitte.

11 Institute for Competitiveness and Prosperity and the Boston Consulting Group. (2017). The Future Is Not Destiny: CEO Perspectives on Realizing Ontario's Potential. (Working Paper No. 30). Retrieved from www.competeprosper.ca/uploads/2017_The_future_is_not_destiny_CEO_perspectives_on_realizing_Ontarios_potential_Sept_2017.pdf. 22.5 percent of respondents said capital commitment to innovation was a strong disadvantage, that if left unaddressed, "will cause much of the revenue, potential for profit, and talent to leave Canada, creating a vicious downwards cycle" (p. 18).

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