

THE STATE OF SCIENCE AND TECHNOLOGY IN CANADA, 2012

Executive Summary



Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

THE STATE OF SCIENCE AND TECHNOLOGY IN CANADA, 2012

The Expert Panel on the State of Science and Technology in Canada

THE COUNCIL OF CANADIAN ACADEMIES

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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 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 Council.

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

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The report review procedure was monitored on behalf of the Council's Board of Governors and Scientific Advisory Committee by **Marcel Côté**, Founding Partner of SECOR Inc. The role of the report review monitor is to ensure that the panel gives full and fair consideration to the submissions of the report reviewers. The Board of the Council authorizes public release of an expert panel report only after the report review monitor confirms that the Council's report review requirements have been satisfied. The Council thanks Mr. Côté for his diligent contribution as review monitor.



Elizabeth Dowdeswell, O.C., President and CEO
Council of Canadian Academies

Executive Summary

A detailed understanding of the state of Canadian science and technology (S&T) is fundamental to decision-making related to S&T and innovation, and increasingly important in the rapidly evolving global S&T environment. The Government of Canada, through the Minister of Industry, requested the Council of Canadian Academies (the Council) to undertake an assessment of science and technology in Canada in order to answer the following question:

What is the current state of science and technology in Canada?

Additional direction was provided through two sub-questions:

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? Which scientific disciplines and technological applications have the potential to emerge as areas of prominent strength for Canada?

The Council appointed a multidisciplinary expert panel (the Panel) to address these questions. The Panel's mandate spanned the full spectrum of fields in engineering, the natural sciences, health sciences, social sciences, the arts, and humanities. It focused primarily on research performed in the higher education sector, as well as the government and not-for-profit sectors. The mandate specifically excluded an examination of S&T performed in the private sector (which is the subject of a separate Council assessment on the state of industrial research and development). The Panel's report builds upon, updates, and expands the Council's 2006 report, *The State of Science and Technology in Canada*.

ASSESSING THE STATE OF S&T IN CANADA

The concept of S&T strength is inherently complex and multidimensional and cannot be satisfactorily assessed using any single measure or indicator. Therefore, the Panel adopted a multi-lens approach, incorporating both qualitative and quantitative measures, including bibliometrics (the analysis of peer-reviewed

scientific papers); two opinion surveys, one surveying the top-cited researchers in the world, and the other surveying Canadian S&T experts; technometrics (the analysis of patents); and an analysis of data related to highly qualified and skilled personnel (HQ&SP). Attempts to evaluate additional measures more relevant to the humanities, arts, and social sciences were hampered by lack of available data.

Comparisons and synthesis of the different methodologies were facilitated by the consistent use of a 22-field classification system covering all S&T. Although this classification system is the best available, like all field-based classifications it has limitations. These include the fact that it classifies scientific publications on the basis of the scientific journals in which the research is published, which may differ from the scientific discipline of the authors or traditional academic departments. Despite the inherent limitations of each type of evidence, the collective findings are comprehensive and represent one of the most in-depth examinations of Canadian S&T ever undertaken.

THE CURRENT STATE OF S&T IN CANADA

Canadian S&T, within the scope of this assessment, is healthy and growing in both output and impact. With less than 0.5 per cent of the world's population, Canada produces 4.1 per cent of the world's scientific papers and nearly 5 per cent of the world's most frequently cited papers. In 2005–2010, Canada produced 59 per cent more papers than in 1999–2004, and was the only G7 country with an increase above the world average.

Equally impressive has been the overall impact of Canadian S&T, as measured by Average Relative Citations (ARC) (a bibliometric measure of the frequency of citation of papers), by which Canada is ranked sixth in the world. On a field-by-field basis, Canada's ARC rankings placed it among the five leading countries in the world in 7 of 22 fields of research, and among the 10 leading countries in a further 14 fields.

These bibliometric measurements contribute to a high international regard for the quality and rigour of Canada's S&T. Among authors of the world's top-cited scientific papers, 37 per cent identified Canada as one of the five leading countries in their field, placing Canada fourth overall in the world, behind only the United States, United Kingdom, and Germany. Sixty-eight per cent rated Canadian research in their field as strong compared with the rest of the world. Many of these top-cited researchers also identified world-leading major research facilities and programs in Canada. For fields in the natural sciences, health sciences, and engineering there is a strong correlation between bibliometric impact, in terms

of the share of the top one per cent most highly cited papers, and reputation, indicating the importance of the quality of scientific papers in the international perception of those fields. In contrast, there is no correlation between bibliometric impact and reputation for fields in the humanities, arts, and social sciences, indicating that for those fields other outputs that are not captured by bibliometrics (such as books and exhibitions) are more influential in determining reputation.

Canadian S&T experts also rated Canada's S&T enterprise as strong, although half of those surveyed considered Canada to have lost ground in the past five years.

Canada is part of a network of international S&T collaboration that includes the most scientifically advanced countries in the world. Canadian S&T attracts high quality researchers from abroad, with a sample of publishing researchers in 1997–2010 demonstrating a net migration of researchers into the country.

In contrast to the nation's strong performance in knowledge generation is its weaker performance in patents and related measures. Despite producing 4.1 per cent of the world's scientific papers, Canada holds only 1.7 per cent of world patents, and in 2010 had a negative balance of nearly five billion dollars in royalties and licensing revenues. Despite its low quantity of patents, Canada excels in international comparisons of quality, with citations to patents (ARC scores), ranking second in the world, behind the United States.

FIELDS OF RESEARCH IN WHICH CANADA EXCELS

The multi-lens approach adopted by the Panel provided considerable data on the magnitude, quality, and trends of S&T across fields. Since no single measure alone can be used to identify excellence, depending on the weighting given to each lens, different fields will emerge among the strongest.

The Panel determined two measures of quality, the field's international ARC rank and its rank in the international survey, to be the most relevant in determining the field's position compared with other advanced countries. Based on these measures of quality, the Panel identified six research fields in which Canada excels. These fields are (in alphabetical order):

- Clinical Medicine
- Historical Studies
- Information and Communication Technologies (ICT)
- Psychology and Cognitive Sciences
- Physics and Astronomy
- Visual and Performing Arts

Citation indices rank Canada among the top five countries in the world in five of these six fields. In five of these six fields Canada is also ranked among the top five countries in the world by leading international researchers. Three of the fields (Clinical Medicine, ICT, Physics and Astronomy) are among the five largest research enterprises in the country in terms of output of scientific papers, and the share of world publications in all fields except ICT has grown in 2005–2010 compared with 1999–2004. One of the fields, ICT, accounts for 44 per cent of Canada's patents. Notwithstanding the challenge of assessing research strength in the humanities, social sciences, and creative arts, three of the fields (Historical Studies, Psychology and Cognitive Sciences, Visual and Performing Arts) are at least partly, if not completely, within these disciplines. Collectively, these six fields of strength indicate the breadth of Canadian research excellence.

In addition to six fields of strength, the Panel identified nine sub-fields in which Canada leads the world in scientific impact, as measured by bibliometrics (ARC scores):

- Anatomy and Morphology
- Astronomy and Astrophysics
- Business and Management
- Classics
- Criminology
- Dermatology and Venereal Diseases
- General and Internal Medicine
- Nuclear and Particles Physics
- Zoology

Of these sub-fields, four (Anatomy and Morphology, Business and Management, Criminology, Zoology) are based in fields other than the six identified above. In a total of 56 sub-fields, 32 per cent of the 176 sub-fields studied, Canada is among the top five in the world according to ARC rank.

The data related to strengths in technological applications are less comprehensive, but indicate that Canadian patents related to ICT, Chemicals, and AgriFood have a greater impact than the world average.

GEOGRAPHIC DISTRIBUTION OF S&T STRENGTHS

Canada's most populous provinces, Ontario, Quebec, British Columbia, and Alberta, are the powerhouses of Canadian S&T, by all measures examined in this report. Together they account for 97 per cent of the total Canadian output in terms of scientific papers. Ontario produces 46 per cent of Canada's bibliometric

output, in keeping with the 45 per cent of Canada's gross domestic expenditure on research and development (GERD) that is spent in Ontario. British Columbia is the leading province in terms of impact as measured by ARC.

The same four provinces are most often identified as provinces of strength by Canadian S&T experts, with Ontario most highly ranked in almost all sub-fields. These provinces also have the best performance in patent-related measures, and the highest per capita number of doctoral graduates.

Notwithstanding the dominant position of the four large research-intensive provinces, several fields of particular specialization were also identified in the other provinces, including Agriculture, Fisheries, and Forestry in Prince Edward Island and Manitoba; Historical Studies in New Brunswick; Earth and Environmental Sciences in Newfoundland and Labrador and Nova Scotia; and Biology in Saskatchewan. This diversity among provinces often aligns with local economic strengths and contributes to local and regional clusters of innovation.

IMPROVING AND DECLINING FIELDS OF S&T

This assessment is, in part, an update of the Council's 2006 assessment of the state of S&T in Canada. Results of the two assessments are not entirely comparable due to methodological differences such as the bibliometric database and classification system used in the two studies, and the survey of top-cited international researchers which was not undertaken in the 2006 assessment. Nevertheless, the Panel concluded that real improvements have occurred in the magnitude and quality of Canadian S&T in several fields including Biology, Clinical Medicine, ICT, Physics and Astronomy, Psychology and Cognitive Sciences, Public Health and Health Services, and Visual and Performing Arts. Two of the four areas identified as strengths in the 2006 report — ICT and health and related life sciences and technologies — have improved by most measures since 2006.

The other two areas identified as strengths in the 2006 report — natural resources and environmental S&T — have not experienced the same improvement as Canadian S&T in general. In the current classification system, these broad areas are now represented mainly by the fields of Agriculture, Fisheries, and Forestry; and Earth and Environmental Sciences. The Panel mapped the current classification system for these fields to the 2006 system and is confident that the overall decline in these fields is real, and not an artefact of different classifications. Scientific output and impact in these fields were either static or declined in 2005–2010 compared to 1994–2004. It should be noted, however, that even though these fields are declining relative to S&T in general, both maintain considerable strength,

with Canadian research in Agriculture, Fisheries, and Forestry ranked second in the world in the survey of international researchers, and Earth and Environmental Sciences ranked fourth.

EMERGING AREAS

Although robust methods of identifying emerging areas of S&T are still in their infancy, the Panel used innovative bibliometric techniques to identify research clusters and their rates of growth. Rapidly emerging research clusters in Canada have keywords relating, most notably, to wireless technologies and networking, information processing and computation, nanotechnologies, and digital media technologies.

In another measure of emerging areas, Canadian S&T experts identified personalized medicine and health care, several energy technologies, tissue engineering, and digital media as areas in which Canada is well placed to become a global leader in development and application.

A SNAPSHOT IN TIME

This report provides considerable evidence that Canada's S&T enterprise is highly competitive internationally, with particular strengths in at least six fields of research, in several sub-fields, and in a number of rapidly emerging research clusters.

Although representing only a snapshot in time, this report can inform policy formulation and decision-making related to science, technology, and innovation by governments, academic institutions, and industry.



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