Executive Summary: Competing in a Global Innovation Economy: The Current State of R&D in Canada

Expert Panel on the State of Science and Technology and Industrial Research and Development in Canada

Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

COMPETING IN A GLOBAL INNOVATION ECONOMY: THE CURRENT STATE OF R&D IN CANADA

Expert Panel on the State of Science and Technology and Industrial Research and Development in Canada

THE COUNCIL OF CANADIAN ACADEMIES
180 Elgin Street, Suite 1401, Ottawa, ON, Canada K2P 2K3

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This report was prepared for the Government of Canada in response to a request from the Minister of Science. Any opinions, findings, or conclusions expressed in this publication are those of the authors, the Expert Panel on the State of Science and Technology and Industrial Research and Development in Canada, and do not necessarily represent the views of their organizations of affiliation or employment, or the sponsoring organization, Innovation, Science and Economic Development Canada.

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The Council of Canadian Academies (CCA) is an independent, not-for-profit organization that supports independent, science-based, authoritative expert assessments to inform public policy development in Canada. Led by a Board of Directors and advised by a Scientific Advisory Committee, the CCA's work encompasses a broad definition of science, incorporating the natural, social, and health sciences as well as engineering and the humanities. CCA assessments are conducted by independent, multidisciplinary panels of experts from across Canada and abroad. Assessments strive to identify emerging issues, gaps in knowledge, Canadian strengths, and international trends and practices. Upon completion, assessments provide government decision-makers, researchers, and stakeholders with high-quality information required to develop informed and innovative public policy.

All CCA assessments undergo a formal report review and are published and made available to the public free of charge. Assessments can be referred to the CCA by foundations, non-governmental organizations, the private sector, or any level of government.

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Founded in 1882, the RSC comprises the Academies of Arts, Humanities and Sciences, as well as Canada's first national system of multidisciplinary recognition for the emerging generation of Canadian intellectual leadership: The College of New Scholars, Artists and Scientists. Its mission is to recognize scholarly, research, and artistic excellence, to advise governments and organizations, and to promote a culture of knowledge and innovation in Canada and with other national academies around the world.

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Expert Panel on the State of Science and Technology and Industrial Research and Development in Canada

Under the guidance of its Scientific Advisory Committee, Board of Directors, and Member Academies, the CCA assembled the Expert Panel on the State of Science and Technology and Industrial Research and Development in Canada to undertake this project. Each expert was selected for his or her expertise, experience, and demonstrated leadership in fields relevant to this project.

Max Blouw (Chair), Former President and Vice-Chancellor of Wilfrid Laurier University (Waterloo, ON)

Luis Barreto, President, Dr. Luis Barreto & Associates and Strategic Advisor, NEOMED-LABS (Concord, ON)

Catherine Beaudry, Professor and Canada Research Chair in Creation, Development and Commercialization of Innovation, Department of Mathematical and Industrial Engineering, Polytechnique Montréal (Montréal, QC)

Donald Brooks, FCAHS, Professor, Pathology and Laboratory Medicine, and Chemistry, University of British Columbia (Vancouver, BC)

Madeleine Jean, Vice-president, Business Development and Operations, Prompt (Montréal, QC)

Philip Jessop, FRSC, Professor, Inorganic Chemistry and Canada Research Chair in Green Chemistry, Department of Chemistry, Queen's University; Technical Director, GreenCentre Canada (Kingston, ON)

Claude Lajeunesse, FCAE, Corporate Director and Chairperson of the Board of Directors, Atomic Energy of Canada Ltd. (Magog, QC)

Steve Liang, Associate Professor, Geomatics Engineering, University of Calgary; Director, GeoSensorWeb Laboratory; CEO, SensorUp Inc. (Calgary, AB)

Robert Luke, Vice-President, Research and Innovation; Associate Professor, Faculty of Liberal Arts & Sciences and School of Interdisciplinary Studies, OCAD University (Toronto, ON)

Douglas Peers, Dean of Arts and Professor, Department of History, University of Waterloo (Waterloo, ON)

Message from the Chair

Canada's aspiration to increase national prosperity by becoming a more innovative country is long-standing, but hardly unique. Embedded in a rapidly-evolving global economy, Canada competes intensely in an international race to foster the next wave of research advances and innovations. A recent decline in Canada's ranking on the 2018 Bloomberg Innovation Index is the most recent evidence of the intensity of this competition, and of Canada's faltering place in it. With deep pools of research talent and considerable R&D assets, it is my view that Canada can be among the leaders in this race. Achieving a lead position will require concerted and sustained actions that build upon a careful assessment of the underpinnings of innovation and wealth creation in Canada.

This Expert Panel was tasked to assess evidence on the foundations of innovation, including Canada's recent track record in: fundamental research, applied research and development, business-led R&D, and the relationship of these research efforts to wealth creation and prosperity through innovation. To be clear, innovation does not require research. There are many innovative firms and individuals without formal research programs. However, countries are increasingly ramping up their investments in R&D because it is through R&D that new ideas are reliably and purposefully developed. More important, it is also through R&D that talented people are trained, enhancing their skills in inquiry and problem solving so they can advance the margins of what we know and what we are capable of creating. Unleashing the potential of highly-skilled people to generate and develop new ideas into products, processes, organizations, and systems is the most important function of R&D, and the key to creating lasting prosperity.

Some of the data the Panel reviewed were encouraging. Canada benefits from high levels of educational attainment, and has significant areas of research strength. However, other countries are accelerating their R&D efforts, and the Panel found the trajectory of many aspects of Canadian R&D worrying. Dwindling financial support for R&D across all sectors, most notably in the business sector, is of particular concern. The increasing flow of intellectual property out of Canada is also alarming. More patents are now invented in Canada than are owned in Canada. As a small, open economy, Canada is often an attractive place for companies to conduct R&D (or to procure its products such as patents and talented innovators). However, it is too often a less attractive place for developing and commercializing products, and growing companies with global reach. The end result is a loss of economic benefits and opportunities for Canada.

In summary, while Canada's performance in R&D has retained momentum gained from prior investments, its future is now jeopardized by both relatively low levels of R&D and by the propensity of successful Canadian innovations, entrepreneurs, and researchers to leave the country to pursue opportunities for commercialization and growth elsewhere. Canada's capacity for R&D and innovation remains excellent, but the underpinnings of that capacity are eroding and we are less successful in creating domestic wealth from its innovations than many other jurisdictions.

It was a genuine pleasure to work with the members of this Panel, and I sincerely thank them for their passionate engagement with our charge, their energy, and their good humor as we debated the meaning and causal drivers behind the evidence we were examining. I also appreciated their unflagging willingness to step back from topics of particular personal enthusiasm to reflect on the wider work of the group.

It was also a marvelous experience to work with the exceptional, talented staff of the CCA. They (mostly) did not complain when asked to assemble more evidence, or reanalyze evidence through a different lens, or add endless new requests for sometimes impossible-to-find (but wouldn't it be wonderful if we could) new evidence. The CCA staff is a remarkable collection of individuals doing very important work for our country, and I am in their debt.

I view this assessment as a contribution to critically important discussions on R&D and innovation in Canada, and I look forward to continuing to follow those conversations — and participate in them — as they evolve.

Sincerely,

Max Blouw, Chair,
Expert Panel on the State of Science and Technology and
Industrial Research and Development in Canada

Message from the President and CEO

This assessment of Canada's performance indicators in science, technology, research, and innovation comes at an opportune time. The Government of Canada has expressed a renewed commitment in several tangible ways to this broad domain of activity including its *Innovation and Skills Plan*, the announcement of five superclusters, its appointment of a new Chief Science Advisor, and its request for the *Fundamental Science Review*. More specifically, the 2018 Federal Budget demonstrated the government's strong commitment to research and innovation with historic investments in science.

The CCA has a decade-long history of conducting evidence-based assessments about Canada's research and development activities, producing seven assessments of relevance:

- *The State of Science and Technology in Canada* (2006)
- *Innovation and Business Strategy: Why Canada Falls Short* (2009)
- *Catalyzing Canada's Digital Economy* (2010)
- *Informing Research Choices: Indicators and Judgment* (2012)
- *The State of Science and Technology in Canada* (2012)
- *The State of Industrial R&D in Canada* (2013)
- *Paradox Lost: Explaining Canada's Research Strength and Innovation Weakness* (2013)

Using similar methods and metrics to those in *The State of Science and Technology in Canada* (2012) and *The State of Industrial R&D in Canada* (2013), this assessment tells a similar and familiar story: Canada has much to be proud of, with world-class researchers in many domains of knowledge, but the rest of the world is not standing still. Our peers are also producing high quality results, and many countries are making significant commitments to supporting research and development that will position them to better leverage their strengths to compete globally. Canada will need to take notice as it determines how best to take action. This assessment provides valuable material for that conversation to occur, whether it takes place in the lab or the legislature, the bench or the boardroom. We also hope it will be used to inform public discussion.

It is also worth noting that the Panel itself recognized the limits that come from using traditional historic metrics. Additional approaches will be needed the next time this assessment is done.

I would like to thank Max Blouw, the Panel Chair, and his fellow expert panel members for their insightful work on this topic. I'd also like to thank the CCA's Board of Directors, its Scientific Advisory Committee, and its three

Member Academies — the Royal Society of Canada, the Canadian Academy of Engineering, and the Canadian Academy of Health Sciences — who continue to provide the wisdom, advice, and expert knowledge that helps keep the CCA pointed in the right direction.

Finally, I would like to thank the Minister of Science the Hon. Kirsty Duncan, and the Minister of Innovation, Science and Economic Development, the Hon. Navdeep Bains, for referring this topic to the CCA.

Eric M. Meslin, PhD, FCAHS
President and CEO, Council of Canadian Academies

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The Panel could not have done its job without assistance from many individuals and organizations, especially those that provided data, evidence, and analysis for our review. This includes all three members of the Tri-Agency (the Natural Sciences and Engineering Research Council, the Social Sciences and Humanities Research Council, and the Canadian Institutes for Health Research), the National Research Council of Canada, the Canada Foundation for Innovation, and the Federation of the Humanities and Social Sciences. It also includes Humber College, Colleges and Institutes Canada, Polytechnics Canada, TechAccess Canada, and Reseau TransTech, which together shared evidence and insights on the roles of colleges and polytechnics in Canada. With respect to our analysis of R&D expenditures, Louise Earl and her team at Statistics Canada were kind enough to repeatedly field questions about their data collection methodologies and greatly improved our understanding of this data. Our analysis also would not have been possible without the work of Science-Metrix, and EKOS Research, which respectively supplied the bibliometric and survey data used in this study. Finally, we are grateful to the 5,547 highly-cited researchers from all over the world who took the time to respond to our survey and help us better understand Canada's place in the global R&D and innovation landscape.

Project Staff of the Council of Canadian Academies

Assessment Team:	Emmanuel Mongin, Project Director R. Dane Berry, Research Associate Joe Rowsell, Research Associate Weronika Zych, Project Coordinator Matthew Ivanovich, Researcher Aaron Maxwell, Consultant
With Assistance from:	Stefan Jungcurt, Consultant Lennart Trouborst, Researcher, CCA Clare Walker, Editor and Copyeditor Jody Cooper, Editor François Abraham, Communications Léon Inc., Certified Translator, En-Fr Marc Dufresne, Report Design, CCA

Report Review

This report was reviewed in draft form by the individuals listed below — a group of reviewers selected by the Council of Canadian Academies (CCA) for their diverse perspectives, areas of expertise, and broad representation of academic, industrial, policy, and non-governmental organizations.

The reviewers assessed the objectivity and quality of the report. Their submissions — which will remain confidential — were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring Panel and the CCA.

The CCA wishes to thank the following individuals for their review of this report:

Ronald Burnett, C.M., O.B.C., RCA, Chevalier de l'ordre des arts et des lettres, President and Vice-Chancellor, Emily Carr University of Art and Design (Vancouver, BC)

Michelle N. Chretien, Director, Centre for Advanced Manufacturing and Design Technologies, Sheridan College; Former Program and Business Development Manager, Electronic Materials, Xerox Research Centre of Canada (Brampton, ON)

Lisa Crossley, CEO, Reliq Health Technologies, Inc. (Ancaster, ON)

Natalie Dakers, Founding President and CEO, Accel-Rx Health Sciences Accelerator (Vancouver, BC)

Fred Gault, Professorial Fellow, United Nations University-MERIT (Maastricht, Netherlands)

Patrick D. Germain, Principal Engineering Specialist, Advanced Aerodynamics, Bombardier Aerospace (Montréal, QC)

Robert Brian Haynes, O.C., FRSC, FCAHS, Professor Emeritus, DeGroote School of Medicine, McMaster University (Hamilton, ON)

Susan Holt, Chief, Innovation and Business Relationships, Government of New Brunswick (Fredericton, NB)

Pierre A. Mohnen, Professor, United Nations University-MERIT and Maastricht University (Maastricht, Netherlands)

Peter J. M. Nicholson, C.M., Retired; Former and Founding President and CEO, Council of Canadian Academies (Annapolis Royal, NS)

Raymond G. Siemens, Distinguished Professor, English and Computer Science and Former Canada Research Chair in Humanities Computing, University of Victoria (Victoria, BC)

The report review procedure was monitored on behalf of the CCA's Board of Directors and Scientific Advisory Committee by **Gregory S. Kealey, C.M., FRSC,** Professor Emeritus, Department of History, University of New Brunswick. The role of the peer review monitor is to ensure that the Panel gives full and fair consideration to the submissions of the report reviewers. The Board of the CCA authorizes public release of an expert panel report only after the peer review monitor confirms that the CCA's report review requirements have been satisfied. The CCA thanks Dr. Kealey for his diligent contribution as peer review monitor.

Executive Summary

National prosperity, competitiveness, and well-being are inextricably linked to the capacity to participate in and benefit from research, development, and innovation. A confluence of advances in digital technologies, biotechnology, networked production processes, and autonomous transportation systems could usher in profound economic, social, environmental, and technological shifts in the years to come. Countries that strategically support research and experimental development (R&D) and innovation, and cultivate an extensive base of research talent and expertise, will benefit from coming research advances and discoveries. Countries that do not provide such support or cultivate such skills risk becoming unable to participate in world-leading research and equally unable to reap its eventual social and economic benefits. Policy-makers need a broad spectrum of information, indicators, and insights to support the strongest possible development of broad-based R&D capacity. This report assesses the latest evidence on Canada's R&D and innovation performance, combining up-to-date data with expert insights and analyses, and benchmarking against the performance of other countries.

Charge to the Panel

In 2016, the federal government asked the Council of Canadian Academies (CCA) to undertake a comprehensive assessment of the state of science, technology, and R&D in Canada. The CCA had completed assessments on this topic in 2006 and 2012. Both reports provided a snapshot in time of performance in all fields of research and technology development. A third report, on the state of industrial R&D and gaps in translating R&D strengths to innovation, was published in 2013. The current Expert Panel (the Panel) was tasked with considering the combined charges from the 2012 and 2013 assessments, consisting of the following questions:

> *What is the current state of science and technology and industrial research and development in Canada?*
>
> - *Considering both basic and applied research fields, what are the scientific disciplines and technological applications in which Canada excels? How are these strengths distributed geographically across the country? How do these trends compare with what has been taking place in comparable countries?*

- *In which scientific disciplines and technological applications has Canada shown the greatest improvement/decline in the last five years? What major trends have emerged, and why? Which scientific disciplines and technological applications have the potential to emerge as areas of prominent strength for Canada?*

- *What are the existing industrial R&D strengths in Canada? How are these strengths distributed by sector and geographically across the country? How do these trends compare with what has been taking place in comparable countries?*

- *In which scientific disciplines and technological applications are our relative strengths most aligned with Canada's economic strengths/industry needs?*

- *What are the key barriers and knowledge gaps in translating Canadian strengths in S&T into innovation and wealth creation?*

On Terminology

Terms such as *science*, *research and development*, *technology*, and *innovation*, are often imprecisely and inconsistently applied. Past CCA assessments used the blanket term *science and technology* (S&T). This Panel opted to use the more inclusive term *research and experimental development* (R&D). *R&D* as used here refers to research activities spanning all fields of study, encompassing all stages of research and technology development and performed in all sectors, (i.e., academia, government, industry, and the not-for-profit sector). *Innovation* is not a central focus of the report; however, where relevant to its discussions, the Panel adopted a broad definition of innovation, recognizing that by convention it is often measured as the introduction of new products, processes, organizational methods, or marketing methods in firms. While efforts are underway to extend such measurements to the sphere of social or public-sector innovation, currently there are few internationally comparable data on innovation activities outside of firms. When analyzing internationally comparable data, the Panel relied on standard definitions of R&D and related terms (e.g., basic research, applied research), as defined by the Organisation for Economic Co-operation and Development (OECD) and statistical agencies. Some of these definitions have significant limitations, though they remain the only consistent way to benchmark Canadian performance against that of other nations.

Methodology and Data Limitations

The Panel relied on evidence from multiple sources to address its charge, including a literature review and data extracted from statistical agencies and organizations such as Statistics Canada and the OECD. For international comparisons, the Panel focused on OECD countries along with developing countries that are among the top 20 producers of peer-reviewed research publications (e.g., China, India, Brazil, Iran, Turkey). In addition to the literature review, two primary research approaches informed the Panel's assessment:

- a comprehensive bibliometric and technometric analysis of Canadian research publications and patents; and,
- a survey of top-cited researchers around the world.

Despite best efforts to collect and analyze up-to-date information, one of the Panel's findings is that data limitations continue to constrain the assessment of R&D activity and excellence in Canada. This is particularly the case with industrial R&D and in the social sciences, arts, and humanities. Data on industrial R&D activity continue to suffer from time lags for some measures, such as internationally comparable data on R&D intensity by sector and industry. These data also rely on industrial categories (i.e., NAICS and ISIC codes) that can obscure important trends, particularly in the services sector, though Statistics Canada's recent revisions to how this data is reported have improved this situation. There is also a lack of internationally comparable metrics relating to R&D outcomes and impacts, aside from those based on patents.

For the social sciences, arts, and humanities, metrics based on journal articles and other indexed publications provide an incomplete and uneven picture of research contributions. The expansion of bibliometric databases and methodological improvements such as greater use of web-based metrics, including paper views/downloads and social media references, will support ongoing, incremental improvements in the availability and accuracy of data. However, future assessments of R&D in Canada may benefit from more substantive integration of expert review, capable of factoring in different types of research outputs (e.g., non-indexed books) and impacts (e.g., contributions to communities or impacts on public policy). The Panel has no doubt that contributions from the humanities, arts, and social sciences are of equal importance to national prosperity. It is vital that such contributions are better measured and assessed.

R&D Investment and Capacity

Canada's international reputation for its capacity to participate in cutting-edge R&D is strong, with 60% of top-cited researchers surveyed internationally indicating that Canada hosts world-leading infrastructure or programs in their fields. This share increased by four percentage points between 2012 and

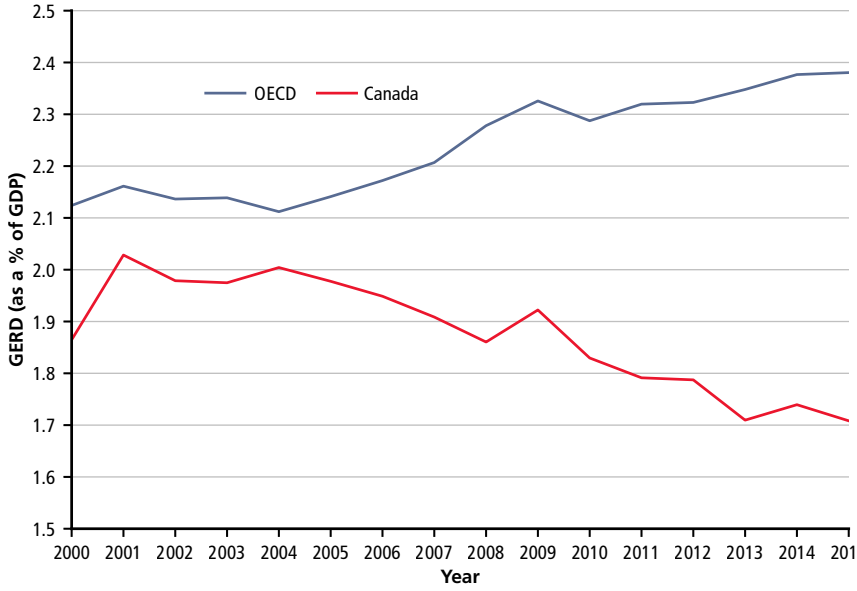
2017. Canada continues to benefit from a highly educated population and deep pools of research skills and talent. Its population has the highest level of educational attainment in the OECD in the proportion of the population with a post-secondary education. However, among younger cohorts (aged 25 to 34), Canada has fallen behind Japan and South Korea. The number of researchers per capita in Canada is on a par with that of other developed countries, and increased modestly between 2004 and 2012. Canada's output of PhD graduates has also grown in recent years, though it remains low in per capita terms relative to many OECD countries.

In contrast, the number of R&D personnel employed in Canadian businesses dropped by 20% between 2008 and 2013. This is likely related to sustained and ongoing decline in business R&D investment across the country. R&D as a share of gross domestic product (GDP) has steadily declined in Canada since 2001, and now stands well below the OECD average (Figure 1). As one of few OECD countries with virtually no growth in total national R&D expenditures between 2006 and 2015, Canada would now need to more than double expenditures to achieve an R&D intensity comparable to that of leading countries.

Low and declining business R&D expenditures are the dominant driver of this trend; however, R&D spending in all sectors is implicated. Government R&D expenditures declined, in real terms, over the same period. Expenditures in the higher education sector (an indicator on which Canada has traditionally ranked highly) are also increasing more slowly than the OECD average. Significant erosion of Canada's international competitiveness and capacity to participate in R&D and innovation is likely to occur if this decline and underinvestment continue.

Research Output, Impact, and Strength

Between 2009 and 2014, Canada produced 3.8% of the world's research publications, ranking ninth in the world. This is down from seventh place for the 2003–2008 period. India and Italy have overtaken Canada although the difference between Italy and Canada is small. Publication output in Canada grew by 26% between 2003 and 2014, a growth rate greater than many developed countries (including United States, France, Germany, United Kingdom, and Japan), but below the world average, which reflects the rapid growth in China and other emerging economies. Research output from the federal government, particularly the National Research Council Canada, dropped significantly between 2009 and 2014.



Data Source: OECD, 2016a

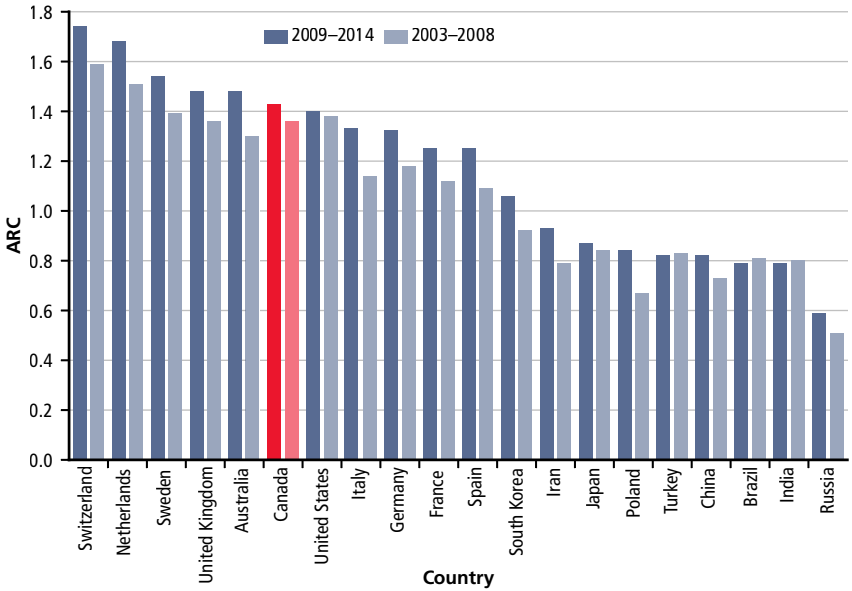
Figure 1

R&D Intensity in Canada and the OECD, 2000–2015

Canada's R&D intensity or Gross Domestic Expenditures on R&D (GERD) as a share of GDP has declined steadily since peaking in 2001. Across OECD countries, however, R&D spending relative to GDP has continued to increase. The OECD average is now 2.4% of GDP and leading countries have R&D intensities above 4%.

Canada, relative to the world, specializes in subjects generally referred to as the humanities and social sciences (plus health and the environment), and does not specialize as much as others in areas traditionally referred to as the physical sciences and engineering. Specifically, Canada has comparatively high levels of research output in Psychology and Cognitive Sciences, Public Health and Health Services, Philosophy and Theology, Earth and Environmental Sciences, and Visual and Performing Arts. It accounts for more than 5% of world research in these fields. Conversely, Canada has lower research output than expected in Chemistry, Physics and Astronomy, Enabling and Strategic Technologies, Engineering, and Mathematics and Statistics. The comparatively low research output in core areas of the natural sciences and engineering is concerning, and could impair the flexibility of Canada's research base, preventing research institutions and researchers from being able to pivot to tomorrow's emerging research areas.

Canada is maintaining its international standing in measures of research impact, though evidence suggests a minor erosion of competitiveness in some fields. Its Average Relative Citation (ARC) rank in 2009–2014 remained unchanged at sixth place from 2003 to 2008 (Figure 2). Canada's research reputation also remained unchanged at fourth place, according to a survey of top-cited researchers from around the world, with around 36% of respondents identifying Canada as among the top five countries in their field. The country's ARC scores are above the world average in all fields in 2009–2014. Canada ranks among the top five countries in Psychology and Cognitive Sciences, Clinical Medicine, Physics and Astronomy, Historical Studies, and Visual and Performing Arts.



Data Source: Calculated by Science-Metrix using Scopus database (Elsevier)

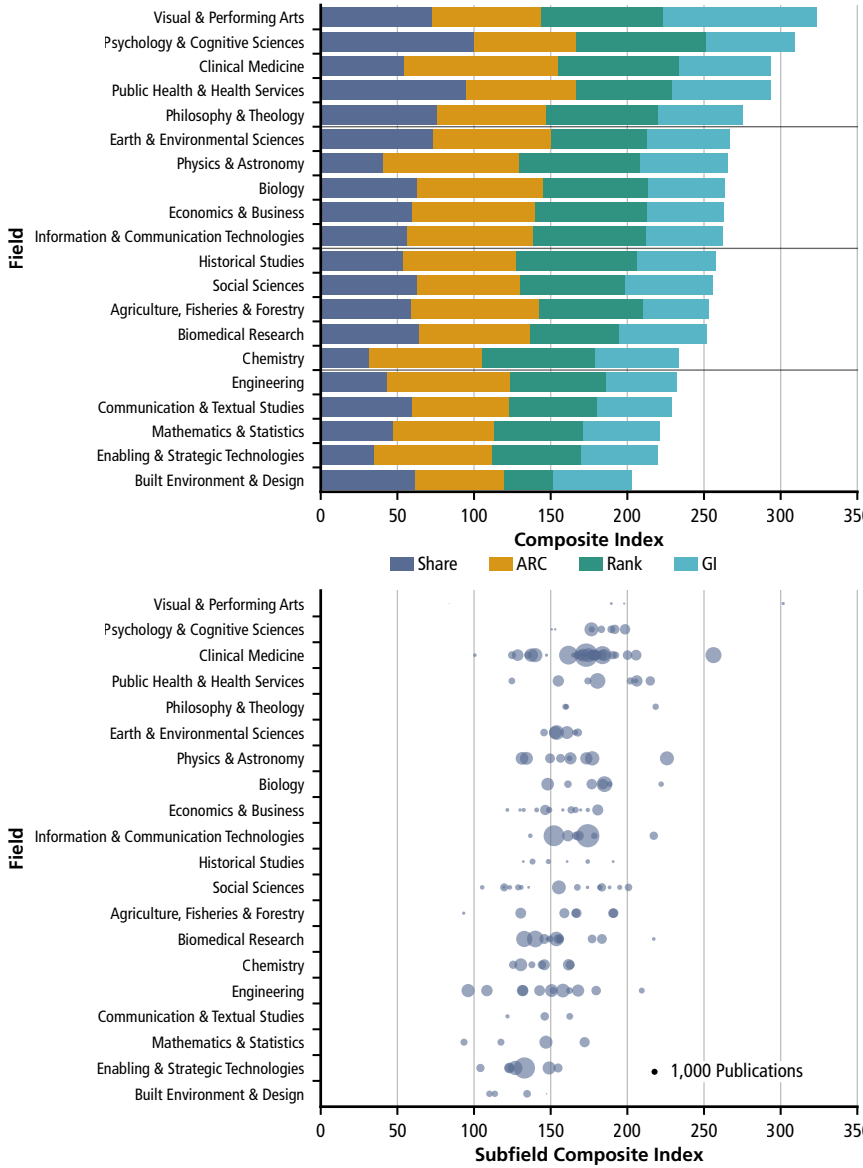
Figure 2

ARC Scores for Top 20 Countries by Number of Publications, 2003–2008 and 2009–2014

Countries are ranked by ARC score for the 2009–2014 period.

Analysis of ARC and survey rankings suggests that Canada's research strengths have remained generally stable since the 2012 CCA S&T report.

The Panel developed a composite indicator of research strength based on three dimensions: *magnitude* (based on Canada's share of world publications in that field), *impact* (based on ARC score and ARC rank), and *growth* (based on the Growth Index (GI) score, reflecting Canada's growth in research output relative to the rest of the world). Research fields can be divided into three general groups based on this indicator (Figure 3). The top quartile represents areas of



Data Source: Panel calculations based on data provided by Science-Metrix using Scopus database (Elsevier)

Figure 3

Composite Score by Research Field in Canada, 2009–2014

Composite scores are based on four indicators: ARC scores, ARC ranks, GI scores, and Canada's share of world publications in that field or subfield. Field scores (ARC, ARC rank, GI and share) were normalized relative to the other fields and subfields scores normalized relative to the other subfields. All four indicators are weighted equally. The top panel shows composite scores for fields, along with their four subcomponents. The bottom panel shows the dispersion of composite scores for subfields within each field, with the size of bubbles corresponding to the number of publications.

comparative strength for Canada: Visual and Performing Arts, Psychology and Cognitive Sciences, Clinical Medicine, Public Health and Health Services, and Philosophy and Theology. The second and third quartiles together feature a strong middle pack of Canadian fields that typically perform well on two of the three dimensions. The bottom quartile contains fields in which Canada is less competitive internationally. An analysis of composite scores at the subfield level reveals substantial variation within fields. In Philosophy and Theology and Physics and Astronomy, for example, Applied Ethics and Astronomy and Astrophysics rank much higher than the other subfields within those fields.

When it comes to research on most enabling and strategic technologies, however, Canada lags other countries. Bibliometric evidence suggests that, with the exception of selected subfields in Information and Communication Technologies (ICT) such as Medical Informatics and Personalized Medicine, Canada accounts for a relatively small share of the world's research output for promising areas of technology development. This is particularly true for Biotechnology, Nanotechnology, and Materials science. Canada's research impact, as reflected by citations, is also modest in these areas. Aside from Biotechnology, none of the other subfields in Enabling and Strategic Technologies has an ARC rank among the top five countries. Optoelectronics and photonics is the next highest ranked at 7th place, followed by Materials, and Nanoscience and Nanotechnology, both of which have a rank of 9th. Even in areas where Canadian researchers and institutions played a seminal role in early research (and retain a substantial research capacity), such as Artificial Intelligence and Regenerative Medicine, Canada has lost ground to other countries.

Trends in Industrial R&D

There has been a sustained erosion in Canada's industrial R&D capacity and competitiveness. Canada ranks 33rd among leading countries on an index assessing the magnitude, intensity, and growth of industrial R&D expenditures. Although Canada is the 11th largest spender, its industrial R&D intensity (0.9%) is only half the OECD average and total spending is declining (−0.7%). Compared with G7 countries, the Canadian portfolio of R&D investment is more concentrated in industries that are intrinsically not as R&D intensive. Canada invests more heavily than the G7 average in oil and gas, forestry, machinery and equipment, and finance where R&D has been less central to business strategy than in many other industries. However, it can be difficult to determine the implications of R&D trends for industries such as wholesale trade, which include a diverse range of firms united only by the predominance of sales and distribution activities in their business operations. About 50% of Canada's industrial R&D spending is in high-tech sectors (including industries such as ICT, aerospace, pharmaceuticals, and automotive) compared with the G7 average of 80%. Canadian Business Enterprise Expenditures on R&D (BERD) intensity is also

below the OECD average in these sectors. In contrast, Canadian investment in low and medium-low tech sectors is substantially higher than the G7 average. Canada's spending reflects both its long-standing industrial structure and patterns of economic activity.

R&D investment patterns in Canada appear to be evolving in response to global and domestic shifts. While small and medium-sized enterprises continue to perform a greater share of industrial R&D in Canada than in the United States, between 2009 and 2013, there was a shift in R&D from smaller to larger firms. Canada is an increasingly attractive place to conduct R&D. Investment by foreign-controlled firms in Canada has increased to more than 35% of total R&D investment, with the United States accounting for more than half of that. Multinational enterprises seem to be increasingly locating some of their R&D operations outside their country of ownership, possibly to gain proximity to superior talent. Increasing foreign-controlled R&D, however, also could signal a long-term strategic loss of control over intellectual property (IP) developed in this country, ultimately undermining the government's efforts to support high-growth firms as they scale up.

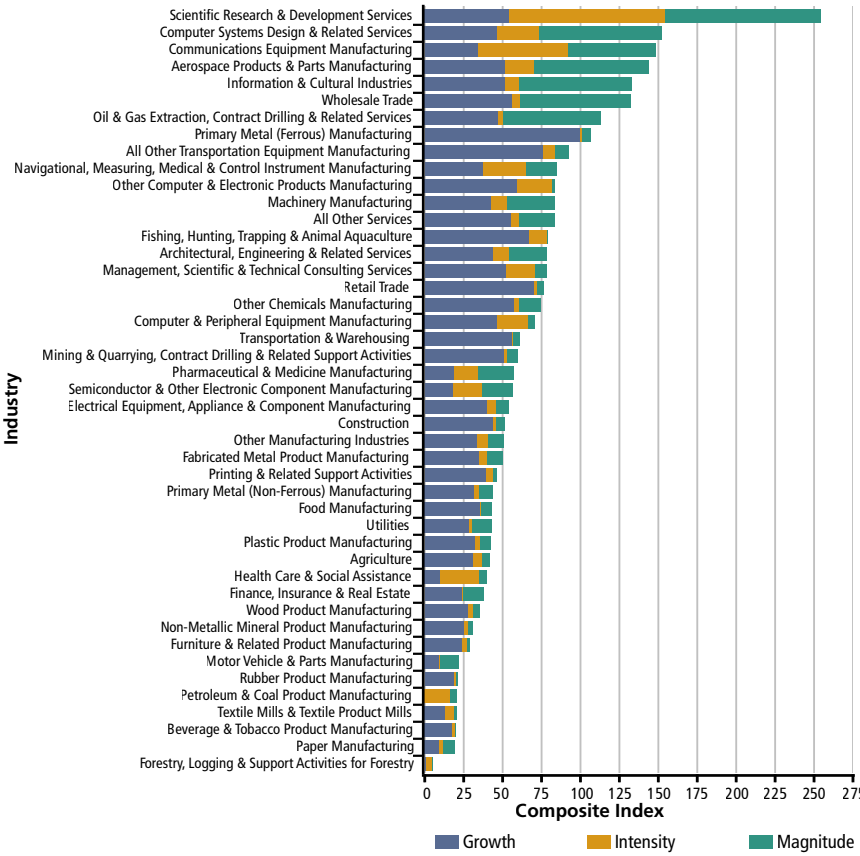
Canada produces about 1% of global patents, ranking 18th in the world. It lags further behind in trademark (34th) and design applications (34th). Despite relatively weak performance overall in patents, Canada excels in some technical fields such as Civil Engineering, Digital Communication, Other Special Machines, Computer Technology, and Telecommunications. Canada is a net exporter of patents, which signals the R&D strength of some technology industries. It may also reflect increasing R&D investment by foreign-controlled firms.

The Panel relied on three indicators to identify industries of R&D strength: magnitude (annual average R&D expenditures between 2006 and 2015), intensity (R&D expenditures as a share of revenues between 2009 and 2013), and growth (compound annual growth between 2006 and 2015). Based on a composite indicator, the Panel classified four industries of R&D strength:

- Scientific research and development services
- Computer systems design
- Communications equipment manufacturing
- Aerospace products and parts manufacturing

Between 2006 and 2015, Canada business R&D spending grew less than both inflation and OECD average spending and recent estimates suggest further erosion. Between 2014 and 2017, Canadian business R&D is projected to decline by 2.8% per year, with more than half of this decline in oil and gas extraction and software publishing. Among the largest industries, only six increased their

spending on R&D, lead by chemical manufacturing and telecommunications services. Most Canadian industries are now spending less on R&D than in the previous decade.



Data Source: StatCan, 2017a, 2017i

Figure 4

Domestic Industrial R&D Strength, Canadian Industries, 2006–2015

The figure ranks Canadian industries (NAICS) based on a composite index of industrial R&D spending: magnitude (BERD spending, average 2011–2015), intensity (BERD/GDP, average 2009–2013), and growth (BERD CAGR, 2006–2015). Each component is adjusted as a fraction of 100 implying a maximum score of 300.

This Panel was also tasked with identifying the "scientific disciplines and technological applications where Canada's relative strengths are most aligned with Canada's economic strengths/industry needs." R&D activities conducted (or contracted out) by industry inherently reflect their perceived needs. Trends in industrial R&D reflect these needs and tend to mirror Canada's industrial structure. The comparatively high level of business funding for R&D in Canadian universities, coupled with growing numbers of research partnerships between universities and businesses, does not suggest an overall deficit of connectivity between industry and academia. Regarding alignment with Canada's economic strengths, the Canadian economy is dominated by industries in which R&D is not a core component of business strategy and Canadian business R&D expenditures reflect this. Oil and gas, construction, real estate, and finance industries, for example, rely more extensively on natural resources, capital, and talent than on R&D. At the same time, Canada's technology-intensive industries such as ICT, the biopharmaceutical sector, aerospace, and the automotive industry clearly benefit from Canada's research activity and strength in related fields. Canada's research capacity in artificial intelligence (AI) technologies also could have widespread relevance across the economy. However, in the Panel's view Canada's R&D capacity remains generally underutilized by Canadian industry given the relative lack of R&D-intensive industries and major corporate R&D funders.

R&D Activity and Trends by Region

R&D investment, output, and impact are unequally distributed across Canada. Almost the entire decline in national R&D spending from 2006 to 2015 occurred in Ontario and Quebec. By contrast, R&D spending grew in most other provinces and, as such, is becoming slightly less concentrated across provinces. Despite their decreasing share of total Canadian R&D, Ontario and Quebec remain dominant. If assessed independently, they would each rank among the top 25 countries in total R&D spending.

Tremendous research diversity exists across provinces. Each province produces at least twice as many publications as the world average in at least 15 academic subfields. Ontario, Quebec, British Columbia, and Alberta are the largest centres of research activity by province. They also have the highest average and median impact, and the highest levels of growth in research output and international collaboration. Table 1 shows the top five subfields by specialization and impact (i.e., by specialization index (SI) and ARC score) for each province. Between 2003 and 2014, patent output grew in all provinces except Quebec, as pharmaceutical activity declined. Notably, all provinces except Prince Edward Island are now net exporters of patents.

Table 1

Top Five Subfields by SI and ARC Score by Province/Region, 2003–2014

Province	Top Five Subfields by SI Score	Top Five Subfields by ARC Score
British Columbia	Forestry Drama & Theatre Fisheries Geography Ornithology	General & Internal Medicine General S&T Mining & Metallurgy Nuclear & Particle Physics Astronomy & Astrophysics
Alberta	Geology Physiology Sport, Leisure & Tourism Sport Sciences Medical Informatics	General & Internal Medicine Nuclear & Particle Physics Anatomy & Morphology Mining & Metallurgy General Physics
Prairies	Ornithology Veterinary Sciences Agronomy & Agriculture Agricultural Economics & Policy Physiology	General & Internal Medicine Nuclear & Particle Physics Surgery Allergy Electrical Engineering
Ontario	Drama & Theatre Rehabilitation Gender Studies Criminology Experimental Psychology	General & Internal Medicine Nuclear & Particle Physics Gastro & Hepatology Respiratory System Dermatology
Quebec	Forestry Econometrics Industrial Relations Developmental Psychology Experimental Psychology	General & Internal Medicine Anatomy General Physics Music Nuclear Physics
Atlantic Provinces	Veterinary Fisheries Oceanography Horticulture History	General & Internal Medicine Dermatology Food Science Design & Management Mechanical Engineering

Data Source: Calculated by Science-Metrix using Scopus database (Elsevier)

Canadian R&D capacity is concentrated in cities, particularly Toronto, Montréal, Vancouver, Ottawa, and Calgary. These five cities create patents and high-tech companies at nearly twice the rate of other cities. They also account for half of all clusters in the services sector (e.g., ICT, finance) and many clusters in advanced manufacturing. Many R&D clusters in Canada relate to natural resources and long-standing areas of economic and research strength. Natural resource clusters have emerged around the location of resources, such as forestry in British Columbia, oil and gas in Alberta, agriculture in Ontario, mining in Quebec, and maritime resources in Atlantic Canada. The automotive, plastics, and steel industries have the most individual clusters because of these industries'

economic success in Windsor, Hamilton, and Oshawa. Advanced manufacturing industries, such as aerospace, life sciences, and ICT manufacturing, tend to be more concentrated, often located near specialized research universities.

Linking R&D, Innovation, and Wealth Creation

Canada's combination of high performance in measures of research output and impact, and low performance on measures of industrial R&D investment and innovation (e.g., subpar productivity growth), continue to be viewed as a paradox, leading to the hypothesis that barriers are impeding the flow of Canada's research achievements into commercial applications. The Panel's analysis suggests the need for a more nuanced view. The process of transforming research into innovation and wealth creation is a complex multifaceted process, making it difficult to point to any definitive cause of Canada's deficit in R&D investment and productivity growth. Based on the Panel's interpretation of the evidence, Canada is a highly innovative nation, but significant barriers prevent the translation of innovation into wealth creation. The available evidence does point to a number of important contributing factors that are analyzed in this report. Figure 5 represents the relationships between R&D, innovation, and wealth creation.

The Panel concluded that many factors commonly identified as points of concern do not adequately explain the overall weakness in Canada's innovation performance compared with other countries. Academia-business linkages appear relatively robust in quantitative terms given the extent of cross-sectoral R&D funding and increasing academia-industry partnerships, though the volume of academia-industry interactions does not indicate the nature or the quality of that interaction, nor the extent to which firms are capitalizing on the research conducted and the resulting IP. The educational system is high performing by international standards and there does not appear to be a widespread lack of researchers or STEM (science, technology, engineering, and mathematics) skills. IP policies differ across universities and are unlikely to explain a divergence in research commercialization activity between Canadian and U.S. institutions, though Canadian universities and governments could do more to help Canadian firms access university IP and compete in IP management and strategy. Venture capital availability in Canada has improved dramatically in recent years and is now competitive internationally, though still overshadowed by Silicon Valley. Technology start-ups and start-up ecosystems are also flourishing in many sectors and regions, demonstrating their ability to build on research advances to develop and deliver innovative products and services.

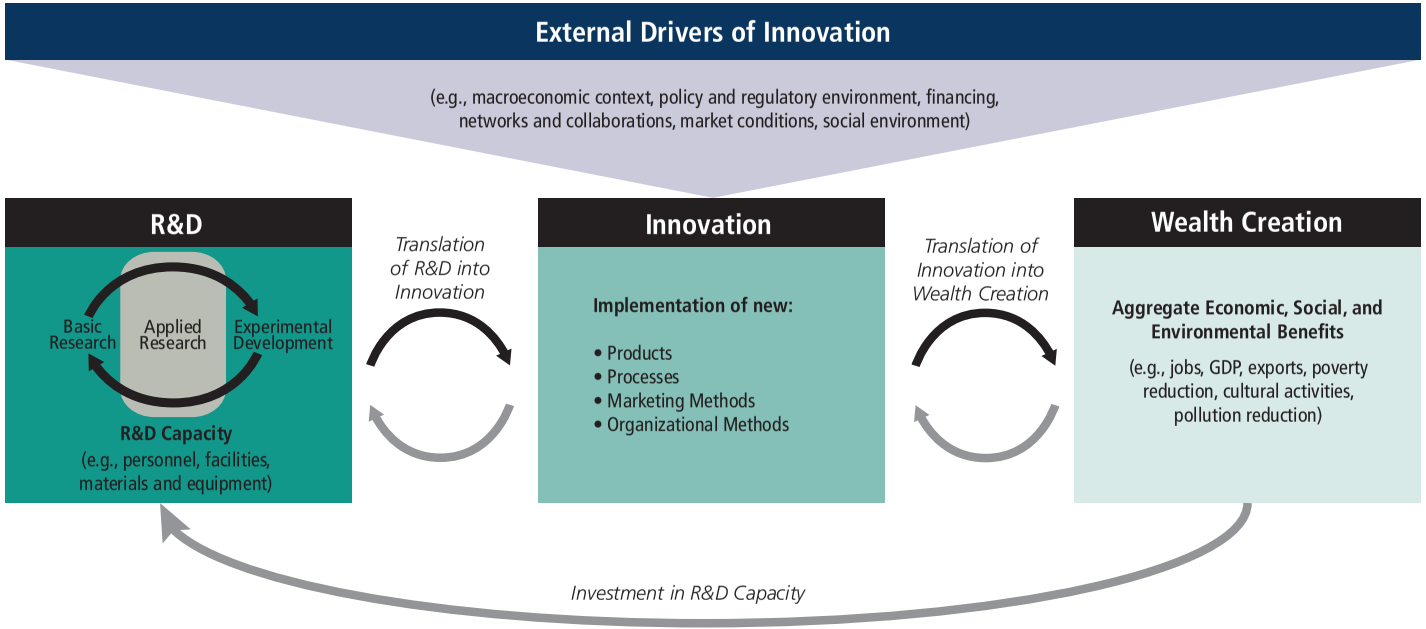


Figure 5

The Links Between R&D, Innovation, and Wealth Creation

The translation of R&D into innovation and wealth creation is complex, occurring through distinct stages. Advances in basic research and experimental development are mutually supportive (linked, in many cases, through applied research). R&D feeds into innovation by supporting the creation of new products, processes, and marketing or organizational methods. This report focuses primarily on product and process innovation as those types of innovation are more closely linked to R&D and technology development. Innovations are also fed by external drivers such as macroeconomic context, policy, regulatory or social environments. Innovations lead to economic benefits through productivity increases, job creation, GDP growth, etc. Innovations may also provide other social benefits, such as reducing environmental impacts or improving the efficiency or effectiveness of public services.

Growing start-up firms into large, mature, and sustainable businesses involves significant challenges that are hindering technology firms from scaling up domestically in Canada. Although macroeconomic conditions and the regulatory environment appear to be conducive to business creation and development, Canada's promising start-ups are often acquired and developed in other countries, leading to a loss of economic and commercial benefits. This trend is driven by many factors including the larger size of the U.S. market, the structure and nature of capital markets in Canada, and the rapidly growing interest of China in Canadian commercial activities. The fact that Canada's R&D tax credits are more competitive for smaller firms than for large corporations suggests that Canada is a better place to start a technology company than to grow one. Survey evidence from Canadian firms and technology stakeholders also suggests that a lack of managerial talent and experience in growing domestic technology firms to scale is a critical impediment.

Conclusion

Canada's mostly undiminished capacity for high-quality research and extensive pools of research talent are a legacy of past investments. Canada remains home to world-leading researchers, facilities, and programs, and their accomplishments and importance continue to be regarded with much esteem by the international community. A broad base of research talent, a stable macroeconomic context, a diverse and welcoming social environment, and a history of seminal R&D contributions are Canada's most important R&D strengths. Together, they could serve as the foundation for a future where Canada continues to produce world-leading research and counts among the most innovative and productive economies. Currently, however, that future is threatened. Declining levels of private and public R&D expenditures threaten to erode Canada's research capacity over time. The loss of innovative start-ups to foreign buyers, and the inability to grow a sufficient number of start-ups to scale, means that Canadians do not fully capture the social and economic benefits stemming from Canadian research advances. Furthermore, recent developments suggest a growing risk of foreign-based technology companies capturing a disproportionate share of the benefits of past government investments in R&D. While some of the commercial benefits of that R&D may remain in Canada, there is also a risk that a fair proportion of it will be developed offshore. Addressing these challenges requires overcoming the inertia inherent in current, anemic patterns of institutional support for R&D in Canada. Success is not assured. However, the potential gains from an improved state of R&D in Canada in the future would make it well worth the effort.

Table 2

Selected Bibliometric Indicators

Indicator	Description
Number of Publications	Number of publications measures the publication count for a given entity such as a country, a province, or a research field. Publication counts can be presented in whole and fractional counts. With whole counting, each publication is counted once for each unit with a participating author. For example, if a publication is co-authored by two researchers from different countries, the publication will be counted once for each country. With fractional counting, each co-author (and associated entity) is credited with a fraction of a publication corresponding to the number of authors. In the preceding example, each researcher (and country) would be allotted one-half of a publication. Unless otherwise indicated, the counts presented in this report are based on whole counts. However, some metrics use fractional counts.
Specialization Index (SI)	This indicator is a measure of the relative research intensity for an entity in a specific field of research. An SI score greater than 1.0 means that more publications were published in a given field or subfield than would be expected based on world averages. For example, if publications in Physics and Astronomy account for 10% of a country's total publications, but only 5% of total world publications, that country would have an SI score of 2.0 in that field. An SI score below 1.0 means that less research is produced than expected based on world averages.
Growth Index (GI) and Growth Rate (GR)	GI score measures the growth of publications between two periods of time (2003–2008 and 2009–2014 in this report) relative to the growth of a reference entity (e.g., the world) for the same period of time. For example, if Canada's GI is above 1.0 for a specific field or subfield, it means that Canada's publication output in that field or subfield is growing faster than the world average. The GR indicator simply corresponds to the percentage change in total publication output between the two periods; a GR score of 1.37, for example, indicates that output increased by 37% between the two periods.
Collaboration Index (CI)	Based on publication co-authorships, the CI indicator measures the level of collaboration of a given entity with another entity in the context of the entity's total publications (countries producing more publications tend to collaborate less internationally, given their increased potential for internal collaboration). A collaboration score over 1.0 means that the entity collaborates more than expected given its total publication output.
Average Relative Citations (ARC)	This indicator measures the impact of publications produced by a given entity as reflected in citations. An ARC score over 1.0 indicates that the entity publishes publications that are more highly cited than the world average. ARC scores are normalized by publication type, year, and field of research. ARC scores (along with other measures of impact) are less reliable for fields or entities producing low numbers of publications, as the score can be driven by outliers.

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Indicator	Description
Median Relative Citations (MRC)	The MRC is similar to the ARC and is also a measure of research impact based on field-normalized citations. However, the MRC is calculated with reference to the median score rather than to the average. It is arguably a better measure of the central tendency in most areas of research given that citation distributions tend to be skewed, with a small number of publications attracting large numbers of citations.
Highly Cited Publications (HCP1%)	HCP1% is a measure of research impact based on the upper tail of the distribution of normalized citation counts. The top-cited 1% of publications are identified by field or subfield for a given period. A value above 1.0 indicates that the entity has more highly cited publications than expected based on its share of all publications in that field or subfield. For example, if Paleontology in Canada represented 1% of global publications but 2% of highly cited publications, its HCP1% value would be 2.0.