INVESTING IN CANADA'S FUTURE

Strengthening the Foundations of Canadian Research

CANADA'S FUNDAMENTAL SCIENCE REVIEW

2017

CANADA'S FUNDAMENTAL
SCIENCE REVIEW

April 10, 2017

The Honourable Kirsty Duncan
Minister of Science
Government of Canada

Dear Minister Duncan,

We are very pleased to submit the final report of the Advisory Panel on Federal Support for Fundamental Science. The report would not have been possible without the dedication and expertise of a very large number of individuals inside and outside the Government of Canada; they are acknowledged elsewhere. The report has also been informed by our consultations with stakeholders and the public, and by literature reviews and analyses of digital and printed materials from a wide variety of sources, including international research funding agencies. However, the findings and recommendations ultimately reflect our consensus interpretations of the available evidence, and our considered judgments as to what course of action the Government of Canada should follow to strengthen the foundations of Canadian research. We are grateful for the opportunity to provide this advice to you and your Cabinet colleagues. We also remain available, as needed, to assist with interpretation of the report and to advise on its implementation.

Sincerely,

C. David Naylor, *Professor of Medicine,* University of Toronto (Chair)

Robert J Birgeneau, *Silverman Professor of Physics and Public Policy*, UC Berkeley

Martha Crago, *Vice President – Research & Professor of Human Communication Disorders*, Dalhousie University

Mike Lazaridis, *Founder & Managing Partner,* Quantum Valley Investments

Claudia Malacrida, *Associate Vice-President – Research & Professor of Sociology,* University of Lethbridge

Arthur B. McDonald, *Professor Emeritus,* Queen's University

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ACKNOWLEDGMENTS

A report like this can only be written with strong participation by a community. The Advisory Panel for the Review of Federal Support for Fundamental Science benefitted enormously from the formation of a vigorous and insightful community around our mandate. The interest in our work by active researchers, institutions, stakeholder organizations, and the general citizenry was both inspiring and a daunting reminder of the importance of our task.

We received 1,275 written submissions, most of exceptional quality. We are grateful to all who took the time to respond to our call. The Panel also learned a great deal from meetings with researchers that we convened across the country. Some 230 people participated (see Appendix 2 for attendees), and the discussions played a key role in shaping our views. Many participants made special arrangements to travel at their own expense to spend time with us. We expressed our deep appreciation during those meetings, and simply wish to reiterate those sentiments here.

Given the Panel's wide mandate and limited time, we were very fortunate to have enjoyed full cooperation from the three granting councils, the Canada Foundation for Innovation, and other organizations that met with us and responded to our questions. We especially wish to thank Doctors Alain Beaudet of CIHR, Ted Hewitt of SSHRC, Gilles Patry of CFI, and Mario Pinto of NSERC for their time and counsel, and for making their capable staff and information so readily available to us.

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A special acknowledgement goes to Simon Pratt, Director of Policy and Analysis, and Marny Scully, Deputy Chief of Government Relations at the University of Toronto. Mr Pratt's analyses helped immensely with our international comparative profiles of research investments and outputs. They figure strongly in Chapter 3, illuminate Appendix 3, and constitute Appendix 4.

The Council of Canadian Academies was especially helpful in sharing drafts it developed for its report, *Preliminary Data Update on Canadian Research Performance and International Reputation*, released in December 2016. We drew heavily on CCA's analyses and insights for Chapter 3. For their collegiality and valuable contribution to our deliberations, we thank CCA president Dr Eric Meslin, Professor Max Blouw who is chair of the relevant CCA Expert Panel, and Project Director Emmanuel Mongin.

Between the worldwide web and internet, it is reasonably easy to access information on international models of support for science and research. However, we were curious to learn more about Germany's unique and successful strategies. We are therefore indebted to Dr Max Vögler, director of the North American Office of the Deutsche Forschungsgemeinschaft (DFG), who kindly travelled to Toronto and spent an informative day with us.

Finally, we owe a special debt to the members of the secretariat who provided us with exceptional support throughout our work. Ably led by Executive Director Jeannie Dempster who managed an ever-evolving variety of challenges from the beginning to end of our efforts, the secretariat staff organized our consultations, sought out information, and prepared the multiple iterations of briefs that supported our discussions and served as draft preliminary versions of key sections of the report. The team included, in alphabetical order, Aouled-Nasteh Djama (summer student), Erica Hendry, Stephanie Hunter, Nadine Kolas, Valerie La Traverse, Marc Legault, Aaron Percival, and Sreerekha Pillai. Coming together from across the Public Service of Canada, this group brought creative energy and a variety of perspectives that served us very well.

While everyone in the secretariat made an important contribution, we would like to thank in particular a few people who joined us later in the venture and became indispensable. Writer and editor Clare Walker provided us with much needed support and wise guidance in organizing the report and keeping our messages clear. Dr Matthew Lucas from SSHRC lent us his academic expertise and insights into science policy at critical times. Dr Gregory Huyer brought wide-ranging experience and knowledge of the subjects under review, offering consistently excellent advice as we began finalizing drafts, and putting in untold hours to bring the report to fruition.

Last, we wish to express collective gratitude to Robert Dunlop. Mr Dunlop was happily and recently retired from the Public Service of Canada, when the Panel determined that a policy advisor with relevant ADM-level experience would be an invaluable resource to the Panel members and secretariat alike. Mr Dunlop graciously agreed to become a player-coach for the secretariat and went on to make an absolutely enormous contribution to every dimension of the work of the Panel.

Credit for the positive elements of the report is shared fully with all of the foregoing individuals and all those who made submissions or participated in our consultations. Responsibility for errors or omissions rests with the Panel.

TERMINOLOGY & ABBREVIATIONS

A Note on Terminology

Throughout this report, the Panel uses a variety of terms that should be briefly elucidated at the outset.

We use "research" as an umbrella term covering both "science" and "scholarly inquiry". In all cases it refers to work done to generate new knowledge or insights, carried out using methods and reported in forms that can withstand critical scrutiny by expert peers.

The distinction between science and other forms of scholarly inquiry is not straightforward; readers can find hundreds of thousands of words published on that topic. As our aim is to be inclusive, we take a pragmatic approach: science is done by scientists; scholarly inquiry is carried out by those with similar motivations who use methods that are often distinct from those used by scientists. With the same inclusive orientation, we comment briefly in the report on the complex interplay between basic and applied research.

Another terminology issue concerns the characterization of different kinds of grants and awards.[i] The largest group of awards, delivered through well-known programs such as Discovery (NSERC), Project/Foundation Grants (CIHR), and Insight (SSHRC), covers costs such as research material, small equipment, professional services, travel, workshops and seminars, and stipends for students. These awards are commonly referred to as "research grants" or "research operating grants". However, in this report we refer to them as "direct project funding" to distinguish them from the other operating costs that we examine, including awards covering capital equipment, equipment operating costs, personnel, and the institutional costs of research.

We also found it useful to divide direct project funding into two broad groups. The first group is support for what can be called "investigator-led research", also termed discovery-oriented, inquiry-driven, or simply "independent"—a concise description that we have used most often for this group. In this category, grant-making competitions are structured such that decisions about what to study and how to conduct research rest largely with researchers themselves.

The second group is what we term "priority-driven research". This includes research carried out in partnership with government, business, and non-profit sectors where the partnership is pre-specified as a condition rather than chosen by researchers as the preferred mode of pursuing a line of investigation. The category also includes competitions with tightly defined areas of focus. One federal agency has placed these latter grants in the "investigator-led" category on the grounds that researchers have latitude to pursue varied lines of investigations within the defined focus, but the Panel believes they are better situated here. In like fashion, this category includes direct project funding with formal network configurations and institutional block grants. Some of these competitions involve both top-down priorities and requirements for partnerships and matching funds. Priority-driven research also includes programs with a strong innovation or knowledge translation focus directed towards a specific application. As these programs are outside the Panel's mandate, we did not examine them in detail.

i We use these terms interchangeably but recognize that in some circumstances they have different meanings.

The Panel fully appreciates that direct project funding within the "priority-driven" category can generate important new knowledge and insights, assuming researchers are given appropriate independence in defining methods, interpreting results, and publishing the relevant reports. Furthermore, as will become clear, we believe that some degree of pluralism in funding arrangements is essential for the health and resilience of any research ecosystem. However, among the reasons the Panel was constituted was to assess whether federal patterns had shifted such that fully independent research was no longer adequately supported. These distinctions, and the associated terminology, will therefore figure on a number of occasions in the course of the report.

Abbreviations

BERD	business enterprise expenditures on R&D
CCA	Council of Canadian Academies
CCI	College and Community Innovation
CCV	Common CV
CECR	Centres of Excellence for Commercialization and Research
CERC	Canada Excellence Research Chairs
CFI	Canada Foundation for Innovation
CFREF	Canada First Research Excellence Fund
CGS	Canada Graduate Scholarships
CIFAR	Canadian Institute for Advanced Research
CIHR	Canadian Institutes of Health Research
CRC	Canada Research Chairs
CREATE	Collaborative Research and Training Experience
CSA	Chief Science Advisor
CSO	Chief Science Officer
DG	Discovery Grant
DRI	digital research infrastructure
ECR	early career researcher
F&A	facilities and administration
FPT	federal-provincial-territorial
GERD	gross domestic expenditures on R&D
HERD	higher education expenditures on R&D
HQP	highly-qualified personnel
HR^2	high-risk, high-reward
IOF	Infrastructure Operating Fund
ISED	Innovation, Science and Economic Development

JELF	John R. Evans Leadership Fund
KIP	Knowledge Infrastructure Program
KTEE	knowledge translation, exploitation, and exchange
LCDI	Leadership Council for Digital Infrastructure
MRC	Medical Research Council of Canada
MRF	major research facility
MSI	major science initiative
NACRI	National Advisory Council on Research and Innovation
NCE	Networks of Centres of Excellence
NIH	National Institutes of Health (U.S.)
NRC	National Research Council (Canada)
NSA	National Science Advisor
NSE	natural sciences and engineering
NSERC	Natural Sciences and Engineering Research Council
NSF	National Science Foundation (U.S.)
O&M	operating and maintenance
PCO	Privy Council Office
PDF	postdoctoral fellow
PI	principal investigator
PMO	Prime Minister's Office
PSE	postsecondary education
R&D	research and development
RSF	Research Support Fund
RTI	Research Tools and Instruments
SPOR	Strategy for Patient-Oriented Research
SSH	social sciences and humanities
SSHRC	Social Sciences and Humanities Research Council
STEM	science, technology, engineering, and mathematics
STIC	Science, Technology and Innovation Council
UCASS	University and College Academic Staff System

ABSTRACT

Canadian accomplishments in science and scholarly inquiry have long been a source of national pride. However, by various measures, Canada's research competitiveness has eroded in recent years when compared with international peers. The change coincided with a period of flat-lining of federal spending through the four core funding agencies that support researchers in universities, colleges, institutes, and research hospitals. In those years funds were also directed preferentially to priority-driven and partnership-oriented research, reducing available support for independent, investigator-led research by frontline scientists and scholars.

The proportion of federally derived funding for research has also declined. Canada ranks well globally in higher education expenditures on research and development as a percentage of GDP, but is an outlier in that funding from federal government sources accounts for less than 25 per cent of that total, while institutions now underwrite 50 per cent of these costs with adverse effects on both research and education.

Despite high levels of talent, expertise, and dedication on the part of those serving each agency, there is evidence to suggest that the overall stewardship of the federal research ecosystem needs to be strengthened. Coordination and collaboration among the four agencies is suboptimal, with variations in governance, administrative practices, and funding priorities within and across agencies that are not explicable either by disciplinary differences or by the needs of the relevant research communities. Investments in infrastructure and related operating costs are not consistently aligned, and funding for areas such as international partnerships or multidisciplinary research is uneven. Early career researchers are struggling in some disciplines, and a career-spanning strategy for operating and personnel supports is lacking. For example, flagship personnel programs such as the Canada Research Chairs have had the same value since 2000. Levels of funding and numbers of awards for students and postdoctoral fellows have not kept pace, variously, with inflation, peer nations, or the size of the applicant pools.

This report accordingly outlines a comprehensive agenda to strengthen the foundations of Canadian extramural research. It recommends legislation to create an independent National Advisory Council on Research and Innovation (NACRI). Working closely with Canada's new Chief Science Advisor (CSA), the new council would raise the bar in terms of ongoing evaluations of all programming. The report also recommends wide-ranging improvements to oversight and governance of the four agencies, including the appointment of a coordinating board chaired by the CSA. Other changes would promote lifecycle oversight of national-scale research facilities, and improved methods for initiating, reviewing, and renewing or terminating contribution agreements with external non-profit entities operating in the research realm.

Concurrent with these improvements designed to augment the effectiveness, accountability, and efficiency of various elements of the system, significant reinvestment is required. This reinvestment should be undertaken on a multi-year basis, coupling predictability with better planning. Targeted increases are recommended based on benchmarking, contingent in several cases on presentation and approval of multi-agency plans for improvements to programs. New spending would be balanced across:

- investigator-led research operating grants (the highest priority);
- enhanced personnel supports for researchers and trainees at different career stages;
- targeted spending on infrastructure-related operating costs for small equipment and Big Science facilities; and
- enhancement of the environment for science and scholarship by improved coverage of the institutional costs of research.

The cumulative base increase would move annual spending in steady-state across the four agencies and closely related entities from approximately $3.5 billion to $4.8 billion. This phased-in increase requires dedicating an additional 0.4 per cent of the Government of Canada's annual budget to an area of shared jurisdiction where federal leadership is essential and welcomed. Given global competition, the current conditions in the ecosystem, the role of research in underpinning innovation and educating innovators, and the need for research to inform evidence-based policy-making, it is also among the highest-yield investments in Canada's future that any government could make.

EXECUTIVE SUMMARY

1. Mandate and Consultations

The Advisory Panel on Federal Support for Fundamental Science was appointed in June 2016. Our mandate entailed a review of the federal system of supports for extramural research, understood to be research conducted by scientists and scholars employed outside of federal, provincial, or territorial government departments and agencies.

Our mandate was further clarified as follows. We were expected to cover the full range of disciplines involving peer-reviewed science or inquiry, with either a basic or applied orientation. As well, our focus was to be on programs supporting knowledge generation, as contrasted with programs oriented primarily to fostering partnerships with industry or civil society, or promoting knowledge translation, innovation, and commercialization.[i] We focused our work primarily on the four pillar agencies that support the Canadian extramural research ecosystem: the three granting councils—the Natural Sciences and Engineering Research Council (NSERC), the Canadian Institutes of Health Research (CIHR), and the Social Sciences and Humanities Research Council (SSHRC)—as well as the federal infrastructure agency, the Canada Foundation for Innovation (CFI).

Consistent with our mandate, we examined funding arrangements in peer nations. Our assessments have been shaped by their international practices, and by the organizing principles we observed in the strongest agencies and programs here and abroad. These principles may be encapsulated by the following brief descriptors: World-leading and Globally-collaborative; Meritocratic; Independent yet Accountable; Coordinated; Balanced; Responsive; Talent-focused; Diverse and Equitable; Efficient; and Outward-facing.

The Panel's call yielded 1,275 written submissions from individuals, associations, and organizations. We also convened roundtables in five Canadian cities, engaging some 230 researchers at different career stages in conversations on diverse topics. We identified many strengths and found much to commend.

Our mandate, however, was to identify gaps and address specific questions posed by the Minister of Science. The concluding chapter of the report addresses each of those questions. This précis in contrast tracks the logic of the report itself, opening with an overview of the system's funding and performance and then summarizing our recommendations in three interlocking categories.

2. Funding

Canadian gross domestic expenditure on R&D from all sources relative to GDP (GERD intensity) has been declining slowly over the last 15 years, as contrasted with our G7 peers and key east Asian nations. Worldwide, including non-OECD nations, we are no longer in the top 30 nations in terms of total research intensity. HERD is a subset of GERD related to extramural research conducted by institutions of higher education and affiliates. In 2014 Canada's HERD intensity was seventh in the OECD, but highest in the G7.

i The Advisory Council on Economic Growth has recently recommended a wide-ranging review of federal supports for innovation. We have endorsed that recommendation (**R1.1**), and indicated areas of synergy with our other recommendations.

This higher standing compared with overall R&D spending is often linked to the growth in federal research spending that started in 2001, and seems at odds with the extensive concerns about funding that we heard from scientists and scholars. However, in 2015 almost 50 per cent of HERD in Canada was funded by universities and colleges themselves, while the federal government contributed only 23 per cent. Internationally this is a highly anomalous situation, and it is having adverse effects on both research and higher education across Canada.

As well, growth in federal spending was matched by growth in the number of people engaged as researchers at Canadian universities and colleges. Thus, in constant dollars, granting council funding per researcher has been in steady decline since 2008-09. We examined a number of international peer jurisdictions and found no evidence that there was either unusually fast growth in Canada or that there is now a uniquely Canadian glut of extramural researchers. Indeed, for doctoral-level graduation rates, Canada ranked 22nd among 35 comparator OECD countries in 2013; contrary to popular belief, Canadian enterprises in the for-profit and not-for-profit sectors are hiring PhDs at a rate commensurate with rising graduation rates.

The years from 2006-07 to 2013-14 also saw a shift in funding away from independent research, be it basic or applied, that allows individuals or teams to define their topics and/or the structure of the research collaboration. We estimated that scholars, scientists, and trainees wishing to pursue fully independent research work saw a decline of available real resources per researcher of about 35 per cent in that period.

3. Performance Measures

There are many possible measures of the quality and impact of science and scholarly inquiry. Two commonly used are summarized here: bibliometric analyses of publication counts in indexed journals and profiles of major prizes and awards. Canada's publication output is growing, but, according to a December 2016 update from the Council of Canadian Academies: "Production of publications in most fields of research in Canada grew more slowly than the world average in 2003–2014. This is a change from the 2012 report, which noted that half of the fields grew more quickly than the world average in 1999–2010." As a result, Canada's global rank in total research output dropped, from seventh in 2005–2010 to ninth in 2009–2014, as Italy and India moved ahead. Examining numbers of recent publications in *Nature* and *Science*, the two flagship journals of basic research, Canada ranked 8th among nations, with only 1 Canadian institution in the top 20 worldwide, and 2 more in the top 100.

Citations, which occur when publications are referenced in articles by other scientists and scholars, are a proxy for impact of Canadian-authored work. Canadian papers were cited at a rate 43 per cent higher than the global average in 2009–2014, standing commendably in the top six nations globally. However, our growth rate ranked 15th, suggesting again that Canada is stalling relative to peers. Examining the numbers of publications in the top 1 or 10 per cent worldwide for frequency of citation, on a per capita basis Canada lags other small nations such as the Netherlands, Sweden, and Switzerland.

Canada's performance in winning international prizes is trailing traditional powerhouses such as the U.S. and U.K. It is also well behind Australia, which now outperforms Canada on several other measures. In recent decades, twice as many Canadians have won research-related Nobel prizes while working in the U.S. as have been awarded to Canadian-born or foreign-born scientists working in Canada.

4. Findings and Recommendations in Brief

We emphasize that the summary of findings and recommendations below is highly abbreviated. It would be irresponsible for any secondary summary or other interpretation of our report, let alone policy action, to depend solely on this précis rather than on careful reference to the full text.

4.1 Broad Oversight, Rigorous Evaluation

Based on consultations and its own research, the Panel concluded that Canada's federal research ecosystem, despite many strengths, is weakly coordinated and inconsistently evaluated, and has not had consistent oversight. Further, the links between extramural and intramural research should be strengthened, as should federal-provincial-territorial (FPT) collaboration. The current external advisory body, the Science, Technology and Innovation Council (STIC), has no independent reporting authority and a constrained disciplinary mandate. The imminent appointment of a new Chief Science Advisor (CSA) for Canada is a major step forward, but more needs to be done.

We recommend (**R4.1**)[ii] that the Government of Canada, by an Act of Parliament, should create a new National Advisory Council on Research and Innovation (NACRI) to provide broad oversight of the federal research and innovation ecosystems. STIC should be wound down as NACRI is established **(R4.2)**.

NACRI should have 12 to 15 members, appointed through Orders in Council, comprising distinguished scientists and scholars from a range of disciplines as well as seasoned innovators with strong leadership and public service records from the business realm and civil society. Domestic members should be drawn from across Canada and reflect the nation's diversity and regions **(R4.3)**. An external member should hold the Chair of NACRI with the CSA serving as Vice Chair. NACRI should be supported by a dedicated secretariat working within the larger expert team supporting the CSA **(R4.4)**.

As a council of senior volunteers with a broad mandate of national importance, NACRI should have a publicly acknowledged working connection to the Prime Minister/PMO, parallel to that established for the CSA. NACRI should report to and interact most directly with the Minister of Science and the Minister responsible for Innovation and Economic Development, and liaise closely with the Minister of Health given Health Canada's linkages to CIHR. It should also have open channels of communication with ministers of key departments involved in intramural and extramural research (**R4.6**). Connections to officials in Finance will be particularly important to facilitate input by the CSA/NACRI on intramural and extramural research budgets.

Among NACRI's responsibilities would be:

- advice to the Prime Minister and Cabinet on federal spending as well as broad goals and priorities for research and innovation;
- improving the coordination and strategic alignment of different elements of federal support for research and innovation;
- evaluation of the overall performance of the extramural research enterprise;
- public reporting and outreach on matters determined by the Council;
- confidential or public advice on other matters as requested by the Government of Canada;
- a foresight function for research and innovation;
- in concert with the CSA, ongoing advice on (i) the effectiveness of extramural research agencies and the intramural research groups, and (ii) the facilitation of collaboration among them and with the extramural research realm;
- advice on unusual requests for research support that fall outside the usual remit of the granting councils and CFI; and
- liaison with parallel bodies in provinces and territories and internationally as appropriate.

ii R4.1, etc. correspond to Recommendation 4.1, etc. in our report.

A relatively recent development has been the growth in numbers of "contribution agreements" whereby the Government of Canada channels research funds through or directly into external entities (e.g., Genome Canada or Mitacs). We did not review specific entities in detail, but believe more rigorous reviews should be undertaken before agreements are renewed. The Panel therefore recommends **(R5.8)** that NACRI be mandated not only to review proposals to create new third-party delivery organizations, but also to guide the periodic review processes for all existing third-party organizations, and advise as to the continuation or modification of their contribution agreements. As well, the Panel applauds the success of these entities in leveraging research funds, but recommends careful oversight of the implications of placing matching requirements on the funding of independent research **(R5.9)**.

A more interconnected intramural research realm is important both for sound policy formulation and for collaboration with extramural researchers. The Panel accordingly recommends **(R4.5)** that the Privy Council Office, working with departmental officials and the newly appointed CSA, examine mechanisms to achieve improved whole-of-government coordination and collaboration for intramural research and evidence-based policy-making.

As well, many informants recommended that the federal government should manage its investments in Big Science in a more coordinated manner. The Panel agrees. We recommend (**R4.7)** that the CSA convene a Special Standing Committee on Major Research Facilities (MRFs), chaired by an eminent scientist. This body would provide advice on the life cycle of federally supported MRFs, extending from a peer-reviewed decision to initiate an MRF, through budgeting, planning, and construction, then periodic reviews of effectiveness, and finally a decommissioning plan. Our report offers advice on the structure of the committee, its intersection with NACRI, and a tentative list of major science initiatives (MSIs) that might be considered to fall into the MRF category. This expert group would also improve decision-making about Canada's participation in global science initiatives, such as major astronomical telescopes.

Strong FPT collaboration is essential if Canada is to compete internationally. The Panel learned that interactions among the relevant officials and ministers are sporadic. Among the issues that seem likely to benefit from enhanced dialogue are matching requirements, human resource planning for research and innovation, and the institutional costs of research.[iii] We accordingly recommend **(R4.8)** that the CSA, with advice from NACRI, take the lead in promoting a shared agenda on matters of national concern. Ongoing interactions and annual in-person meetings should be established to strengthen collaborative research relationships among FPT departments with major intramural or extramural research commitments.

This is a special year for Canada. In that spirit, we recommend **(R4.9)** that the Government of Canada propose and initiate planning for a First Ministers' Conference on Research Excellence in 2017, both celebrating and cementing a shared commitment to global leadership in science and scholarly inquiry as part of Canada's sesquicentennial celebrations.

4.2 The Four Agencies: Strengthened Core, Better Coordination

The granting councils and CFI have made a vital contribution to Canadian science and scholarly inquiry. However, while assorted self-commissioned evaluations have occurred, the Panel could not find any broad external review of the federal agencies and research ecosystem since the 1970s. It is perhaps unsurprising that the Panel heard and read concerns about coordination, governance, strategy, budgeting, and programming. For example, while there is some apparent congruence in the conceptual basis of the Discovery (NSERC), Insight (SSHRC), and Foundation (CIHR) programs, success rates, funding levels, and peer review practices have all diverged across those programs to a degree that is hard to explain based on disciplinary differences alone.

iii This latter group of costs is sometimes (inaccurately) termed "indirect costs"; we believe, however, that the term, "facilities and administration costs" (F&A costs), better captures the direct financial impact of these activities.

There have been encouraging but piecemeal efforts to improve coordination, promote collaboration, and share best practices. However, the inconsistent governance of the agencies means that these have been highly dependent on the preferences of agency presidents. To improve this situation, the Ministers of Science and Health should **(R4.10)** mandate the formation of a formal coordinating board for the four agencies, chaired by the CSA, with membership including agency heads, department officials, and external experts. Reporting to the Ministers of Science and Health, the new Four Agency Coordinating Board would expeditiously determine and implement avenues for harmonization, collaboration, and coordination of programs, peer review procedures, and administration. In the event that the CSA and NACRI determine that progress on a shared agenda is unduly slow, the Board's composition would be revised and its authority extended such that its decisions would be binding for coordination of the agencies.

The Panel identified several areas that require the early attention of the new Board and the four agencies. Elimination of mandatory retirement has led to an aging of the professoriate, and is likely to constrain opportunities for early career researchers (ECRs) over the next decade. We also observed that the prospects for ECRs vary across the three granting councils, not only creating a demographic deficit, but also impeding the progress of women and other underrepresented groups that are more prevalent in the next generation, e.g., Indigenous people, those with disabilities, and members of racialized groups. Peer review practices vary, the program landscape is cluttered, and inefficiencies were identified by researchers in the organization and administration of grant competitions.

We accordingly recommend **(R5.2)** that the Government of Canada direct the new Coordinating Board to develop and harmonize funding strategies across the agencies, using a lifecycle approach that balances the needs and prospects of researchers at different stages of their careers. The four agencies should examine best practices in supporting ECRs, augment their support of ECRs at consistent levels across disciplines, and track and report publicly on the outcomes **(R5.6)**.The Board should **(R5.3)** also create a mechanism for harmonization as well as continuous oversight and improvement of peer review practices across the three councils and CFI, starting with a common set of guiding principles or values for peer review.

A further priority should be **(R5.4)** the development of consistent and coordinated policies to achieve better equity and diversity outcomes in the allocation of research funding while sustaining excellence as the key decision-making criterion. On this latter point, given experience with unaddressed gender bias in allocation of both Canada Research Chairs (CRCs) and Canada Excellence Research Chairs (CERCs), the federal ministers responsible should consider hard equity targets and quotas where inexplicable discrepancies persist **(R5.5)**.

Approximately 1.5 million Canadians have Indigenous roots, but the participation of this community in science and scholarly inquiry continues to be limited. As a small nation, Canada cannot compete globally in any realm without strong participation by all communities. The three granting councils should **(R5.7)** accordingly collaborate in developing a comprehensive strategic plan to promote and provide long-term support for Indigenous research, with the goal of enhancing research and training by and with Indigenous researchers and communities. The plan should be guided by the Truth and Reconciliation Commission's recommendations on research as a key resource.

The Panel also examined the legislative history, governance, and mandates of each of the four agencies. CFI functions as an independent non-profit with the president accountable to a corporate board, and the entire operation subject to a contribution agreement. If CFI moves from intermittent contributions to a regularized A-base budget, as recommended below, its governance will need to be revised. NSERC, SSHRC, and CIHR are all departmental corporations with advisory councils. Whereas SSHRC and NSERC have skeletal legislated mandates, the CIHR Act embodies an expansive and detailed mandate. Accountabilities for the tri-council presidents are less than clear.

The Government of Canada should (**R4.11**) undertake a comprehensive review to modernize and, where possible, harmonize the legislation for the four agencies that support extramural research. The review would clarify accountabilities and selection processes for agency councils and presidents, promote good governance and exemplary peer review practices, and give priority to inter-agency collaboration and coordination. On this last point, the goal must be to strengthen linkages between agencies, and not to thicken the walls of silos. Initiation of the Four Agency Coordinating Board should precede any legislative review.

Last, the Panel considered the thorny issue of allocation of funds across the three granting councils. We found no logical consistency to the current allocations but it is clear that all three councils are currently underfunded. CIHR's expansive mandate is not appropriately supported; its budget is sharply lower on a per capita basis than the counterpart U.S. National Institutes of Health, even taking into account the standard differences in funding models between U.S. and Canadian agencies. NSERC has a larger weighting of innovation-facing or priority-driven programming. While it does have much higher approval rates than the other councils for its flagship Discovery program, funding constraints above all have held the average size of those grants at a seriously suboptimal level for 15 years. Despite claims that funds are allocated on a 40-40-20 basis across the councils, SSHRC's share has been under 15 per cent for three decades. It has the largest constituency of faculty-level researchers, but over half of its funding goes to graduate awards. Its share of tri-council funding is likely to fall owing to its minimal participation in the large-scale Canada First Research Excellence Fund (CFREF) launched in 2015.

The Panel sees a period of reinvestment as the right moment for NACRI to review the allocation of new funds across the granting councils and recommend changes as appropriate **(R5.1)**. Particular attention should be paid to evidence that the structures of tri-council programs have adversely affected the funding opportunities for scholars in the social sciences and humanities.

4.3 Strategic Clarity and a Multi-year Plan for Renewal

The Panel's overall conclusion is that independent science and scholarly inquiry have been underfunded for much of the last decade, as the federal government has concentrated resources on innovation-facing and priority-driven programs. In reaching that conclusion we considered the small and declining share of HERD attributable to the federal government; Canada's anomalous dependence on institutional subsidies to carry the extramural research enterprise; and our declining research performance on multiple measures, as compared not just with traditional powerhouses, but with smaller nations such as Australia and the Netherlands. We weighed temporal trends in per researcher funding, the demographics of the research community, Canada's density of full-time researchers and senior research trainees, and, not least, the distressingly low success rates (CIHR) and persistently low funding levels (NSERC, SSHRC) in the granting competitions that support independent research. We have no doubt that a major boost to funding for the ecosystem is urgently needed, with shortfalls affecting research operating grants, personnel awards, reimbursement of the institutional costs of research, and operations and maintenance of specific types of facilities.

4.3.1 Direct Project Funding: Research Operating Grants

The Panel's single most important recommendation **(R6.1)** is that the federal government should rapidly increase its investment in independent investigator-led research to redress the imbalance caused by differential investments favouring priority-driven targeted research over the past decade. The recommended investment is $485 million, phased in over four years, directed to funding investigator-led research. This is an increase of about 30 per cent on the $1.66 billion envelope currently committed to direct project funding for both priority-driven and investigator-led research. This would move the balance of funding within this envelope a meaningful distance back towards the 70:30 ratio in favour of investigator-led research that prevailed in the early 2000s. The lion's share of this amount, $405 million a year, would be devoted to the granting councils' core "open" competition programs. While the remainder would support investigator-led projects, it would be channelled to promote the emergence of a more vibrant research ecosystem by encouraging international collaborations, multidisciplinary work, high-risk ventures, and projects requiring rapid response. These are examined, in turn, below.

The Panel also examined the configuration of two priority-driven programs that, while constrained in key respects, provide operating funds to coalitions of frontline researchers. Each aims to create critical mass in a different way. The "classic" element ($62 million per year) of the Networks of Centres of Excellence (NCE) suite of programs draws together researchers from multiple institutions. It imposes requirements for knowledge translation and commercialization that preclude or limit the creation of national networks of independent researchers, especially those working in basic research and, to some extent, in the social sciences and humanities more generally. CFREF is a newer program that aims to promote institutional specialization; some limited inter-institutional networks emerged in the second round of funding, but its strategic intent is one of local critical mass rather than national capacity. The concentration of funds is significant, approximating $200 million per year flowing into a limited number of centres for research in specific areas aligned with the previous government's science and technology priorities.

The Panel sees these two strategies as complementary over time, but recommends refinements in one case, and a mid-course evaluation for the other. In particular, the Government of Canada should **(R6.2)** direct the new Four Agency Coordinating Board to amend the terms of the NCE program so as to include the fostering of collaborative multi-centre strength in basic research in all disciplines. This would mean, *inter alia,* removing requirements for knowledge "exchange and exploitation" and expectations of funding self-sufficiency for some competitions. For CFREF, the Panel recommends (**R6.3)** that an interim evaluation be undertaken before the third wave of awards is made. The CSA and NACRI should be engaged in the design of the review.

There are also four areas where operating grants are being made on an ad hoc basis. The Panel believes that these areas require a more systemic and coordinated approach, supported by earmarked funding.

First, international collaborations have become the norm in research. A stronger mechanism is needed for funding smaller- and mid-scale collaborative projects so that Canadian agencies and researchers can be more effective partners and participants in global science and inquiry (**R6.4**).

Second, multidisciplinary research continues to grow in prevalence and importance. The councils have taken steps to support some joint initiatives, but the Panel believes that more must be done—not only to welcome and fairly review multidisciplinary proposals, but also to ensure that individuals working in convergent fields (e.g., health law, medical anthropology, design) are not orphaned **(R6.5)**.

Third, the councils should (**R6.6)** develop a coordinated strategy for adjudicating and supporting high-risk, high-reward (HR^2) research. Other jurisdictions have successful HR^2 programming from which Canada should learn.

Fourth and finally, crises and urgent issues may occasionally require rapid responses by the research community. These needs have been accommodated in an ad hoc fashion in recent years, but a more formal process involving the CSA would be appropriate today **(R6.7)**.

The required funds for these four areas can arguably be aggregated in one or two contingency pools. Given extant funding pressures and challenges in the governance and oversight of the councils, we recommend that a portion of the base increase of $485 million be earmarked for these purposes, starting at $20 million in base funding in the first year, and rising progressively to a steady-state of $80 million per year over four years, with early priority given to strengthening international collaboration.

4.3.2 Infrastructure

CFI confers distinct strategic advantages on Canadian research by depoliticizing research infrastructure decision-making. It functions as a core agency, but is governed by contribution agreements with a separate non-profit corporate structure because it originally received and held unspent year-end funds. The federal government terminated that funding model, and CFI has since been funded by large and intermittent one-time-only allocations that it deploys over some years. The resulting saw-tooth pattern of funding impedes planning and coordination. Continued A-base funding would be budget neutral.[iv] The Panel recommends **(R6.8)** that the Government of Canada shift CFI to a stable annual budget scaled at minimum to its recent annual capital commitment (currently around $300 million per year). This shift would likely require governance changes, covered as part of the four agency review recommended above **(R4.11)**.

The need for further growth in CFI's capital fund should be monitored. However, the Panel observes that the relevant sectors have benefitted both from the Knowledge Infrastructure Fund (2009–2011) and the ongoing Post-Secondary Institutions Strategic Investment Fund (2016–2018).

CFI's institutional operating and maintenance (O&M) outlays are provided through its Infrastructure Operating Fund and scaled to recent capital awards. These one-time allocations serve more as a pool of funds in support of start-up costs than as a continuing offset of the institutional costs of research. We address those liabilities below.

As contrasted with the one-time O&M support to institutions, CFI since 2010 has provided ongoing funding to a number of MSIs. The MSI funding mirrors CFI's capital ratio (40:60) for matching of eligible O&M costs. A number of national-scale MSIs are struggling to meet this matching requirement. We have recommended **(R4.7** above**)** additional oversight for these MRFs with a view to averting future problems, but these national facilities are unfortunately at immediate risk. We therefore recommend (**R6.10)** that the federal government mandate and fund CFI to increase its share of the matching ratio for national-scale MRFs from 40 to 60 per cent. The annual cost of doing so is estimated at $35 million.

One other element of infrastructure that drew our attention relates to the digital research realm. There are many players active here, and an effort is underway to develop a coordinated plan through the Leadership Council on Digital Infrastructure. The two cornerstone organizations receiving federal funding are Compute Canada and CANARIE. We recommend **(R6.9)** that the Government of Canada merge these organizations and provide the new entity with consolidated long-term funding and a mandate to lead in refining and implementing a national digital research infrastructure (DRI) strategy.

4.3.3 Personnel

Support for Doctoral Students and Postdoctoral Fellows.

Doctoral students and postdoctoral trainees or fellows (hereafter PDFs) are integrally involved in the majority of postsecondary research in Canada. The recommended increase in support for independent investigator-led funding will enhance stipendiary support and enrich the training environment for graduate students and PDFs across the ecosystem. However, while these and other sources of support (institutional, provincial, industrial, and charitable) underwrite most of the relevant salaries and awards, we estimate that over 6,000 doctoral students and 1,400 PDFs across Canada hold direct federal awards at any time. These awards set a bar for funding and quality.

The number of core graduate awards (Canada Graduate Scholarships) has not increased since 2007 despite major increases in graduate enrolments. In addition, the value of graduate awards has not changed since

iv CFI does not currently have continuing A-base funding, but the Department of Finance makes provision for its ongoing expenditures. As we are recommending that CFI spending on capital continue at recent activity levels, this recommendation is budget neutral.

2003, and PDF awards levels are similarly lagging, not least in comparison to U.S. rates. There is also a puzzling mix of council-specific and tri-council awards, with variation in value, duration, and international portability. The complexity was augmented in 2008 and 2010 with the addition of smaller numbers of more remunerative awards to doctoral students (Vanier) and PDFs (Banting), respectively. These are flexible as regards recruitment of international students or international placements for domestic students, but their numbers are small. A clear strategy is needed to increase the recruitment of top-flight international graduate students and PDFs, and to ensure that more domestic students and trainees have opportunities to learn from international exposure to leading scientists and scholars.

We recommend **(R7.1)** that the Four Agency Coordinating Board be directed to oversee a tri-council process to reinvigorate and harmonize scholarship and PDF fellowship programs, and rationalize and optimize the use of current awards to attract international talent. While strict uniformity may be neither feasible nor desirable, more consistent and, in many cases, more generous levels of support (value and duration) are needed. We undertook benchmarking to estimate the financial implications of harmonizing, upgrading, and bringing strategic focus to the system of graduate student and PDF supports. As a result of these analyses, we recommend that a total base increase of $140 million per year be phased in over four years, in equal increments of $35 million per year.

Research Chairs for Excellent Scholars and Scientists

The major sources of federal funding for researcher salary support are the CRC and CERC programs. Launched in 2000, the CRC program aimed "to attract and retain some of the world's most accomplished and promising minds" by creating 2,000 research professorships across Canada. Chairs are allocated to institutions based on shares of competitive grant funding received from the three councils. Tier 1 Chairs, valued at $200,000 per year, are intended for researchers recognized as world leaders in their fields and renewable on seven-year terms. Tier 2 Chairs, valued at $100,000 per year, target exceptional emerging researchers, and can be renewed once with a five-year term. The value of these awards has not changed for 17 years.

The CERC program was established in 2008 to "support Canadian universities in their efforts to build on Canada's growing reputation as a global leader in research and innovation." It awards world-renowned researchers and their teams up to $10 million over seven years to establish ambitious research programs at Canadian universities. The 27 CERCs awarded to date are non-renewable and require 1:1 matching funds from the host institution. All CERCs have been recruited from abroad. All, until the most recent round, have been constrained to the government's STEM-related priorities, restricting their availability for scholars and scientists from the SSHRC-supported disciplines.

A 2016 evaluation of the CRC program observed that a rising number of chairholders originated from within the host institution, with a further 14.4 per cent recruited from other Canadian institutions. For the 2010–2014 period, international recruits accounted for only 13 per cent and 15 per cent of new Tier 1 and 2 nominees, respectively, whereas in 2005–2009, the averages were 32 per cent and 31 per cent, respectively.

Due to turnover and delays in filling Chair positions, approximately 10 to 15 per cent of Chairs are unoccupied at any one time. As a result, the CRC program's budget was cut by $35 million in 2012. This predictably drove numbers down further, with an all-time low of only 1,612 Chair positions (80.6 per cent of the original plan) filled as of December 2016.

This flagship program is vitally important to Canada and requires major renewal. We recommend **(R7.2)** a three-stage process. First, funding of the overall program should be restored to 2012 levels (a $35 million base commitment), but only after the granting councils and Chair Secretariat produce an approved plan for (i) allocating the new Chairs asymmetrically in favour of Tier 2 awards to help ECRs, and (ii) improving logistics in managing numbers and reducing delays in awarding Chairs so as to improve the uptake of available funds.

Second, the granting councils should be directed to cap the number of renewals of Tier 1 Chairs, and develop a plan in concert with universities and CFI to reinvigorate international recruitment and retention.

Third, once that plan is reviewed by NACRI and approved by the government, the value of the CRCs should be adjusted to account for their loss in value due to inflation since 2000 (estimated cost of $105 million). Staged over two to three years, the total cost is approximately $140 million.

The disciplinary distribution of CRC awards should be re-examined *pari passu* with the review recommended in **R5.1**. Closer scrutiny of internal nominations is needed to ensure that they reflect proven retention priorities. We also support setting specific targets for international recruitment, as recommended by the recent CRC evaluation.

Last, the Panel heard many concerns about the relative value of the CERC awards, and the uncertain sustainability of programs that focus such substantial resources around a single international recruit. The Panel acknowledges the quality of the CERCs who currently hold these awards, and the need for high-value awards to attract the brightest and best from around the world. However, the extant evaluations are not adequate. A detailed review of the relative cost-benefit of the CERC versus CRC programs should be undertaken in 2017 to determine where the investments should be directed for the greatest impact.

If the renewal of the CRC program is not sufficient in itself to improve international recruitment, then specific modifications of the program to that end may be a more sustainable strategy than the CERCs currently are likely to provide.

4.3.4 Facilities and Operations

The CFI Infrastructure Operating Fund (IOF) provides a one-time payment equivalent to 12 per cent of the total capital. This treatment contrasts with the partial funding of ongoing operating costs as is provided for MSIs. The large shortfall in coverage of the institutional costs of research means that these funds are not always available to individual researchers and teams that rely on small-scale equipment, leading to a productivity drain. The Government of Canada should **(R6.11)** accordingly mandate and fund CFI to meet the special operating needs of individual researchers with small capital awards. We benchmarked this need and estimated that approximately $30 million per year earmarked for the relevant awardees would ensure continuity of operations. To facilitate rapid implementation of this recommendation, this amount should be offset against recommended increases to the Research Support Fund (RSF) to render it costless to the federal government.

The much larger issue is strengthening the overall institutional fabric of Canadian research. All postsecondary research depends upon maintaining common-use equipment; meeting regulatory standards; regularly upgrading institutional computer services; keeping libraries stocked; cleaning, lighting, and heating laboratories and research space; and administering grant awards. Additional costs relate to funding the protection of intellectual property and the commercialization of technologies arising from the research. Two programs (CRCs and CFREF) allow the research grants themselves to cover a limited number of these charges. For the vast majority of research operating grants, no budget lines for F&A costs are allowed, and a separate program, the RSF, instead offers partial reimbursement. The current reimbursement level averages 21.6 per cent of eligible direct operating costs of grants and is formulaic and arbitrary. In contrast, the F&A reimbursement range for U.S. institutions is based on actual audited costs, and typically runs from approximately 40 to 60 per cent. Canadian institutions that have submitted detailed F&A expenses to U.S. funders are reimbursed at an average of 49.3 per cent. As a further example within Canada, the Government of Quebec has a sophisticated system of provincial research grants, and provides 60 per cent coverage for "heavy" or *lourde* research disciplines (e.g., medicine, engineering, chemistry) and 45 per cent for "light" or *légère* disciplines (e.g., history, psychology, communications).

Institutions of higher learning are absorbing these F&A costs by using tuition dollars and provincial grants that should be dedicated to their teaching and learning mission. Greater success in winning federal research funding leads to more intense budgetary pressure on the teaching and learning mission—a counter-productive arrangement.

The federal government's underfunding of F&A costs can also be linked to complaints that the Panel heard from researchers about the challenges in keeping equipment in top operating shape, and their frustration with obtaining adequate assistance for administration of research grants. Moreover, to be effective partners in innovation, universities must engage in knowledge translation, manage intellectual property, and partner with for-profit and non-profit enterprises. Without comparable levels of F&A funding, Canadian institutions will never be able to compete successfully with the technology transfer record of U.S. universities.

A further concern is that the RSF formula operates on a reverse income tax model that sees smaller institutions paid first at rates of between 40 to 80 per cent with the remainder of the funds distributed by equal proportion to institutions receiving more than $7 million a year in research funding. This helps small institutions cope with higher F&A costs due to diseconomies of scale. Concerns about the formula therefore focus on the fact that larger institutions are perversely penalized for success. However, the decline in reimbursement is actually fastest for smaller universities in a growth phase between $7 million and $30 million. The current RSF accordingly penalizes the "gazelle" institutions where research activities grow fastest in future.

The federal government currently pays about $369 million per year through the RSF on eligible grants totalling $1.708 billion (21.6 per cent). To take the current rate to 30 per cent would add approximately $143 million to the tri-council base. The corresponding numbers for 35 per cent and 40 per cent are $229 million and $314 million.

The Government of Canada should take immediate steps to reduce this accumulated and growing liability and to obtain a proper return on its research investments. Given the size of the shortfall and the priority that must be given to new operating grants for independent research, a staged approach would be needed to improve F&A reimbursement rates across both existing and new RSF-eligible grants. The recommended target **(R7.3)** is a reimbursement rate of 40 per cent for all institutions with more than $7 million per year of eligible funding. Current thresholds should be maintained to enable additional support for smaller institutions. As the size of the envelope of RSF-eligible operating grants grows, the funding of the RSF should be increased in lock-step to sustain the reimbursement rate of F&A costs on a trajectory towards this 40 per cent goal.

As the program moves to more adequate levels of reimbursement, closer oversight and reporting will be required. Phased growth in reimbursement rates has the advantage of offering time for the granting councils, CFI, and RSF Secretariat to work with universities and research institutes on mechanisms that ensure full transparency for the use of these funds, with priority given to expenditures that improve the daily productivity and ongoing success of Canadian scientists and scholars.

Last, the federal government's RSF strategy represents rational leverage. Federal grants are eagerly sought and welcomed by researchers; institutions, provinces, benefactors, and fee-paying university students have continued for decades to subsidize the federal research efforts. However, while this has allowed the federal government to sustain a leadership role based on fractional funding in an area of shared jurisdiction, it has also adversely affected the funding of the teaching and learning mission of the nation's universities, and constrained the quality of the research environment for our scholars and scientists. We applaud federal leadership as essential but believe that, at 23 per cent of overall HERD spending, the Government of Canada's fractional funding has fallen to unsustainable levels. Failure to act on this issue, in concert with improvements in direct funding of operating grants, will also, for reasons given, sharply worsen the situation. In brief, augmenting F&A reimbursement rates is an essential part of our plan.

5. Conclusion

We conclude that the recent erosion of Canada's research competitiveness is linked to changes in federal funding for extramural research that have both constrained funding per researcher, and directed funding preferentially to priority-driven and partnership-oriented research. The situation has been exacerbated by a policy shift in favour of new programs that focus resources on a limited number of individuals and institutions, without commensurate reinvestment to lift frontline research more broadly or sustain the value of existing programming. While Canada's HERD ratio is high, federal sources account for less than 25 per cent of total HERD, and we are now an outlier among nations in the extent to which institutions underwrite the costs of research.

These challenges have been exacerbated by suboptimal coordination and collaboration among the four pillar agencies. The variations in governance, administrative practices, and funding priorities within and across agencies cannot be explained by disciplinary differences or by the needs of the relevant research communities.

We have accordingly recommended substantial improvements in governance, oversight, and advice. These include creation, by legislation, of an independent National Advisory Council on Research and Innovation. NACRI in tandem with Canada's new CSA would advise on evaluations for all programming in both the research and innovation spheres, including proposals for new agreements with external entities and renewals of extant agreements. An external expert group should be convened by the CSA to improve the oversight of national-scale MSIs. The Panel has also recommended wide-ranging improvements to oversight and governance of the four agencies, including the appointment of a Four Agency Coordinating Board chaired by the CSA. The Board would play a key role in driving a number of priorities identified in the report, targeting the effectiveness, accountability, efficiency, and equity of various elements of the system.

Concurrent with these changes to governance and improvements to accountability, major reinvestments are urgently required. We envisage a four-year phase-in involving base increases averaging 9 per cent each year. Many of the specific increases are contingent on approval of plans to ensure efficient use of new funds. New spending would be balanced across:

- investigator-led research operating grants (the highest priority);
- enhanced personnel supports for researchers and trainees at different career stages;
- targeted spending on infrastructure-related start-up (small equipment) and operating costs (Big Science facilities); and
- enhancement of the environment for science and scholarship by improved coverage of the institutional costs of research.

The cumulative base increase would move annual spending in steady-state across the four agencies and related entities from approximately $3.5 billion to $4.8 billion. The steady-state increase in base by the end of four years amounts to 0.4 per cent of the Government of Canada's annual budget. This commitment would both affirm renewed federal leadership and greatly strengthen the foundations of Canadian research. Given global competition, the role of research in underpinning innovation and educating innovators, the need for evidence to inform policy-making, and the current unsettled conditions in the research ecosystem, the Panel firmly believes that this commitment is also among the very highest-yield investments in Canada's future that any government could make.

LIST OF RECOMMENDATIONS

This list of recommendations is drawn directly from the text of the report. The first number refers to the chapter in which the recommendation appears, and the second to the order of appearance within that chapter. We caution again that recommendations should be reviewed and interpreted in context. Every recommendation is accompanied by a rationale in the body of the report. In most cases, additional text follows the recommendation to elaborate on it. Hence, to facilitate rapid reference to the context and elaboration, the title of each recommendation is an active link to the page of the report on which the recommendation appears.

Recommendation 1.1

Consistent with the recommendation by the Advisory Council on Economic Growth, the Government of Canada should undertake a wide-ranging and multi-departmental review of innovation-related programming, including both direct and indirect supports for business research and development.

Recommendation 4.1

The Government of Canada, by an Act of Parliament, should create a new National Advisory Council on Research and Innovation (NACRI) to provide broad oversight of the federal research and innovation ecosystems.

Recommendation 4.2

The Science, Technology and Innovation Council should be wound down as NACRI is established.

Recommendation 4.3

NACRI should have 12 to 15 members, appointed through Orders in Council, comprising distinguished scientists and scholars from a range of disciplines as well as seasoned innovators with strong leadership and public service records from the business realm and civil society. Domestic members should be drawn from across Canada and reflect the nation's diversity and regions.

Recommendation 4.4

An external member should hold the Chair of NACRI with the CSA serving as Vice Chair. NACRI should be supported by a dedicated secretariat working within the larger expert team supporting the CSA.

Recommendation 4.5

The Privy Council Office, working with departmental officials and the newly appointed CSA, should examine mechanisms to achieve improved whole-of-government coordination and collaboration for intramural research and evidence-based policy-making.

Recommendation 4.6

As a council of senior volunteers with a broad mandate of national importance, NACRI should have a publicly acknowledged working connection to the Prime Minister/PMO, parallel to that established for the CSA. NACRI should report to and interact most directly with both the Minister of Science and the Minister responsible for Innovation and Economic Development. It should also have open channels of communication with the Minister of Health and other ministers of key departments involved in intramural and extramural research.

Recommendation 4.7

A Special Standing Committee on Major Research Facilities should be convened by the CSA and report regularly to NACRI. The committee would advise NACRI and the Government of Canada on coordination and oversight for the life cycle of federally supported MRFs.

Recommendation 4.8

Ongoing interactions and annual in-person meetings should be established to strengthen collaborative research relationships among federal, provincial, and territorial departments with major intramural or extramural research commitments. The CSA, with advice from NACRI, should take the lead in promoting a shared agenda on matters of national concern, such as human resource planning to strengthen research and innovation across Canada.

Recommendation 4.9

The Government of Canada should propose and initiate planning for a First Ministers' Conference on Research Excellence in 2017. The conference would celebrate and cement a shared commitment to global leadership in science and scholarly inquiry as part of Canada's sesquicentennial celebrations.

Recommendation 4.10

The Ministers of Science and Health should mandate the formation of a formal coordinating board for CFI, CIHR, SSHRC, and NSERC, chaired by the CSA. The membership of the new Four Agency Coordinating Board would include the four agency heads, departmental officials, and external experts. Reporting to the Ministers of Science and Health, the Coordinating Board would expeditiously determine and implement avenues for harmonization, collaboration, and coordination of programs, peer review procedures, and administration.

Recommendation 4.11

The Government of Canada should undertake a comprehensive review to modernize and, where possible, harmonize the legislation for the four agencies that support extramural research. The review would clarify accountabilities and selection processes for agency governing bodies and presidents, promote good governance and exemplary peer review practices, and give priority to inter-agency collaboration and coordination.

Recommendation 5.1

NACRI should be asked to review the current allocation of funding across the granting councils. It should recommend changes that would allow the Government of Canada to maximize the ability of researchers across disciplines to carry out world-leading research. Particular attention should be paid to evidence that ongoing program changes have adversely affected the funding opportunities for scholars in the social sciences and humanities.

Recommendation 5.2

The Government of Canada should direct the new Four Agency Coordinating Board to develop and harmonize funding strategies across the agencies, using a lifecycle approach that balances the needs and prospects of researchers at different stages of their careers.

Recommendation 5.3

The new Four Agency Coordinating Board should create a mechanism for harmonization as well as continuous oversight and improvement of peer review practices across the three councils and CFI.

Recommendation 5.4

The Four Agency Coordinating Board should develop consistent and coordinated policies to achieve better equity and diversity outcomes in the allocation of research funding while sustaining excellence as the key decision-making criterion. This priority intersects efforts to improve peer review practices and requires a multipronged approach.

Recommendation 5.5

The federal ministers responsible should consider hard equity targets and quotas where persistent and unacceptable disparities exist, and agencies and institutions are clearly not meeting reasonable objectives.

Recommendation 5.6

The four agencies should examine best practices in supporting early career researchers, augment their support of them consistently across disciplines, and track and report publicly on the outcomes.

Recommendation 5.7

The three granting councils should collaborate in developing a comprehensive strategic plan to promote and provide long-term support for Indigenous research, with the goal of enhancing research and training by and with Indigenous researchers and communities. The plan should be guided by the Truth and Reconciliation Commission's recommendations on research as a key resource.

Recommendation 5.8

NACRI should be mandated not only to review proposals to create new third-party delivery organizations, but also to assess ongoing activities of all existing third-party organizations that receive federal support. It should guide their formal periodic review processes and advise the Government of Canada on the continuation, modification, or termination of their contribution agreements.

Recommendation 5.9

When the intent is to support independent research, requirements for matching funds should be used sparingly and in a coordinated and targeted manner. In general, matching requirements should be limited to those situations where the co-funder derives a tangible benefit.

Recommendation 6.1

The Government of Canada should rapidly increase its investment in independent investigator-led research to redress the imbalance caused by differential investments favouring priority-driven research over the past decade.

Recommendation 6.2

The Government of Canada should direct the Four Agency Coordinating Board to amend the terms of the NCE program so as to include the fostering of collaborative multi-centre strength in basic research in all disciplines.

Recommendation 6.3

The Government of Canada should direct the granting councils to undertake an interim evaluation of the CFREF program before the third wave of awards is made. The CSA and NACRI should be engaged in the design of the review. The results would guide a decision on whether to launch or defer the program's third round, but not impede the fulfilment of existing commitments.

Recommendation 6.4

The Government of Canada should mandate the Four Agency Coordinating Board to develop multi-agency strategies to support international research collaborations and modify existing funding programs so as to strengthen international partnerships.

Recommendation 6.5

The Government of Canada should mandate the Four Agency Coordinating Board to develop strategies to encourage, facilitate, evaluate, and support multidisciplinary research.

Recommendation 6.6

The Government of Canada should mandate the granting councils to encourage and better support high-risk research with the potential for high impact.

Recommendation 6.7

The Government of Canada should mandate the granting councils to arrive at a joint mechanism to ensure that funds and rapid review mechanisms are available for response to fast-breaking issues.

Recommendation 6.8

The Government of Canada should provide CFI with a stable annual budget scaled at minimum to its recent annual outlays.

Recommendation 6.9

The Government of Canada should consolidate the organizations that provide digital research infrastructure, starting with a merger of Compute Canada and CANARIE. It should provide the new organization with long-term funding and a mandate to lead in developing a national DRI strategy.

Recommendation 6.10

The Government of Canada should mandate and fund CFI to increase its share of the matching ratio for national-scale major research facilities from 40 to 60 per cent.

Recommendation 6.11
The Government of Canada should mandate and fund CFI to meet the special operating needs of individual researchers with small capital awards.

Recommendation 7.1
The Government of Canada should direct the Four Agency Coordinating Board to oversee a tri-council process to reinvigorate and harmonize scholarship and fellowship programs, and rationalize and optimize the use of current awards to attract international talent.

Recommendation 7.2
The Government of Canada should renew the CRC program on a strategic basis in three stages:

1. Restore funding to 2012 levels, upon development of a plan by the granting councils and Chairs Secretariat to allocate the new Chairs asymmetrically in favour of Tier 2 Chairs, and increase the uptake of available funds through improved logistics in managing numbers and reduced delays in awarding Chairs;
2. Direct the granting councils to cap the number of renewals of Tier 1 Chairs and, in concert with universities and CFI, develop a plan to reinvigorate international recruitment and retention, for review by NACRI and approval by the government; and
3. On approval of that plan, adjust the value of the CRCs to account for their loss in value due to inflation since 2000.

Recommendation 7.3
The Government of Canada should gradually increase funding to the RSF until the reimbursement rate is 40 per cent for all institutions with more than $7 million per year of eligible funding. Current thresholds should be maintained to enable additional support for smaller institutions. As the size of the envelope of RSF-eligible operating grants grows, the funding of the RSF should be increased in lock-step to sustain the reimbursement rate of F&A costs on a trajectory towards this 40 per cent goal.

CHAPTER 1

PANEL MANDATE, SCOPE OF REVIEW, AND PRINCIPLES

1.1 Panel Mandate and Modus Operandi

1.1.1 Mandate

The Advisory Panel for the Review of Federal Support for Fundamental Science (the Panel) was formally launched on June 13, 2016 by the federal Minister of Science, Dr Kirsty Duncan. The Minister summarized the Government's motivation as follows:

> The Government is committed to supporting research excellence in Canada. In the face of increasing global competition, there is a need to take stock of the steps required to preserve Canada's world-class standing. This review will help ensure that federal support for research is strategic and effective and that it delivers maximum benefits to the research community and the Canadians whose lives are enriched by its discoveries.[1]

The Government's framing of the Panel's mandate highlights that the focus is on what is commonly termed the "extramural research" landscape, i.e., science and scholarly inquiry led by researchers working in universities, research hospitals, and other institutes (an overview of the key funding organizations can be found in Appendix 1). This research activity by individuals not in the employ of any government is distinct from what is commonly termed "intramural research" carried out in government facilities by public servants.[i] The Panel's mandate excluded research carried out within government departments or the National Research Council (NRC), except insofar as collaboration between intramural and extramural researchers was seen to be mutually advantageous.

Our mandate was summarized in two broad questions:

1. *Are there any overall program gaps in Canada's fundamental research funding ecosystem that need to be addressed?*
2. *Are there elements or programming features in other countries that could provide a useful example for the Government of Canada in addressing these gaps?*

These two questions have recurred through the deliberations and consultations undertaken by the Panel and shaped the research and analyses done for the Panel by the secretariat and others (see Acknowledgments).

We are aware of two possible effects of the framing of these questions. First, the focus on gaps could be taken as mandating an incremental approach in which structural changes or serious reforms are never in play. While we have been moderate in the scope of changes proposed, members of the research community can rest assured that larger reforms were indeed considered, as will be explained in due course.

i In 2015-16, the federal government spent $5.34 billion on intramural scientific research and regulation-related scientific activities.

Second, the focus on gaps creates the risk of an unduly critical portrait of Canada's research funding ecosystem. As discussed later in the chapter, this system has achieved a strong record of supporting internationally competitive science and scholarship over what is, by global standards, a short period of time. Furthermore, the Panel has enjoyed good cooperation from the four pillar agencies[ii] with which this review is most centrally concerned: the Natural Sciences and Engineering Research Council (NSERC), the Social Sciences and Humanities Research Council (SSHRC), the Canadian Institutes of Health Research (CIHR), and the Canada Foundation for Innovation (CFI). We commend the creativity and commitment of those who work in these and other organizations that are part of the wider federal system that supports research, development, and innovation. Indeed, many of the issues we raise in this report, and the gaps we describe, were identified by senior staff of the agencies themselves, or by officials in government departments—most notably Innovation, Science and Economic Development (ISED) and Health Canada.

Exhibit 1.1 shows the more specific questions put to the Panel by Minister Duncan. The current report addresses all these questions *pari passu*, and more directly in its final chapter.

1.1.2 Consultations

Along with seeking responses to these questions, the Minister indicated the following:

> The panel will be expected to consult widely with the research community and to solicit input from relevant stakeholders—including universities, colleges and polytechnics,[iii] research hospitals, research institutes, industry, civil society—and the general public representing the diversity of views from across Canada. Those consultations and submissions may lead the panel to raise additional questions and offer additional advice to the Government. Such input will be welcomed.[2]

Consistent with this guidance, the Panel consulted widely and, as expected, received substantial input that has led us to offer additional advice. This input was solicited over the course of more than three months through an online portal. The Panel and secretariat sent out numerous general and specific invitations to respond. In soliciting this feedback, the Panel referred both to the broad questions that framed our mandate and the more specific questions per Exhibit 1.1. We received 1,275 written submissions from scores of organizations, hundreds of individual researchers, and members of the general public. Submissions are summarized in more detail in Appendix 2. The Panel remains very grateful for the extraordinary engagement of the research community in this process.

To allow for face-to-face interchanges between subsets of Panel members and representatives of the research community, the Panel organized a series of roundtable sessions. Twelve separate sessions were held in Toronto, Montreal, Calgary, Ottawa, and Halifax. Sessions bridged career stages, e.g., graduate students and postdoctoral trainees, early and mid-career researchers, and individuals who have held or currently hold major research leadership positions. We specifically convened leaders of major science infrastructure facilities, researchers active across a wide range of disciplines, and scholars with a particular interest in equity and diversity issues, as well as those engaged in research involving Indigenous people. In all, almost 230 researchers participated in these face-to-face meetings (see Appendix 2 for attendees).

Commentary received online and at the roundtables tended to track our mandate and focus on gaps and opportunities to improve the workings of different research agencies and programs. However, we were left in no doubt about the gratitude of researchers for the public funds they receive to support their work, and the value they place on the work of the four agencies above and related research funding bodies.

ii We use the term "agencies" throughout this report to refer collectively to the three granting councils (NSERC, SSHRC, and CIHR) and CFI.

iii Both Colleges and Institutes Canada and Polytechnics Canada advised us that their input would focus on the Innovation Consultation. We did receive thoughtful submissions from both associations and from individual community colleges and polytechnics regarding the College and Community Innovation Program under NSERC's aegis. Although that program was outside our mandate, we return to their concerns briefly in Chapter 4.

Exhibit 1.1: Detailed Questions for the Advisory Panel on Fundamental Science

Funding of fundamental research

The central question regarding the effectiveness and impact of the granting councils in supporting excellence in fundamental research is whether their approach, governance and operations have kept pace with an ever-changing domestic and global research landscape. Key questions for the review:

1. Are granting councils optimally structured and aligned to meet the needs of the current research community in Canada? Are the current programs the most effective means of delivering the objectives of these organizations? And are they keeping pace internationally? The review should take into account the several reviews and evaluations that were performed in recent years on the councils and on science and scholarly inquiry in Canada.
2. Are students, trainees and emerging researchers, including those from diverse backgrounds, facing unique barriers within the current system and, if so, what can be done to address those barriers?
3. Is there an appropriate balance between funding elements across the research system, i.e., between elements involving people and other direct research costs, operating costs, infrastructure and indirect costs? What are best practices for assessing and adjusting balances over time?
4. Are existing review processes rigorous, fair and effective in supporting excellence across all disciplines? Are they rigorous, fair and effective in supporting riskier research and proposals in novel or emerging research areas or multidisciplinary/multinational areas?
5. Are granting council programs and structures sufficiently flexible to reflect and accommodate the growing internationalization of research? Are granting council programs and structures accommodating the full range of research areas; multidisciplinary research; and new approaches ranging from traditional knowledge, including indigenous research, to more open, collaborative forms of research? If not, what steps could be taken?

Funding of facilities/equipment

1. Is the Canada Foundation for Innovation optimally structured to meet the needs of the current research community in Canada? What are the strengths and weaknesses of the current model in delivering the objectives of this organization, including its ability to work complementarily with the granting councils? What is the appropriate federal role in supporting infrastructure operating costs and how effective are current mechanisms in fulfilling that role?
2. What are best practices (internationally/domestically) for supporting big science (including, inter alia, international facilities and international collaboration)?
3. Many requests for government support for research are not tied to the cycles of the four major research agencies, but they have economic or competitive relevance nationally or regionally, or major non-governmental financial support, or implications for Canada’s international standing as an active participant in big science projects or major multi-institutional projects. How can we ensure that the Government has access to the best advice about funding these types of projects in the future?

Funding of platform technologies

1. What types of criteria and considerations should inform decisions regarding whether the Government should create a separate funding mechanism for emerging platform technologies and research areas of broad strategic interest and societal application? Are there any technologies that would appear to meet such criteria in the immediate term? When there is a rationale for separate funding, how to ensure alignment of funding approaches?
2. Today’s emerging platform technology may rapidly become a standard tool used tomorrow by a wide variety of researchers. If such technologies are initially given stand-alone support via a dedicated program or agency, what factors should inform decisions on when it would be appropriate to “mainstream” such funding back into the granting councils?

1.1.3 Guiding Questions

For the organization of the report itself, it was tempting to use the specific questions (per Exhibit 1.1) as a template. However, the Panel concluded that these questions were best answered within an overall logic model for the report. That logic model can be summarized simply, starting with this chapter, which asks: What was our mandate and how did we interpret it?

A series of further questions then define the report's chapters. In order:

- Why does science and scholarship matter as Canada enters its sesquicentennial year (Chapter 2)?
- How, in general, does Canada measure up in research, considering inputs such as funding levels, outputs such as publications and citations, and cornerstone elements such as talent development and recruitment (Chapter 3)?

We then turn to a series of analyses aimed at pinpointing gaps and opportunities for improvements. These analyses are informed by some guiding principles outlined below. The four chapters with their various recommendations unfold in stages as follows:

- What changes are needed in system-level governance oversight and advice and agency-specific governance (Chapter 4)?
- What are the cross-cutting or broad issues facing all four pillar agencies and what should be done about them (Chapter 5)?
- What are the identifiable gaps specific to funding programs, and how can they be addressed? The breadth of programming is such that two distinct chapters were required to cover the relevant issues (Chapters 6 and 7). Chapter 7 includes a costing of our recommendations, with a four-year phased plan for implementation.

The last chapter (Chapter 8), as already noted, takes the specific questions in our mandate, cross-references each one to the relevant sections of the report, and briefly recapitulates the pertinent answers and recommendations. It also reflects on prospects for the Canadian research ecosystem and our expectations for positive change from these recommendations and the associated investments.

1.2 Scope of the Panel's Review

1.2.1 Full Range of Disciplines

Among the early challenges for the Panel were misinterpretation of its moniker and the related scope of its work. The term "fundamental science" originated with federal Budget 2016, which announced the Government of Canada's intent to undertake a review.[3] Alignment of terminology followed. Some members of the anglophone research community were understandably concerned that the Panel's mandate excluded applied science in a range of fields, as well as the social sciences and humanities. Francophone researchers, accustomed to *les sciences sociales et humaines*, were more sanguine.

Minister Duncan, whose own scholarship cuts across the natural sciences, social sciences, and humanities, made it clear from the outset that the Panel was to examine the full range of scientific and scholarly disciplines. The Panel's secretariat and members similarly emphasized the breadth of our review. We were accordingly delighted to receive submissions from many researchers and organizations representative of disciplines supported by the three granting councils, others doing transdisciplinary research who sometimes find themselves in limbo, and others again frustrated that the lack of collaboration across the councils has effectively shut out their disciplines altogether.

A residual source of some confusion was the term "fundamental", which is used infrequently in the social sciences and humanities even though much scholarship in those fields is arguably basic or conceptual.

The Panel again took a pragmatic view. Our mandate was derived in meaningful measure from concerns that Canada's capacity for generation of exciting new knowledge had been eroded. We therefore assumed our remit ranged from basic science focused on making major discoveries to applied science with important technological implications, and from deep philosophical inquiry to rigorous economic evaluations of policies and programs.

The Panel emphasizes in this latter regard that societies without great science and scholarship across a wide range of disciplines are impoverished in multiple dimensions. From the social sciences and humanities, contributions range from deeper understanding of the complexity of human nature and social structures to grace in self-expression and excellence and beauty in the creative and performing arts. From the natural and health sciences and engineering, while attention often focuses on practical applications, basic research provides the breakthrough insights that fundamentally change our understanding of the natural world and our cosmos. We return to this subject in Chapter 2.

The Panel also observes that these categorizations are all focused on research subject matter, when in fact the subject that really matters may be the person doing the research. Postsecondary education enriched by exposure to basic research provides citizens with an outlook and intellectual tools that are extraordinarily well-suited to technological and social innovation. Indeed, countless authors of abstract graduate theses have gone on to lives of deep and productive engagement with practical problems, bringing with them perspectives that reflect an inquiring and critical mind.

In brief, the Panel's primary interest is in the extramural research realm, and particularly in supports for research into topics chosen by scholars and scientists from the full range of disciplines, using methods that they have developed or adapted, and subject to review by research colleagues. This research may be basic or applied. It may be project-based or programmatic. And it may have early application or no immediate relevance. However, a key criterion is that the work is sufficiently excellent to withstand critical scrutiny by peers, and produces knowledge that, after appropriate review, can be shared widely to advance the collective store of knowledge and ideas in the relevant field or fields.

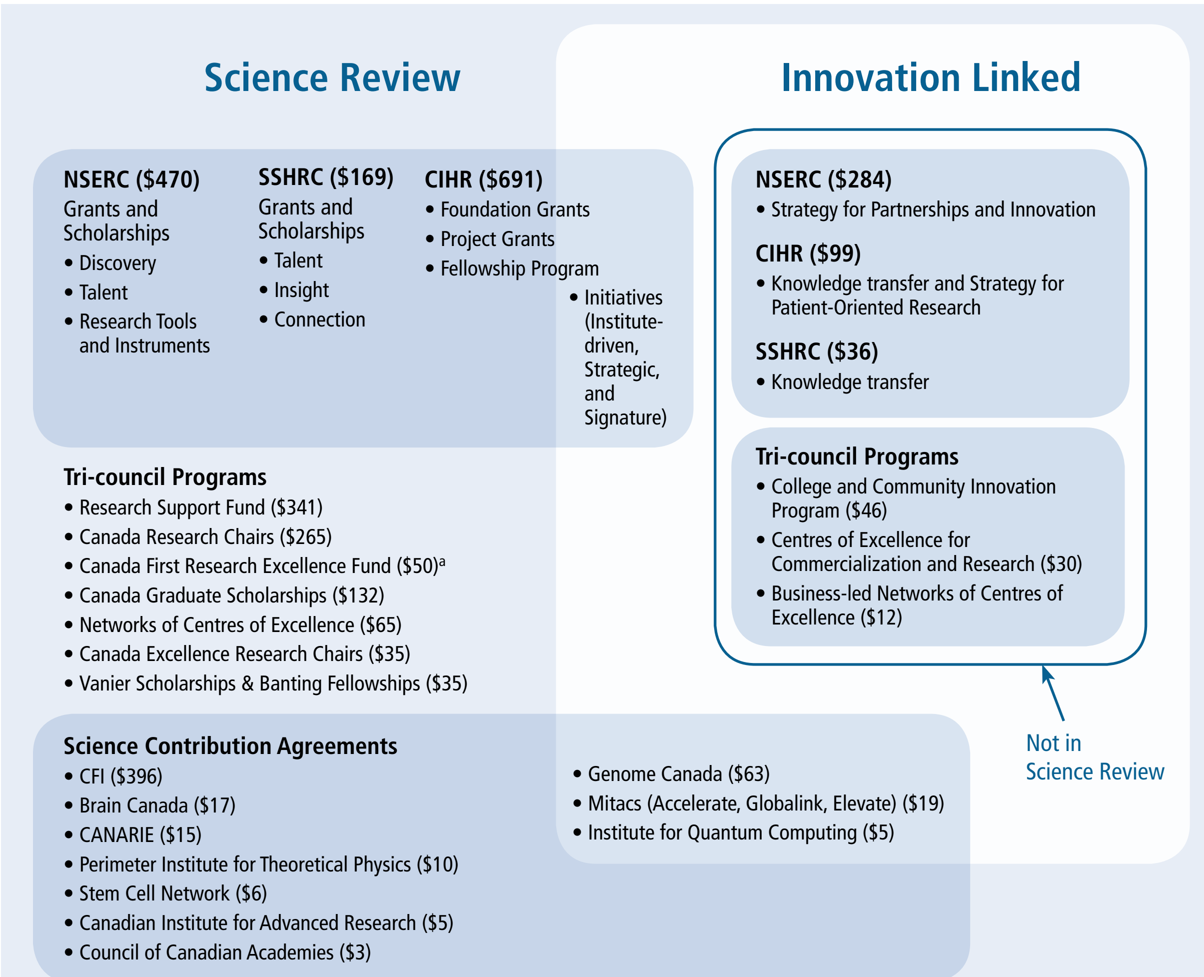
1.2.2. Programmatic Scope—and a First Recommendation

Exhibit 1.2[iv] shows the potential scope of the review in schematic form. What is apparent is a sharp differentiation in scale and remit of the entities shown. Despite CFI's structure and multi-year one-time-only allocations, it clearly belongs with the three granting councils in terms of budget and breadth. Together the four pillar agencies cut across all disciplines, touch all parts of the nation, and account for well over $3 billion per year in total spending, of which some $2.7 billion was in scope for the review, exclusive of administrative costs at the council level. Other than CFI, the remaining entities funded through contribution agreements varied in size from $3 million per year (Council of Canadian Academies, CCA) to $63 million per year (Genome Canada), with a total outlay of $146 million per year. The Panel was apprised that the status of these agreements ranged from recent five-year extensions to imminent review. We had neither the specialized expertise nor the time to review each of these smaller entities, but fortunately, that was not the expectation. Instead, the questions in our mandate (reflected under "Funding of Facilities/Equipment", no. 3, and "Funding of Platform Technologies", nos. 1 and 2) had to do with how such reviews might be conducted and guided in the years ahead. In contrast, as Exhibit 1.1 makes clear, the Panel was asked to look much more closely at the four pillar agencies, and has done so.

iv This exhibit highlights the elements of federal government extramural science and research spending that are part of our review and those that are excluded. As many programs have both basic and applied research components, an estimate was made of the relevant proportions and applied to the appropriate categories. Given space limitations, a number of programs are grouped together under general headings. Accordingly, several of the numbers here cannot be compared to those in other parts of the report.

We turn finally to exclusions and our mandate as regards support for what Zuckerman and Trend in the 1960s called "operational applied research" and "development",[4] or what in modern parlance might be called innovation programming. The exclusions within the tri-council realm are shown in Exhibit 1.2, and account for some $507 million per year in spending. Additional federal government support for business research, development, and innovation is provided by a much larger set of programs not only within ISED but also across many other government departments (see Appendix 3).

Exhibit 1.2: Canada's Science and Innovation Ecosystem



Note: Amounts reflect annual expenditures for 2015-16 (in millions of dollars) with the exception of Stem Cell Network, as funding starts in 2016-17, and the figures for CFI and Genome Canada are recent average annual expenditures. Please see this chapter's Annex for further details and explanatory notes for individual programs and expenditures.

[a] Full funding of $200 million per year will be achieved in 2018-19.

Innovation has become a buzzword with varied definitions and many categorizations. One popular definition provided by the CCA in its 2009 report is commendably brief but very broad: Innovation is "new or better ways of doing valued things."[5] The Conference Board of Canada in contrast defines innovation with greater specificity: viz. "the process through which economic and social value is extracted from knowledge through the generation, development and implementation of ideas to produce new or improved strategies, capabilities, products, services or processes."[6] The key differentiating feature in both cases seems to be that the focus is not on generation of new knowledge but on use or application of existing knowledge, be it through commercialization, social innovation, or uptake into public policy.

At the time of our review, two parallel initiatives by the Government of Canada were considering the interconnected realms of innovation and economic development. One, under the auspices of ISED Minister Navdeep Bains, was a wide-ranging consultation to understand the concerns of social and business innovators across Canada.[7] The other, under the auspices of Finance Minister Bill Morneau, was focused on delineating strategies to accelerate economic growth.[8] The latter review has been carried out by volunteers on an Advisory Council on Economic Growth (commonly known as the "Growth Council") chaired by Mr Dominic Barton, global managing partner of McKinsey & Company. This Panel's mandate accordingly excluded federal programming that primarily targets commercialization and industry-facing or social innovation.

We have respected those exclusions with three caveats.

First, some research programming—for example, the Networks of Centres of Excellence (NCEs)—is multi-modal, insofar as it seeks to bridge generation and translation or uptake of research insights. We have excluded the Business-led NCEs and included the others in our overview. Other programs, as shown in Exhibit 1.2, were also categorized as representing a blend, e.g., SSHRC's Connection, Partnership, and Partnership Development Grants.

Second, no review of this nature can be undertaken without examining the extent to which federal support in recent years has migrated away from independent research, and been directed instead to industry-facing programs that purport to promote innovation and economic growth. The effects of the resulting redirection of grant-seeking behaviour were highlighted in multiple submissions and conversations with researchers. Those effects, including their impact on the overall availability of resources for research, will be considered and reported here.

Third, as noted earlier, the reviews cited above do not bring the researcher's perspective to a consideration of the overall intent, architecture, and outcomes of Canada's innovation programming. We have therefore briefly assessed some features of the innovation machinery, and, with the concurrence of the Science Minister, have framed the following recommendation in collaboration with the Growth Council.

Recommendation 1.1

Consistent with the recommendation by the Advisory Council on Economic Growth, the Government of Canada should undertake a wide-ranging and multi-departmental review of innovation-related programming, including both direct and indirect supports for business research and development.

The Panel believes that the review must be careful to include not only programs under tri-council aegis that have been excluded from our review, but also those subject to external contribution agreements, such as Mitacs and the innovation programming inside Genome Canada. If a new Chief Science Advisor (see Chapter 4 for more discussion) has been appointed by the time of the review, he/she may be a useful contributor to assessments involving entities with a mixed mandate of supporting independent research and research responsive to the missions of social or business enterprises.

Before we look ahead to the principles that guided our review, it may be helpful to look back briefly at the evolution of the four federal pillar agencies.

1.3 A Short History: The Pillars of Federal Research Funding

In comparison with many peer nations in the Organisation for Economic Co-operation and Development (OECD), Canada's system of federal supports for intramural and extramural research is a relatively recent creation. Its scientific and scholarly traditions have therefore developed over decades rather than centuries. Indeed, the research funding agencies that are best known to Canadians all emerged in the post-war period (see Exhibit 1.3).

Exhibit 1.3: Milestones in the Evolution of the Canadian Research Ecosystem

Year/Period	Development
1916	National Research Council (NRC) is created to undertake industrial and scientific research. No real progress is made until after the First World War.
1919	Parliamentary Special Committee is appointed to consider "the Development in Canada of Scientific Research", chaired by Hume Cronyn. It recommends making scientific research a national priority and outlines mandates for NRC: weights and measures, national science advice, funding of university research to create human resources for future development, and in-house research on industrial problems.
1920s	NRC develops slowly in the face of opposition from intramural researchers in government departments and ambivalence on the part of universities. Attempts to create national laboratories are blocked in 1921 and 1924. Ottawa laboratory complex is approved in 1928 and completed in 1932.
1930s	NRC seeks to relocate/annex research laboratories/programs from government departments, with minimal success.
1939–1945	Massive expansion of NRC occurs on multiple sites for military and strategic research purposes during the Second World War.
1951	Massey Commission recommends improvement of science advisory functions, together with better coordination of intramural and extramural research, and the creation of the Canada Council to support the arts, humanities, and social sciences. It warns against structural conflict of interest with NRC funding extramural research while competing with universities in the same fields.
1952–1962	NRC sidesteps Massey Commission cautions. It augments in-house basic research activity and grows extramural funding for university research on the watch of Dr. E.R. Steacie as president.
1950s	Government of Canada seeks with mixed results to directly engage and fund large companies to undertake research-intensive projects—including the famed Avro Arrow (Canada CF-105 jet fighter airplane).
1957	Canada Council for the Arts is established and it begins grant-making operations.
1960	Medical research funding is spun out from NRC into a new and independent Medical Research Council of Canada (MRC). MRC is founded to support medical schools and fundamental biomedical research.
1963	Glassco Commission notes absence of oversight and coordination of science and research and recommends creation of a new National Science Advisory Council. Commission also criticizes NRC's emphasis on basic research and judges it largely ineffective at promoting industrial research.
1964–1971	Science secretariat is established within the Privy Council Office. It is responsive to Cabinet/government issues but does not have an oversight role. Its director is upgraded in 1968 to be principal science advisor to Cabinet.
1966–1992	Science Council of Canada is established as an arm's length Crown corporation with mix of representatives from government departments, industry, and academe. First major report argues that "a major failing in Canadian science has been the performance of too much basic research remote from the training of new scientists and the performance of too much applied research far from the point of innovation." It commissions the Macdonald review of federal support for research in Canadian universities, rejects its 1969 recommendation for new grant-making bodies for extramural research, and waters down its recommendation of coverage of indirect costs of research (estimated at approximately 35 cents per dollar of direct research support).
1960s	Government reduces reliance on contracting with industry and intensifies other incentives to industry. Multiple programs are initiated to promote industrial R&D, ranging from sector-specific to generic (e.g., tax credits, grants from NRC to universities for industry-facing research centres, creation of industrial research institutes at universities by the Department of Industry).
1967–1973	Over the course of more than five years, the Senate Special Committee on Science Policy chaired by Senator Maurice Lamontagne undertakes an exhaustive review of the history, administration, organization, funding, and comparative performance of Canada's research enterprises. First report is issued in 1970.
1971–1986	Ministry of State for Science and Technology is created. It has 13 ministers between 1971 and 1986.

Exhibit 1.3: Milestones in the Evolution of the Canadian Research Ecosystem (continued)

Year/Period	Development
1972–1973	Final two reports of the Lamontagne Committee lay the foundations for restructuring both NRC and the Canada Council, embracing the Macdonald report for the Science Council, and endorsing creation of a social sciences and humanities research foundation and a physical sciences and engineering research foundation. They also recommend broadening MRC's mandate to include all life sciences, and creating a formal Canada Research Board to oversee and strengthen coordination of the three granting councils.
1978	Legislation establishing the Social Sciences and Humanities Research Council (SSHRC) and the Natural Sciences and Engineering Research Council (NSERC) comes into force.
1987–1996	National Advisory Board on Science and Technology (NABST) provides advice to the Prime Minister on national science and technology goals and policies and their application to the Canadian economy.
1990–1993	Minister for Science is named.
1993–2003	Secretaries of State (Science, Research and Development) are named.
1994	A science and technology review is announced to investigate how federal investment in science and technology can best create economic growth and jobs within the context of sustainable development, while enhancing the quality of life and advancing knowledge.
1996–2008	Advisory Council on Science and Technology (ACST) provides the Prime Minister, through the Minister of Industry, with non-partisan advice on national science and technology (S&T) goals and policies and their application to the Canadian economy.
1997	Canada Foundation for Innovation (CFI) is established, responding to recommendations for formal research infrastructure support dating back four decades.
1998–2008	Council of Science and Technology Advisors (CSTA) is created to provide the government, through Cabinet, with external advice on the management of federal S&T by examining issues common across science-based departments and agencies. Canadian Biotechnology Advisory Committee (CBAC) is created to provide expert advice on the ethical, social, regulatory, economic, scientific, environmental, and health aspects of biotechnology.
1999	Genome Canada is funded as a not-for-profit organization to advance genomics research and transform knowledge to enhance the impact of genomics.
2000	Canada Institutes of Health Research Act is passed, embodying a major broadening of MRC's mandate and interweaving of health research with healthcare, innovation, and commercialization.
2003–2008	National Science Advisor (NSA) is created, offering advice to the Prime Minister and operating out of the Privy Council Office.
2003–2008	Minister of Industry is responsible for S&T files.
2005	Council of Canadian Academies (CCA) is created as an independent, not-for-profit organization providing evidence-based expert assessments to inform public policy development.
2007	Science, Technology and Innovation Council (STIC) is created as an external committee to provide integrated, confidential advice on science, technology, and innovation policy issues to the Minister (Industry). STIC replaces ACST, CSTA, CBAC, and NSA.
2008–2015	Ministers of State (Science and Technology) are named.
2015	Minister of Science is named.
2016	Federal government launches search for a Chief Science Advisor (CSA), who will provide scientific advice to the Prime Minister, Minister of Science, and members of Cabinet.

Extramural grants for basic and applied research in natural and health sciences and engineering were made to university researchers under the aegis of NRC at an increased rate starting from the 1920s. However, the Medical Research Council (MRC) and NSERC were not spun out of NRC until 1960 and 1978 respectively. Scholar-initiated research in the social sciences and humanities was orphaned for decades. University-based researchers in those fields did receive extramural grants from the Canada Council after its creation in 1957, but its focus was primarily on the performing and creative arts, including literature. A separate SSHRC was accordingly created at the same time as NSERC in 1978. Although the need for an infrastructure agency had been acknowledged since the 1960s, CFI was not created until 1997. Moreover, it was not until 2000 that MRC was given a mandate to cover the full spectrum of health research and transformed into CIHR.

This report is not the place in which to detail the evolution of the research ecosystem in Canada. However, we would make two immediate observations based on our understanding of this short history.

First, individual councils, organizations, and programs have, of course, been reviewed on a cyclical basis. Most of those reviews, however, were organized by the councils and agencies themselves and, so far as we can ascertain, there has been no multidimensional review of this nature since the Lamontagne Committee tabled its report in 1973.[9] It is hard to imagine another developed nation that would allow more than 40 years to pass before undertaking an integrated and integrative review of functions that have such clear-cut national importance and involve billions of dollars each year. This unfortunate vacuum may explain why the landscape we have been exploring embodies and supports tremendous professionalism and accomplishment, but also features a proliferation of small agencies and one-off investments in research facilities and programs. Moreover, notwithstanding some fine collaboration on varied fronts, many examples of inconsistencies and poor coordination are clearly visible across the four pillar agencies. These issues, to which we return in the body of the report, should be seen less as problems, and more as low-hanging fruit—opportunities for rapid improvement and greater achievements in the years ahead.

Second, given the comparative youthfulness of Canadian science and scholarship, our national record is impressive. However, other young nations are excelling, established powers in science and scholarship show little sign of flagging, and China has leapt ahead in a dramatic fashion over the last decade. The scope of investments in research being made worldwide underscores the fact that the success of modern societies—their economic prosperity, creativity, and social coherence—is seen to be increasingly dependent on the application of insights from the physical and life sciences, social sciences, and humanities. Canada must therefore raise its game or fall behind.

1.4 Some Guiding Principles

In taking stock of the health of the Canadian extramural research ecosystem and the four pillar agencies that support it, the Panel has kept in mind a set of principles. Our thoughts in this regard have been shaped by our review of research systems in nations with strong performance, by our interchanges with some 200 researchers of different career stages and interests, and by the 1,200+ submissions received by the Panel.

World-leading and Globally-collaborative:

Canada is a comparatively wealthy country, with traditions of political stability, pluralism, and sustained prosperity. Our system of supports for science and scholarship should therefore be guided by aspirations to be truly excellent across a wide range of disciplines and to be a world leader in a select number of fields that are deemed strategically vital to Canada's future or represent comparative advantages owing to geography, natural resources, or demographics. Given our relatively small population and the intensifying global competition, this is not achievable unless Canada's levels of investment in independent research are among the highest per capita in the world.

Those investments must include support for Canadian participation in global research at all levels from major science initiatives[v] (MSIs) to small team grants, with related response capacity and reciprocal agreements across research agencies. Those agreements, in turn, will require that Canadian competitions be opened up to recognize and support greater numbers of international collaborators. With science and scholarship more globalized than ever before, Canada cannot be a global leader with a parochial or protectionist approach to research funding.

Meritocratic:

For Canadian research to be globally recognized as outstanding, the domestic processes of adjudication must be rigorous, drawing as appropriate on international peer review. In this regard, for all its limitations, review by peers with relevant expertise and experience remains the best means of judging the merit of research proposals. These reviews must not only be conducted fairly, but be seen to be fair and supportive of truly excellent proposals. In the applied research realm, reviews will inevitably have overlays of relevance and partnership/network building. In general, however, the cornerstone of adjudication should be the quality of the research question and methods in scientific and scholarly terms. Whatever the criteria, peer review sometimes becomes risk averse. In thriving research ecosystems, members of the research community must have opportunities to pursue lines of investigation that are high risk but high reward.

Independent yet Accountable:

The strongest systems are characterized by a high degree of independence to avoid politicization of research. Funding agencies, however, are also held clearly accountable for the integrity of their processes and for successful outcomes. We envisage the federal government committing to sustained investment in extramural research based on international benchmarking, and receiving in turn ongoing third-party assessments that measure performance against agreed targets. Those targets should reflect desired domestic impacts and aspirations for globally competitive excellence, with high-impact insights and breakthroughs. They should also take stock of whether those involved in management/governance are fostering a vibrant, equitable, and productive research environment.

Coordinated:

Whether through consolidation or other bridging and oversight structures, strong coordination across agencies, programs, and jurisdictions is vital to every successful research funding system. It should lead to enhanced administrative efficiency, better accommodation of inter- and multidisciplinary research, and seamless coverage so that no sub-disciplines fall through the cracks. Coordination and oversight mechanisms are particularly important to manage the life cycle of MSIs that have vital regional or national roles. For MSIs, and research supports more generally, there is a pressing need to coordinate research supports across federal, provincial, and territorial governments.

Balanced:

Balance is needed in relative allocations to programming constrained by pre-determined topics or objectives, as opposed to inquiry that is variously described as unfettered, investigator-led, or researcher-defined. Global experience shows that every successful research ecosystem involves meaningful amounts of co-creation of

v The Panel adopts the term "major science initiatives" (MSI) from CFI, which defines these as major research facilities serving "communities of researchers from across the country and internationally". In Chapters 4 and 6, the Panel distinguishes between MSIs that meet CFI's basic criteria and those that, by virtue of scale and complexity and/or cost, track more closely to CFI's definition of a "national research facility", i.e., one that "requires resource commitments well beyond the capacity of any one institution" and "is specifically identified or recognized as serving pan-Canadian needs and its governance and management structures reflect this mandate." We call these "major research facilities" (MRF) to make it clear that facilities proposed for inclusion are based on the Panel's initial assessment.

knowledge with communities, industry, or other partners. However, no extramural research ecosystem can thrive unless it starts from a strong foundation in basic research cutting across all disciplines, and is oriented first and foremost to path-breaking discoveries or highly original insights.

Moreover, as in nature, ecosystems depend on a multidimensional balance. Funds are finite, and allocations must be carefully balanced in many ways, e.g.:

- across capital, research operating costs, and personnel support for trainees and researchers at different career stages;
- across fields and disciplines, including funding agencies;
- between targeted multi-million dollar investments in institutions and individuals, and programs of much smaller grants to larger numbers of frontline researchers;
- between direct supports to people and projects, and facilities and administration costs (sometimes called indirect costs);
- between MSIs and networks, and support for individuals and smaller teams;
- between theme-based programs of a multi- or transdisciplinary nature and funds dedicated to supporting deep disciplinary dives; and
- between mainstream research and high-risk endeavours.

Responsive:

The best funding ecosystems maintain capacity to accommodate shifts in the currents of science and scholarship, to respond nimbly to crises, and to drive forward with strategic priorities as needed. Those working within them are at liberty to form productive partnerships with the citizenry, communities, civil society, industry, and governments to pursue applied or even basic research. Such partnerships may involve the co-creation of knowledge, and accelerate the translation of knowledge and amplify its impact in exciting ways.

Talent-focused:

Research talent has never been more mobile or in higher demand. The development and retention of outstanding students, trainees, and young researchers must be at the top of any priority list for the national research enterprise. Similarly, with a relatively small population but many other advantages, Canada must redouble its efforts to attract top-tier talent from around the world.

Diverse and Equitable:

Scientific and scholarly merit must be the foundation for any allocation of scarce research dollars. That said, merit and equity alike are compromised if success rates fall too low or vary radically across disciplines. Moreover, so long as standards are upheld, the goals of excellence, equity, and diversity are mutually reinforcing. Many research funding agencies abroad accordingly have special competitions or allocations for young scholars and scientists, pay close attention to gender balance and diversity more generally, and engage in careful capacity building to put underrepresented groups on a footing that brings them into the full competitive fold. As noted above, the development of talent is critical, and Canada's population is small. We handcuff ourselves in international competitions and collaborations if our research funding ecosystem fails to capitalize on the talents and energies of large segments of our population—whether it be women who make up more than 50 per cent of our citizenry or the 1.5 million Canadians with Indigenous roots.

Efficient:

Efficient research funding systems limit waste. They constrain overhead costs, align the flow of funds for research equipment and operations, and maintain high standards in granting funds to applicants while avoiding punitively low success rates. The Panel believes that the principle of simplicity should govern all programs and competitions to avoid wasting the scarcest non-renewable resources of some of Canada's brightest people: the waking and working hours of our scientists and scholars.

Outward-facing:

Great research ecosystems support public outreach including, as noted above, efforts to engage citizens in research. They recognize that conveying the excitement of science and scholarship to wide audiences, not least to children and youth, is essential to inspiring ensuing generations of research leaders. That activity will also be integral to the transition that Canada must undergo if it aspires to become the world's smartest and most successful society.

1.5 Seizing the Leadership Moment

As highlighted above, Canada's credible research showing to date reflects our substantial advantages in natural, financial, and human resources. Those advantages create a moral imperative for Canada to contribute to the global stock of scientific knowledge and scholarly insights, to be part of unlocking the mysteries of human and non-human nature and deepening our understanding of cultures and communities, and, more generally, to help address the serious challenges confronting our species as a whole. When billions live in circumstances vastly less favourable than ours, Canada cannot excuse middling contributions with self-congratulatory memes that we punch above our weight on a population-adjusted basis. For that matter, many less wealthy nations are now rapidly expanding their research capacity, while many of our OECD peers are investing heavily in both research and innovation. In this context of accelerating change and intensifying competition, the Panel believes that a world-leading extramural research enterprise is essential to the maintenance of Canada as a successful society and a prosperous sovereign nation.

> The federal review of fundamental research provides a tremendous opportunity to develop a bold and ambitious strategy for Canada. By recognizing our assets and leveraging our current strengths, Canada can bolster its capacity for global leadership and excellence in a wide range of research fields. To achieve this vision, we must invest in and mobilize Canada's people and ideas. An innovative, inclusive and prosperous Canada depends on a dynamic and excellent research ecosystem.
>
> – Universities Canada

We have therefore approached our work with a sense of urgency occasioned by more than the necessarily short timeline accompanying our mandate. We have been inspired by the excellence of Canadian research and the enthusiasm and engagement of the scholars and scientists with whom we have met. Those colleagues have also conveyed to us some of the challenges they face in their daily work. We have been dismayed to discover how often similar challenges are highlighted in a variety of commissioned reports extending back over more than 50 years, and how many opportunities for improvement have been missed in the intervening decades owing to shifting political and economic tides, and those chronic Canadian afflictions—lack of confidence and limited ambition. Now is the time to recover lost ground and seize the moment. We firmly believe that Canada must aspire to be a world leader in a select number of disciplines, and a consistent contender across the board. The Panel is also convinced that the national research enterprise is at a pivotal point where it can make enormous strides if the Government of Canada responds to our recommendations with imagination, courage, resolve, and dispatch.

ENDNOTES

1 Canada's Fundamental Science Review – Questions and answers [Internet]. Ottawa: Innovation, Science and Economic Development Canada; 2016. Available from: http://www.sciencereview.ca/eic/site/059.nsf/eng/00005.html#q1

2 Canada's Fundamental Science Review – Mandate of the Advisory Panel for the Review of Federal Support for Fundamental Science [Internet]. Ottawa: Innovation, Science and Economic Development Canada; 2016. Available from: http://www.sciencereview.ca/eic/site/059.nsf/eng/h_00010.html

3 Budget 2016, Chapter 2 – Growth for the Middle Class: Ensuring Federal Support for Research Is Strategic and Effective [Internet]. Ottawa: Department of Finance; 2016. Available from: http://www.budget.gc.ca/2016/docs/plan/ch2-en.html#_Toc446106702

4 Cited in: Senate Special Committee on Science Policy. A Science Policy for Canada, Volume 1 – A Critical Review: Past and Present, p. 287. Ottawa: Queen's Printer; 1970.

5 The Expert Panel on Business Innovation. Innovation and Business Strategy: Why Canada Falls Short. Ottawa: Council of Canadian Academies; 2009. Available from: http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/inno/(2009-06-11)%20innovation%20report.pdf

6 Innovation Defined [Internet]. Ottawa: Conference Board of Canada; n.d. Available from: http://www.conferenceboard.ca/cbi/innovation.aspx

7 Innovation for a Better Canada [Internet]. Ottawa: Innovation, Science and Economic Development Canada; 2016. Available from: https://www.ic.gc.ca/eic/site/062.nsf/eng/home

8 Advisory Council on Economic Growth [Internet]. Ottawa: Department of Finance; 2016. Available from: http://www.budget.gc.ca/aceg-ccce/home-accueil-en.html

9 Senate Special Committee on Science Policy. A Science Policy for Canada, Volume 3 – A Government Organization for the Seventies. Ottawa: Queen's Printer; 1973.

Annex: Further Details and Explanatory Notes for Exhibit 1.2

Program	Further Details and Explanatory Notes
SCIENCE REVIEW	
GRANTING COUNCILS (core programming delivered directly) – *Program operating costs not included*	
NSERC ($470M)	Includes Discovery Grants suite of programs ($360M), scholarships and fellowships ($76M) that are not industrial, Research Tools and Instruments ($26M), and others.
SSHRC ($169M)	Includes the Insight stream ($94M), the Talent stream ($36M), and estimates for programs (Partnership and Partnership Development Grants in particular) that fund both fundamental research and knowledge transfer activities.
CIHR ($692M)	Includes Foundation and Project Grants, scholarships and fellowships ($550M), as well as Institute-driven, Signature, and Strategic Initiatives ($140M).
TRI-COUNCIL – *Program operating costs included*	
Research Support Fund ($341M)	Funding for each institution is determined based on the grant funding received by researchers at the institution.
Canada Research Chairs ($265M)	Chairs are allocated to institutions based on the grant funding received by researchers, with program-wide regular allocations set at 45 per cent NSERC, 35 per cent CIHR, and 20 per cent SSHRC.
Canada First Research Excellence Fund ($50M)	Full funding of $200M per year will be achieved in 2018-19, with variable profiles for each project funded. In 2015-16, the distribution by granting council was NSERC – $31M, CIHR – $16M, and SSHRC – $2M.
Canada Graduate Scholarships ($132M)	There are granting council-specific allocations of CGS awards at the master's and doctoral levels. Current allocations among the granting councils are 52 per cent SSHRC, 32 per cent NSERC, and 16 per cent CIHR.
Networks of Centres of Excellence ($65M)	The Networks of Centres of Excellence program is a suite of programs that includes the "classic" NCEs, and other initiatives such as the Knowledge Mobilization Initiative. Networks receive funding from each of the granting councils based on the disciplinary activities of the networks. Program-wide, in 2015-16 the distribution was NSERC – $33M, SSHRC – $9M, and CIHR – $22M.
Canada Excellence Research Chairs ($35M)	Chairs are awarded to institutions based on a competitive process. In 2015-16 the distribution by granting council was: NSERC – $25M, CIHR – $10M. Funding can lapse due to turnover of Chairs.
Vanier Scholarships ($25M)	Scholarships are distributed equally between the three granting councils.
Banting Fellowships ($10M)	Fellowships are distributed equally between the three granting councils.
SCIENCE CONTRIBUTION AGREEMENTS	
Canada Foundation for Innovation ($396M)	Annual expenditures vary from year to year. Average annual expenditures, in 2006-07 to 2015-16, were $396M.
Brain Canada ($17M)	Estimate based on assumption that half of Brain Canada's expenditures are linked to federal support.
Perimeter Institute for Theoretical Physics ($10M)	Current contribution agreement provides for expenditures of $10M per year.
Stem Cell Network ($6M)	Funding of $6M per year begins in 2016-17.
Canadian Institute for Advanced Research ($5M)	Current contribution agreement spans 2012-13 to 2016-17.
Council of Canadian Academies ($3M)	Current contribution agreement spans 2015-16 to 2019-20.

Program	Further Details and Explanatory Notes
INNOVATION LINKED	
GRANTING COUNCILS – *Program operating costs not included*	
NSERC ($284M)	Includes programs under NSERC's Strategy for Partnerships and Innovation.
SSHRC ($36M)	Includes the Connection theme ($7M) and estimates for programs (Partnership and Partnership Development Grants in particular) that fund both fundamental research and knowledge transfer activities.
CIHR ($99M)	Includes programs with knowledge transfer and partner orientation including the Strategy for Patient-Oriented Research ($48M), the Collaborative Health Research Projects ($10M) program, the Proof of Principle program ($6M), and others.
TRI-COUNCIL – *Program operating costs included*	
College and Community Innovation Program ($46M)	The College and Community Innovation Program supports applied research at colleges and polytechnics.
Centres of Excellence for Commercialization and Research ($30M)	Centres receive funding from each granting council based on network activities. Program-wide, in 2015-16 the granting council distribution was NSERC – $9M, SSHRC – $7M, and CIHR – $11M.
Business-Led Networks of Centres of Excellence ($12M)	Centres receive funding from each granting council based on network activities. Program-wide, in 2015-16 the granting council distribution was NSERC – $7M, SSHRC – $1M, and CIHR – $3M.
SCIENCE CONTRIBUTION AGREEMENTS	
Genome Canada ($63M)	Annual expenditures vary from year to year. Average annual expenditures, in 2011-12 to 2015-16, were $63M.
Mitacs (Accelerate, Globalink, Elevate) ($19M)	Federal funding levels via contribution agreements vary year to year. In 2015-16 individual funding levels were Accelerate – $7M, Globalink – $7M, and Elevate – $5M.
Institute for Quantum Computing ($5M)	Current contribution agreement spans 2014-15 to 2016-17.

Note: Figures may not add up to the total due to rounding.

CHAPTER 2

A CASE FOR SCIENCE AND INQUIRY

As outlined in Chapter 1, the Panel's review is focused on research as a quest for knowledge and understanding. That quest is pursued using scientific methods and other forms of rigorous inquiry by colleagues across disciplines from the natural sciences and engineering through to the health sciences, social sciences, and humanities. While the work of full-time researchers in Canada and abroad is sometimes viewed as arcane, it is grounded in traditions of science and inquiry that have transformed our world for the better in recent centuries. These impacts have often been entirely unpredictable, as diverse discoveries were forged into inventions that catalyzed the creation of whole new economic sectors, or startling insights from social research coalesced into broad shifts in the evidence base for public policy.

For scientists working long hours in a laboratory or scholars poring over sources in a library, the rewards may be more or less tangible. They range from the accolades of peers and progression through the ranks of a discipline, to the joy of making a breakthrough that illuminates the beauty of nature or the complexity of humankind, or the satisfaction of seeing a graduate student go on to have a stellar career in industry or academe.

For Canada, however, research is ultimately about harnessing the power of human ingenuity and creativity to advance objectives cherished by our citizenry. A vibrant research ecosystem is essential to a wide range of objectives. These include:

- living longer and healthier lives in a cleaner and safer environment;
- protecting and enriching Canada's diverse cultures and heritage;
- developing innovative technologies, goods, and services that contribute to our economic prosperity and create fulfilling jobs;
- sustaining our economic sovereignty, standard of living, and valued social programs;
- fostering a creative, vibrant, and inclusive society;
- stimulating informed public debate; and
- supporting evidence-based policy-making in a period of accelerating change and complex domestic and global challenges.

Research intersects with and advances these objectives in ways that range from immediate and obvious to subtle and long delayed. Nonetheless, if there is one lesson that we can confidently take from history, it is that science and inquiry are the foundations of progress in almost every human endeavour.

We understand that most readers already have an implicit appreciation of the impacts of research on our daily lives and well-being. The Panel is mindful, however, of the old adage that "a fish is never wet." In like fashion, the benefits of research are so pervasive that it is sometimes easy to overlook how much we have all gained from these uniquely human activities, or worse, to only focus on costs and risks. Against that background, we have organized our thoughts about the positive impacts of research in three brief sections.

The first revisits the rationale for basic research, not least its transformative impacts on education. The second focuses on social and cultural benefits. The third considers how research helps fuel economic growth and innovation, before we close with some brief reflections.

2.1 A Uniquely Human Activity

Geological time is daunting. The earth is estimated to have been in existence for 4.6 billion years, and *Homo sapiens sapiens* for no more than 200,000 of those. The brief duration of human existence becomes more comprehensible with the trope of converting geological time to a single day. Humanity's collective rise occupies roughly the last four seconds before midnight. The time in which you blink your eye runs from well before the period of early human settlements and agriculture right up to the present day. It follows that the period in which science and inquiry have utterly transformed and lifted the quality and longevity of life for our species is unimaginably short, measured against the existence of the planet or even against the period in which humankind has been the dominant species on it.

While early work in science and social or philosophical inquiry can be traced back well over 2,000 years, economic historian Joel Mokyr has argued provocatively in a recent essay[1] that the key period of transformation was the 17th century. The enabling factor, he argues, was a growing belief that progress was possible—that the broad human condition could be improved by convergent insights from scientific research and social inquiry. While the forerunners of modern scientists overturned assumptions about the natural world, the forerunners of modern social scientists, along with historians and philosophers, began to challenge assumptions about the social and political order. The prevailing ethos was reflected in the motto adopted by the fellows of the Royal Society of London soon after its founding in 1660: *nullius in verba*. Its intent was clear: Take no one's word for what is or is not true.

At the time that motto was adopted, the average life expectancy across Europe was under 45 years of age, only a tiny fraction of the population could read and write, poverty and hunger were endemic, open sewage ran in the streets, child mortality ranged from 25 to 50 per cent, and misery was rampant. In less than 20 generations, the relentless quest for deeper understanding of human and non-human nature has radically changed the world. Every physical thing we may be tempted to take for granted—from automobiles to antibiotics, from calculators to CAT scans, and from skyscrapers to smartphones—is based on technology enabled by multiple fields of basic and applied science. Everything else that matters—concepts such as democracy, equity, universal suffrage and education, the rule of law, and freedom of assembly and speech—has become part of our lives mainly because of humanistic inquiry and insights from the social sciences.

This blend of curiosity and creativity has arguably become the defining trait of our species. As this report was going to press, South African-Canadian cosmologist Neil Turok reflected eloquently on basic research in a sesquicentennial essay for *The Globe and Mail:*

> Learning from the universe—both nearby and far away—has laid the foundation for every technology that has shaped our world. … Our ability to comprehend the workings of nature, and to apply that knowledge with ingenuity to improve our world, makes us who we are. We contemplate and imagine, experiment and observe. When we understand, we design and we make. In doing so, we continually reshape the world.[2]

Social scientists and humanists would surely want to modify those words to better suit their disciplines. But the sentiments strike the Panel as widely generalizable, and lead us to the links between research and education.

Canadian humanist Edward Chamberlin once replied to the rhetorical question about what professors do at universities in lyrical language as follows: "We tell stories: old stories, about evolution and the decline and fall of the Roman Empire, about the Big Bang and the Great War, about justice and freedom, supply and demand, economy and efficiency. And we make up new stories. We call the old ones teaching, and the new ones research."[3] It is this interweaving of science and inquiry with teaching and education that is among the key national advantages of a vibrant research ecosystem. What it helps secure is a much higher prevalence of open and inquiring minds in the next generation of citizens. Such an outlook is a lifelong asset not only to the individual but to everyone around him or her. Moreover, those students will be much better prepared to write their own stories in a world full of the challenges left by our generation.

The Panel emphasizes that the experience of tackling complex research problems has a particularly profound effect in graduate education. As we outline in Chapter 3, only a fraction of doctoral students will go on to work as academics. Whatever field of endeavour they pursue, these graduates will move ahead with a spirit of adventure and a confidence that they can attack any problem no matter how difficult. (We return to this issue in Section 2.3.)

There are other important attributes of science and inquiry that bear brief mention here.

First, research connects Canada to the world and the world to Canada. Without outstanding scientists and scholars here, we will be poorly positioned to take advantage of breakthrough discoveries and insights arising abroad. Discourse among researchers transcends language, geography, culture, politics, ideology, and religion. Michael Polanyi's 1962 portrayal of "The Republic of Science" as a self-governing democracy may have been idealized.[4] However, in a period when international exchange may be impeded by political and social counterforces, the research community remains highly globalized. A related point, on which we touch in Section 2.3, is that a concentration of world-leading researchers is an enormous magnet for international talent, ranging from undergraduate students to full professors and industrial innovators.

Second, beyond the connections forged among researchers, science and scholarship have the enormous promise of yielding generalizable insights that can rekindle our common humanity in these centrifugal times. For example, human biology is remarkably consistent and genetic differences across the world are trivial. Disease and disability are also global phenomena, and epidemics respect no national borders. Scholars from the SSHRC disciplines can abet the quest for mutual understanding with insights into the similarities and differences in language, literature, culture, and religion. Furthermore, widely shared curiosity about the natural world means that scientific discoveries often ripple across the planet, exciting people on every continent with their novelty and promise. Not least, the quest to understand not just the cosmos, but humanity's place in it, bridges faith and reason, and unites us in the sober recognition that for all our supposed differences, in our infinite ignorance and impermanence we are all equal.

2.2 Social and Health Benefits

While the Panel is highly optimistic about Canada and its prospects, we acknowledge that a glance at the wider world brings Charles Dickens to mind:

> It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair…[5]

Hundreds of millions of people have risen out of poverty.[6] The so-called middle class has never been larger, and with that demographic shift has come unprecedented opportunity for successive generations to thrive as never before. Billions of people live in countries that are governed democratically. Mass communications and information technologies are connecting people and cultures around the world. Human life expectancies are rising and quality of life indices are improving. Our collective understanding of human and non-human nature continues to expand at an exponential rate. Ever more powerful technologies and inclusive growth strategies are being marshalled to improve and enliven the human condition.

We acknowledge, however, that the world is confronted with many challenges. What is unsettling is not so much the number of entries that might be registered on the negative side of the ledger, but their complexity, pervasiveness, and potential further scope. For example, the global population continues to rise, and climate change is exacerbating pressures on water and food supplies. Political instability has intensified, many countries are still struggling to raise a substantial proportion of their populations out of poverty, income inequality has grown in many industrialized nations, and the global aging of the population is creating health, social, and economic challenges that are rippling across Europe, Japan, China, and North America.

Successfully tackling these issues will require efforts that cut across a range of disciplines. Climate change and environmental degradation are prime examples. Responding to these issues will clearly call for major contributions from natural scientists, geographers, and engineers—for example, assessing impacts on Canada's fresh water, atmosphere, and coastal lands, devising alternative energy solutions, and developing clean technologies to reduce greenhouse gas emissions, while staying competitive globally. Health researchers will also need to address any health threats arising from climate change, and the ethical, legal, and social issues seem destined to rise steadily given the global scope of the effects now being seen. Moreover, social psychologists may have a unique niche in addressing the cognitive dissonance that polarizes discourse on this topic.

Population aging will put steady pressure on the Medicare programs that span Canada's 13 provinces and territories and have long been sources of national pride. To manage this trend effectively and efficiently, researchers from a range of disciplines will need to work with decision-makers to reinvent home care. Issues of mobility and activities of daily living for seniors will drive a renewed emphasis on rehabilitation research. Another pressure point will be the rising burden of dementia. The age-adjusted incidence of dementia is falling worldwide, but the prevalence of these disabling conditions, particularly Alzheimer's disease, will rise inexorably over the next two decades. Canada has long been a strong contributor to Alzheimer's research. It would be a world-changing contribution and great Canadian milestone if definitive treatments to arrest or reverse the progression of this scourge were to be developed and proven here.

On a different demographic front, an important window of opportunity has opened for Indigenous reconciliation. The Truth and Reconciliation Commission has laid out a path to secure a better future not just for Canada's 1.5 million citizens with Indigenous roots, but also for the entire nation. Moving along that path will require the development and implementation of evidence-based strategies to address poverty and high unemployment, heal fractured families, build new infrastructure, and improve education, while respecting and preserving Indigenous cultures. The lead here will be taken overwhelmingly by Indigenous scholars and colleagues in the social sciences and humanities.

In this regard, a thoughtful submission by the Federation for the Humanities and Social Sciences makes a more general case for research and scholarship in these fields.

> HSS [humanities and social sciences] scholars are integral to Canada's research system, and their contributions will be critical to supporting a world-leading research system capable of helping Canada address the complex challenges facing our society. HSS researchers bring creativity, historical context, inquiry and critical perspectives to bear on complex problems. They generate new knowledge about human thought, behaviour, experiences and expression, helping us to understand one another better, to design more effective and equitable policies and institutions, and to develop, understand and appreciate our cultures.[7]

In brief, Canadian society—and the world around us—faces multifaceted challenges that require multidisciplinary approaches to arrive at effective solutions. Canada cannot address tomorrow's challenges based on yesterday's research. We must be positioned to access and adapt the best ideas that scientists and scholars in other countries generate, and to do our fair share in addressing global social and health challenges. Furthermore, if Canada is to thrive in the 21st century, our capacity to formulate imaginative, innovative, and evidence-based public policy must be second to none. Policy-making, we understand, involves not just evidence, but values and circumstances. Assessing the relevant trade-offs will be the responsibility of our elected representatives. However, it is very much the responsibility of the research community to generate the relevant evidence, and the reciprocal responsibility of decision-makers to ensure that they have the tools and resources to do so.

Finally, while researchers can help respond to diverse challenges, the Panel believes it is important to acknowledge how research helps build a better nation in two less tangible ways. One arises from the way in which the achievements of top-tier researchers inspire a broader sense of collective pride and individual purpose among researchers and non-researchers alike. Exhibits 2.1 and 2.2 list a sampling of the many outstanding accomplishments by Canadian scientists and scholars over the last 150 years. The other relates to the intersection of a spirit of open inquiry with the ethos of pluralism that is one of Canada's distinguishing characteristics and enduring advantages. We argued in Section 2.1 that research is an expression of humanity's innate interest in understanding our world. A society that does not widely nurture curiosity and creativity across successive generations is at risk of turning inwards. In contrast, a society that values and supports scientists and scholars from a range of disciplines is much more likely to remain a global beacon of inclusion and social solidarity—as we firmly believe Canada has become, and must remain.

2.3 Innovation and Economic Benefits

Innovation is widely recognized as the ultimate driver of long-term economic growth and prosperity. As noted in Chapter 1, innovation is commonly defined as "new or better ways of doing valued things."[8] Unbundling that definition, it becomes apparent that innovation means creating new or improved technologies, processes, goods, and services that enhance our lives. It may involve developing new marketing methods, organizational structures, and business models that produce better economic outcomes. And, on occasion, an innovation can spawn an entirely new market that alters the course of history.

These fruits of innovation do not materialize out of thin air. As already discussed, they grow out of the wellspring of knowledge, ideas, and insights that originate largely, albeit not exclusively, from basic research. The Panel emphasizes that care is needed in assuming that the innovation process is necessarily linear, or that its time-course is readily predicted. From time to time, there is a steady progression from basic research through to applied research, development, and a commercial innovation. However, in many cases the connections can be extremely rapid (as is occurring now with CRISPR gene-editing technology), non-linear, or even inverted in at least two ways. One inversion scenario sees basic scientists pushing the edges of technology; suppliers respond, the research is able to advance, and suppliers have a better product and wider market. Another scenario sees applied scientists collaborating with basic scientists to find new methods of solving a thorny problem, leading to new important insights. In all these cases, students and trainees benefit from a boundary-stretching experience.

Stokes makes these arguments compellingly in his landmark 1997 monograph.[9] He coins the term "Pasteur's quadrant" to honour Pasteur's gift for rapid cycling from industrial to basic research, and examines how basic research inspired by practical questions can both leapfrog rapidly into technological innovation and cycle back to open up major fields of scholarly or scientific inquiry.

In brief, it is often difficult to compartmentalize research activities into discrete categories like "basic" and "applied" when discussing the innovation process. The Panel also fully recognizes that not all basic research begets innovation, just as not all innovation is rooted in basic research. Indeed, massive multinational businesses have been built from process innovations, from imaginative applications of extant technologies in new ways, or from smart bundling of multiple technologies. That said, we believe that, with careful tracking back over time, it will be shown time and time again that basic research is the upstream source of the foundational building blocks for innovations of transformative importance to the world.

Exhibit 2.1: A Small Sampling of Canadian Discoveries, Inventions, and Achievements in Natural Sciences, Engineering, and Health[a]

Year/Period	Discoveries, Inventions, and Achievements
1870–1899	• First telephone (Bell) • First telephone handset or transceiver (Duquet) • Standard time (Fleming) • First rotary railroad snowplough (Jull)[b] • First compass to measure horizontal angles (Brunton)
1900–1929	• Robertson screw (Robertson) • Marquis wheat (Saunders) • Radioactive half-life, foundations of nuclear physics (Rutherford; Nobel Prize 1908) • Insulin discovered (Banting, Best, Collip & Macleod; Nobel Prize 1923 to Banting and Macleod) • First AC-powered commercial radio receiver (Rogers)
1930–1949	• Landmark atlas and classification of congenital heart disease (Abbott) • First caterpillar-tread snowmobile (Bombardier) • Pablum for infants (Tisdall, Drake, & Brown) • Pioneering studies in stress responses begin (Selye)
1940–1959	• Neutron scattering techniques for studying condensed matter (Brockhouse; Nobel Prize 1994) • G-suit invented, tested, flown in combat (Franks) • Voltage controlled musical keyboard—forerunner of synthesizers (Le Cain) • Hypothermic cardiac surgery (Bigelow & Callaghan) • External cardiac pacemaker (Hopps, Callaghan & Bigelow) • Cobalt-60 radiation therapy for cancer (Johns)
1960s	• Ionospheric studies by satellite: Alouette program (Chapman et al.) • Stem cells discovered (Till & McCulloch) • Mathematical ecology emerges with classic textbook (Pielou) • Plate tectonics theory advanced (Wilson) • Breakthroughs in memory begin (Milner)
1970s	• Nobel Prize in Chemistry 1971, Herzberg, for 30 years of pioneering work in spectroscopy and elucidation of free radicals • More insights into memory formation (Tulving & Milner) • Key paper on site-directed mutagenesis; later leads to Nobel Prize for Smith (1993) • Canola developed (Downey & Stefansson)
1980s	• Ongoing studies in infrared luminescence/quantum tracking of chemical kinetics lead to Nobel Prize (1986) for Polanyi • Canadarm: used on space shuttles until 2011 (multiple inventors, Mee credited for the "hand") • First long-term single and double lung transplants (Cooper) • Development of photodynamic therapy for treating macular degeneration (Levy & Dolphin) • Gene for cystic fibrosis discovered (Tsui & Riordan)
1990s	• First smartphone invented/BlackBerry (Lazaridis) • Cancer stem cells discovered (Dick) • Neural stem cells discovered (Weiss) • Beginning of breakthroughs in superconductivity based on Yttrium barium copper oxide crystals (UBC/CIFAR team)
2000s	• Further elucidation of neutrino oscillations and mass (SNO team, led by McDonald; Nobel Prize 2015) • Many stem cell breakthroughs (Rossant, Nagy, Miller, Bhatia, van der Kooy et al.) • Major advances in Artificial Intelligence – Deep Learning (Hinton & Bengio) • Effective vaccine for Ebola fever (National Microbiology Lab team, led by Feldmann) • Elucidation of critical elements of the CRISPR-Cas9 system (Moineau et al.)

[a] Limited to those who lived or worked in Canada full- or part-time at the time of the relevant activity; non-Canadian co-authors/co-inventors not listed but often full partners.

[b] Original design also Canadian, by Dr. J.W. Elliott in 1869.

Exhibit 2.2: A Small Sampling of Great Canadian Thinkers in the Social Sciences and Humanities

Harold Innis (1894–1952). Economic historian and multidisciplinary scholar. Originated the "staples theory" to explain Canadian economic development, later applied to many other national contexts. Early student and critic of mass media and their effects on the fabric of society.

John P. Humphrey (1905–1995). Legal scholar and teacher, and founding director of the UN Division of Human Rights (1946) where he led many pioneering initiatives. Revered as first author of the Universal Declaration of Human Rights, adopted in 1948.

Marshall McLuhan (1911–1980). Philosopher, public intellectual, and pioneering media theorist. Achieved world renown as a guru of mass communications. Predicted the worldwide web in the 1960s. Remains a household name.

Northrop Frye (1912–1991). Globally influential literary critic and theorist, with a massive oeuvre ranging from re-interpretation of the poetry of William Blake to seminal studies of the structure of Western literature and its roots in Judeo-Christian religious writings.

Léon Dion (1922–1997). Pioneering political scientist. Lead researcher for the pivotal Royal Commission on Bilingualism and Biculturalism (1963–1969). Honoured by l'Académie française and l'Académie des sciences morales et politiques.

Guy Rocher (1924 –). Multidisciplinary and prolific social scientist, with special interest in public law and social change. Leadership roles in academe, on government commissions, and in the civil service. Books translated into many languages; honoree of the American Academy of Arts and Sciences.

Natalie Zemon-Davis (1928 –). Historian who has pioneered narrative and ethnographic techniques, eschewing the "great men and events" paradigm. Prolific author of award-winning books translated into many languages. Awarded the U.S. National Humanities Medal and Norway's Holberg Prize.

Richard Lipsey (1928 –). Economist who linked equilibrium models to real world policy-making (viz. General Theory of the Second Best). Internationally renowned as lead author of textbooks that introduced economics to millions of students worldwide.

Charles Taylor (1931 –). Philosophical polymath, interpreter of great thinkers of centuries past with deep engagement in contemporary issues. Champion and expositor of Canadian federalism and multiculturalism. Global honours include Japan's Kyoto Prize.

Margaret Lock (1936 –). Pioneer in medical anthropology. Major contributions in comparative epistemology of medicine, social anthropology of transplantation, and impact of genetics on society. Publications have won many prizes from international learned societies.

Ian Hacking (1936 –). Historically-minded philosopher of science. Examined the transformation of modern thought by probabilistic thinking, and the formation of human identity using mental illnesses as a conceptual lens. Multiple international awards, including Norway's Holberg Prize.

Henry Mintzberg (1939 –). Renowned management theorist, author of 15 books. His iconoclastic views on strategic planning, leadership, and business education, and his work on organizational configurations, have had an enduring influence globally.

Margaret MacMillan (1943 –). Renowned historian of international relations in the 20th century, and public intellectual commenting on global affairs. Author of multiple non-fiction best sellers, and winner of numerous international awards.

Gérard Bouchard (1943 –). Award-winning scholar, with a massive publication record ranging across historical inquiry and quantitative social science. Co-chaired the Bouchard-Taylor committee with its internationally influential delineation of "inter-culturalism" for distinct societies within federal states.

Janet Werker (1951 –). Cognitive scientist of international repute. Her work on language acquisition by infants has fundamentally changed thinking about developmental neurolinguistics. A CIFAR fellow, she has won awards from professional societies in Canada and the U.S.

It is no wonder, then, that prominent U.S. economist Ben Bernanke has lamented that "the declining emphasis on basic research is somewhat concerning because fundamental research is ultimately the source of most innovation, albeit often with long lags."[10] If this is in fact a concern in the U.S. as several major reports have argued,[11] then the concern should be even more acute in Canada, where our scientific community has been reeling from a decade marked by the de-prioritization of basic research.

A temptation to move funds towards applied research, especially during economically challenging times, arises in part out of the uncertainty stemming from the "long lags" to which Bernanke alludes. Such lags occur not only because of the immense complexity of the innovation and commercialization process, but also because major breakthroughs in basic research are frequently the result of serendipitous discoveries that are not foreseeable at the outset. Indeed, setting targets for the social or economic impacts of basic research reflects a profound misunderstanding of its contribution. If the results could reasonably be known in advance, the activity is not really research. Simply put, neglecting basic research owing to impatience or uncertainty contradicts much of the historical evidence.

On this latter score, countless examples can be adduced of basic research that had no immediate application but eventually translated into transformative innovations with substantial long-term benefits. For instance, the information revolution of the 1990s can be traced back to basic science from the 1970s, and those discoveries in turn build on a line of work dating back to the early part of the century. Research findings dating back to the 1950s have contributed to major innovations in biotechnology that are unfolding today. Basic research in physics in the late 1800s led to radio and electrical power generation and transmission along with electric motors and generators. When quantum physics and relativity were born in the early 20th century, no one could have predicted the array of innovations that would result many years downstream—innovations as varied as the transistor and semiconductors, solar cells, rechargeable batteries, the laser, the integrated circuit, the personal computer, the internet, medical imaging, flat-panel high-definition televisions, satellites in orbit, and the BlackBerry, to name but a few. Taking a recent Canadian example, the development of an effective vaccine against the Ebola virus arose from 15 years of research at the National Microbiology Laboratory, pursued to understand curious immune properties of the virus long before Ebola fever mushroomed in an outbreak.

> Federal funding should be used mainly for basic, curiosity driven research. While research that has direct benefits to people is critical, it is important to recognize that this research can be easily monetized, and therefore should be carried out by the private sector. Publicly funded science should focus on more fundamental questions. Answering these fundamental questions will allow for innovations that cannot be predicted today, and may not have any direct benefit to people for many years. Private enterprise cannot work on these long time scales, but public enterprise can.
>
> – Active researcher, Memorial University of Newfoundland

The hard reality, moreover, is that businesses are unlikely to invest in basic research. Writing in December 2016 in the *Wall Street Journal*, Rafael Reif, the president of Massachusetts Institute of Technology, highlighted the record-breaking pace of industrial spending on R&D and asked:

> With industry already investing so much, the question sometimes arises: Why can't our entire national research investment be privatized? Because the qualities that make industry good at applied research and development—an appetite for immediate commercialization, a laser focus on consumer demand, an obligation to maximize short-term returns, and a proprietary attitude about information—make industry a bad fit for supporting basic scientific research. In the days before the burdens of quarterly public earnings reports and intense global competition, Bell Labs and its peers had the freedom to invest in very long-term research. But today, industry R&D disproportionately prefers the "D" in R&D, as a good source of incremental gains. Industry hardly touches the earliest form of "R"—fundamental science—although that is where the gains can be transformational.[12]

For Canada with its different mix of industry and lower rate of business R&D spending, this message has even greater urgency.

A key lesson emerging from the foregoing is that governments must give researchers the support and freedom to pursue their very best ideas, any one of which holds the potential to result in a discovery or insight that is the seed of a future innovation or industry. Indeed, the collective effort of the research enterprise is most fruitful when scientists and scholars can let their curiosity and passions guide them to those areas where they can make their very best contributions. As observed by Bill Downe, Chief Executive Officer of BMO Financial Group, "breakthroughs happen when brilliant minds are given the freedom to probe the nooks and crannies of reality—when exceptional people ask fundamental questions about the deepest problems and make extraordinary discoveries that benefit us all."[13]

This quest for extraordinary breakthroughs must span all disciplines. With the services sector now accounting for 70 per cent of Canada's GDP and three-quarters of its jobs, future economic growth will increasingly be driven by innovation in services, communications, and new cultural products. Humanists and social scientists will also bring much-needed insights into the "human dimension" of technological innovation, helping us understand how technologies affect our society and culture. A memorable observation made to the Lamontagne Commission in the 1970s gets to the heart of this: "Science without humanity is void. Humanity without science is blind."[14]

Science, The Endless Frontier

New products, new industries, and more jobs require continuous additions to knowledge of the laws of nature, and the application of that knowledge to practical purposes. … This essential, new knowledge can be obtained only through basic scientific research. Science can be effective in the national welfare only as a member of a team, whether the conditions be peace or war. But without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world. … A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill.

– Vannevar Bush, July 1945 report to the President of the United States, "Science, The Endless Frontier."

The Panel acknowledges again that it is difficult to predict and precisely measure the long-term impacts of basic research. Nonetheless, a number of studies have endeavoured to do just that. Studies of the yields from research have been done in many contexts, using diverse methods. These studies are most straightforward when they focus solely on private rates of return on R&D. Those rates of return average 30 per cent, with median returns slightly lower, ranging from 20 to 25 per cent.[15] Social rates of return, based on spillover benefits, have been found to be typically two to three times larger than the private returns.[16] Furthermore, one major survey, covering 50 years of economic outcomes, found that the private returns to R&D investments in many countries are generally higher than those accruing to other forms of capital, and social rates of return are almost always estimated to be substantially higher than private returns.[17]

With respect to basic research, the latter survey found that "most estimates for public government-funded R&D suggest that it is less privately productive than private R&D, as it should be, given the fact that it targets goals that either do not show up in conventional GDP or have substantial positive externalities."[18] A corollary is that the existence of these "substantial positive externalities" (or social returns) means that the economic justification for government support of basic research is stronger than for other types of research that are closer to market. This is because the closer an activity is to the marketplace, the more likely that a larger portion of its benefits will be captured by the individual performer, rather than "spill over" to the wider economy and society.

Another key point, from the standpoint of "positive externalities", is that none of these studies fully captures the vital contributions of research-led education in shaping the talents, skills, and ambitions of the next generation. That is because such contributions cannot be measured through any simple metric. How, for instance, can one quantify the opening of an undergraduate's mind by a first-year encounter with a great professor of philosophy, science, or engineering, or a graduate student's intellectual development while completing a dissertation under the supervision of a brilliant computer scientist or psychologist, or a postdoctoral fellow's maturation as an independent researcher when mentored by a world-class linguist or proteomics specialist?

It is essential, in this respect, not to confuse ease of attribution with causation as regards conventional metrics such as GDP growth. To repeat and amplify a point made earlier: Active and exciting research programs enhance learning at the undergraduate, graduate, doctoral, and postdoctoral levels. They give students the opportunity to learn at the frontiers of knowledge, so they are better prepared to take on any challenge, research or non-research related, in their future lives. Analyzing and synthesizing information, testing hypotheses, challenging assumptions, weighing arguments from different viewpoints, communicating effectively, solving problems, thinking critically—these products of a research-intensive education are invaluable competencies that will serve students over the course of their entire lives. Whether they end up in the public sector, academe, civil society, or the private sector, those graduates will be better positioned to innovate and make a mark on the world if their education imbued them with the spirit of inquiry and understanding that lies at the core of research. In short, Canada will be a nation of marginal and incremental innovators if the so-called "Innovation Nation" is not animated by the same ethos that inspires our researchers and drives our research enterprises.

Last and far from least, exciting research programs help attract to Canada talented individuals from all over the world—individuals who enrich our society and culture, and who become entrepreneurs and business people, innovators and cultural figures, politicians and community leaders. When they come to Canada, these new Canadians are our eyes and ears on the world, exposing us to new ideas and practices and enlightening us with unique perspectives and knowledge. Talented people, in turn, attract and inspire even more talent, both domestic and foreign, in addition to capital and investments. In many cases, this can catalyze the creation of regional hubs that are virtuous circles of talent generation, investment, job creation, economic growth, and social and cultural development. That has clearly been the case in the U.S. where a 2016 study found that 51 per cent of billion-dollar start-ups originated with the work of immigrants or were led by them.[19] Other studies have suggested that 30 to 40 per cent of the most successful companies in Silicon Valley are tied to leadership by immigrants who came to do graduate studies at top U.S. universities.[20]

2.4 Conclusion

The central message of this chapter is simple: Research is essential to the health, prosperity, and security of Canadians and to our efforts to foster a creative, inclusive, and vibrant society. Our universities, colleges, and research institutions are responsible for providing the right environment and tools not only to perform this research at the highest levels of excellence, but also to inspire, teach, and shape each new generation of students through research-led education. If the federal funding apparatus is well-tuned and properly resourced, our universities and research institutions can become hubs that will catalyze unprecedented levels of innovation and prosperity. Our research institutions will provide a window into the best ideas generated by the global research community, and contribute in turn to the global trove of knowledge, raising Canada's reputation in the process. As the reputation of Canadian researchers and research institutions continues to grow, they will attract the very best students from around the world—students who, like so many before them, will come for an education and stay for a lifetime. Those institutions, in short, are Canada's Pier 21 for the 21st century, welcoming the next generation of immigrants who will enrich our culture and help us continue to build this great nation.

As a small country, Canada may not be able to invest in basic research at the same levels as the world's top economies in absolute terms. However, in relative terms we must aim to be at or very near the top of the funding pyramid. This is essential if we are to be true leaders in a number of key areas and serious competitors across the board. It also ensures that we can stay fully attuned to the key advances in research across disciplines and around the world. These investments will pay remarkable dividends in the years ahead even as they help distinguish Canada on the global stage. They have the further advantage of helping Canada retain its strongest domestic talent and ensuring that, at a time of global turbulence, we can build on our global reputation as a welcoming, prosperous, pluralistic society and draw the very best and brightest from around the world.

ENDNOTES

1 Mokyr, J. A Culture of Growth: The Origins of the Modern Economy. Princeton: Princeton University Press; 2016.

2 Turok, N. Young Canadians can be the innovators the world needs. The Globe and Mail. 2017 January 2. Available from: http://www.theglobeandmail.com/news/national/canada-150/young-canadians-canbe-the-innovators-the-world-needs/article33465365/

3 Chamberlin, J.E. Convocation Address, University of Toronto, June 2005. Personal communication (2017 January 8).

4 Polanyi, M. The Republic of Science: Its Political and Economic Theory. *Minerva*, 1962; I(1): 54-74.

5 Dickens, C. *A Tale of Two Cities*. London (England): Chapman & Hall; 1859.

6 World Bank Forecasts Global Poverty to Fall Below 10% for First Time; Major Hurdles Remain in Goal to End Poverty by 2030 [Internet]. Washington, D.C.: The World Bank; 2015 October 4. Available from: http://www.worldbank.org/en/news/press-release/2015/10/04/world-bank-forecasts-global-poverty-to-fall-below-10-for-first-time-major-hurdles-remain-in-goal-to-end-poverty-by-2030

7 Submission of the Federation for the Humanities and Social Sciences to the Panel, *Grasping the complexity of things: Building a federal research system to serve all Canadians* (2016), p. 6.

8 The Expert Panel on Business Innovation. Innovation and Business Strategy: Why Canada Falls Short. Ottawa: Council of Canadian Academies; 2009. Available from: http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/inno/(2009-06-11)%20innovation%20report.pdf

9 Stokes, D.E. Pasteur's Quadrant: Basic Science and Technological Innovation. Washington, D.C.: Brookings Institution Press; 1997.

10 Bernanke, B. Promoting Research and Development: The Government's Role [address to the Conference on New Building Blocks for Jobs and Economic Growth]. Washington, D.C.; speech given 2011 May 16. Available from: https://www.federalreserve.gov/newsevents/speech/bernanke20110516a.htm

11 See, for example, Committee on Prospering in the Global Economy of the 21st Century, Committee on Science, Engineering, and Public Policy. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, D.C.: The National Academies Press; 2007, and Members of the 2005 "Rising Above the Gathering Storm" Committee. Rising above the Gathering Storm, Revisited: Rapidly Approaching Category 5. Washington, D.C.: The National Academies Press; 2010.

12 Reif, L.R. The Dividends of Funding Basic Science. The Wall Street Journal. 2016 December 5. Available from: http://www.wsj.com/articles/the-dividends-of-funding-basic-science-1480982516

13 As quoted in: Universities Canada. Universities Canada's Response to the Government of Canada's Review of Federal Support for Fundamental Science, p. 4. Ottawa: Universities Canada; September 2016. Available from: https://www.univcan.ca/wp-content/uploads/2016/10/federal-support-for-fundamental-science-submission-oct-6-2016.pdf

14 Senate Special Committee on Science Policy. A Science Policy for Canada, Volume 1 – A Critical Review: Past and Present, p. 234. Ottawa: Queen's Printer; 1970.

15 Frontier Economics Ltd. Rates of Return to Investment in Science and Innovation: A Report Prepared for the Department for Business, Innovation and Skills (BIS). Frontier Economics Ltd.: London (England); 2014. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/333006/bis-14-990-rates-of-return-to-investment-in-science-and-innovation-revised-final-report.pdf. This is a broad survey of studies on this issue. Definitions of social rates of return and spillover benefits are included in the report.

16 Ibid. Estimates range widely and are sensitive to the data sources utilized, sectors studied, periods covered, and models and methods used.

17 Hall, B.H., Mairesse, J., Mohnen, P. Measuring the Returns to R&D. National Bureau of Economic Research Working Paper 15622. Cambridge (MA): NBER; 2009. Available from: http://www.nber.org/papers/w15622.pdf

18 Ibid.

19 Koh, Y. Study: Immigrants Founded 51% of U.S. Billion-Dollar Startups. The Wall Street Journal. 2016 March 17. Available from: http://blogs.wsj.com/digits/2016/03/17/study-immigrants-founded-51-of-u-s-billion-dollar-startups/

20 Fairlie, R.W. Open for Business: How Immigrants Are Driving Small Business Creation in the United States. The Partnership for a New American Economy; 2012. Available from http://www.renewoureconomy.org/wp-content/uploads/2013/07/openforbusiness.pdf

CHAPTER 3

THE ESSENTIALS: RESEARCH FUNDING, OUTPUTS, AND TALENT

One of the main lessons of Chapter 2 is that countries will thrive in the 21st century based on their ideas, inventions, and capacity to formulate and execute sound public policy. Countries that cannot keep up on these fronts will fall behind.

These challenges are particularly acute for Canada. For much of the past half-century, Canada has prospered owing to our proximity to the huge U.S. market, our wonderfully abundant natural resources, and our efficient manufacturing capacity. Those sectors still have a major economic impact. However, the nation continues to transition to greater reliance on the services sector and must urgently diversify our economy, augment productivity, and drive GDP growth through innovation in every sector, not least our traditional strengths in natural resources and manufacturing.

We argued earlier that this transition could be accelerated if a substantial proportion of the population were motivated and equipped to assimilate and, as needed, generate new ideas, new products, new approaches, new policies, and new ways of working based on sound evidence, rigorous inquiry, and rational discourse. Scientists and scholars accordingly have a vital role to play that goes well beyond their own research agendas. Through their teaching and mentorship, their example to Canadian society, and their interactions with leaders in the public and private sectors, they can accelerate the national quest for new ideas and technologies, a more creative economy and sustainable environment, and a civil society based upon evidence-based public policies. This is one of the paradoxes of independent research. Its immediate relevance and long-term implications may be uncertain; its immediate impact on the intellectual capacity of those exposed to it is not.

It is these goals that informed the Panel's delineation of principles in Chapter 1 to assess Canada's extramural research environment. Later chapters will therefore take a close look at governance as well as funding programs and a number of issues and challenges that cut across the four pillar agencies. While those qualitative assessments and the resulting recommendations draw heavily on stakeholder input, this chapter uses primarily quantitative methods to examine three key elements of our research ecosystem: funding indicators, the quality of research outputs determined primarily through standard bibliometrics, and talent development.

Such measures have limitations, as discussed below, but they also provide an objective sense of the foundations on which Canadian research currently rests. The Panel believes that Canadians can and should take pride in our performance on a number of these indicators. That said, our overall footing appears more than a little uneven. While we are climbing, other nations are on a faster ascent in many respects.

3.1 Funding

We begin with a consideration of the investment in Canadian research. The natural question here is: How much is enough? As with any investment, the goal should be to balance inputs and returns. We emphasized in Chapter 2 that the returns to research, although substantial and demonstrable over time, are also uncertain and lagged. This is especially the case with basic research. Thus, Canada, like other countries, is left with imperfect means to answer the evergreen "How much?" question, and may be best advised to compare our national effort with that of nations achieving admirable research outputs and favourable long-term socioeconomic outcomes. Although the measurement may be complicated, the Panel believes that the motivation must always be how to maximize impact rather than focusing solely on inputs. Hence, while we focus first on levels of funding, we view this as only one part of any decision-making process. The balance comes from considering the quality and potential impacts of the output of our research effort, which is considered later in the chapter.

3.1.1 Gross Domestic Expenditures on R&D: Total Spending in Decline

For international comparisons of funding for R&D, three metrics are commonly highlighted. GERD is the gross domestic expenditures on R&D from all sources, while BERD and HERD represent business enterprise expenditures and higher education expenditures on R&D, respectively. Canada's GERD intensity (i.e., GERD as a share of GDP) has been declining slowly over the last 15 years, as contrasted with our G7 peers and key east Asian nations (top panel of Exhibit 3.1). Indeed, GERD intensity is growing in all these countries except the U.K. where it has been more or less stable at around 1.70 per cent. The lower panel of Exhibit 3.1 shows a series of small and mid-sized research-intensive nations that represent a better match as peers. Canada's GERD intensity is lower than that of all members of the peer group although patterns over time are more variable. The chart shows five-year aggregates. For 2014-15 specifically, the average GERD intensity for OECD countries was 2.38 per cent versus 1.61 per cent for Canada. Canada is below the average and median of the OECD. Worldwide, including non-OECD nations, we have fallen out of the top 30 nations in total research spending.[i]

Canada's GERD from business enterprise is low and approximately half the OECD average, as shown in Exhibit 3.2, which breaks down the components of GERD by sources of funding. We return to a consideration of BERD in Appendix 3. Canada's GERD from government is also low compared with most countries.[ii] This reflects two policy issues. First, Canada incents business R&D primarily through tax credits. Tax credits are not tallied for any nation in these calculations. Second, many other nations either provide direct funding to industry for R&D or support a range of research institutes to conduct military, industrial, and, most notably in Germany, basic research.

3.1.2 Higher Education Expenditures on R&D: Resources and Sources

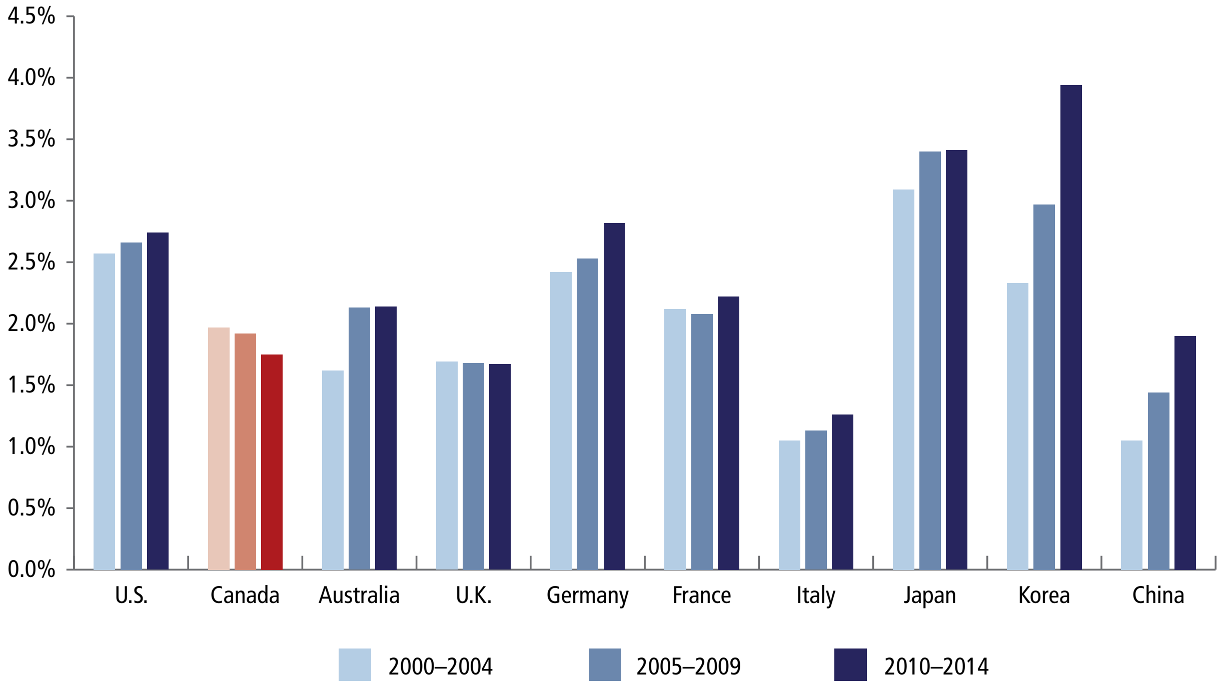
For several years, Canadian politicians, industry leaders, and media commentators have pointed to Canada's relatively high HERD as an indicator that further federal investment in extramural research is unnecessary. However, HERD, as commonly reported, reflects where the research is done, not who paid for it. A close examination of Exhibit 3.2 shows that Canada's GERD from higher education is higher than that of most comparator nations, large or small. In fact, the subsidy to national research from Canadian universities and

i Assembling data from diverse sources, as we have done in this chapter, leads to variability across measures depending on how recent the data are (ranging from 2013 to 2015) and whether fiscal or calendar years are used. The emphasis throughout this chapter is on trends and shares; those comparisons have been made on a level playing field for the years at issue. Later chapters involve more precise benchmarking to guide costing of recommendations.

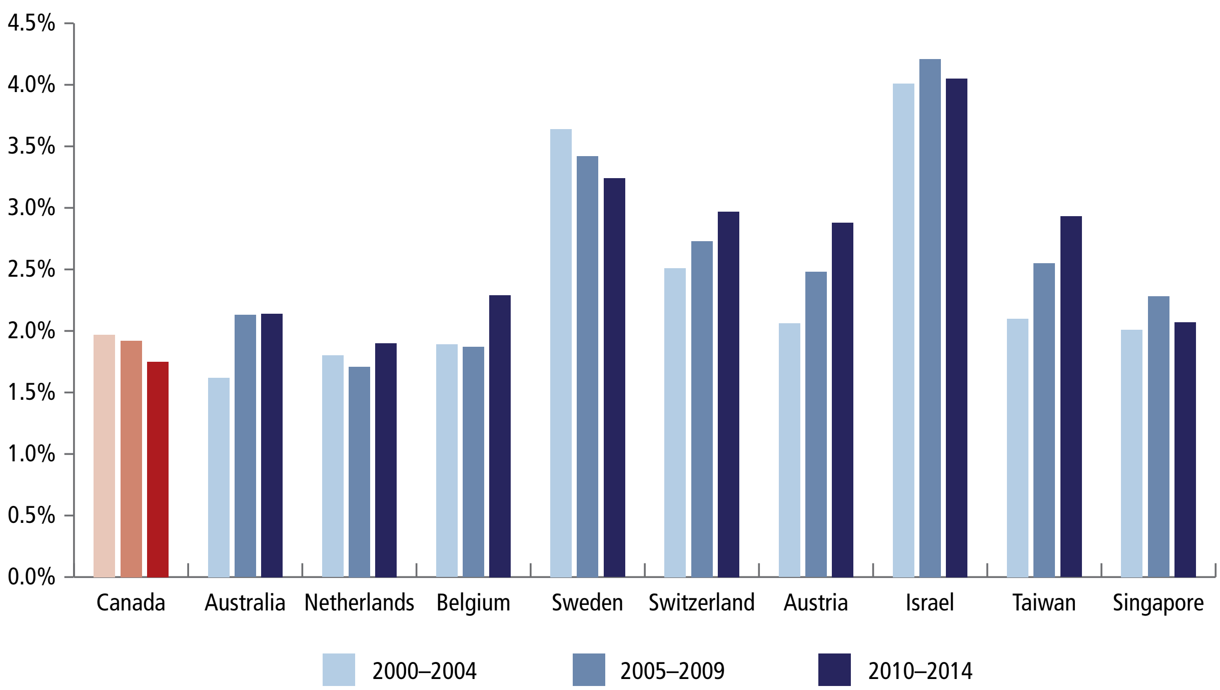
ii Some caution is needed when making comparisons with countries in the European Union because the funding sector GERD from abroad contains a significant contribution of funding from the European Commission, which could also be considered a form of government funding.

Exhibit 3.1: GERD Intensity (GERD as a Percentage of GDP), Rolling Five-year Averages

A. Canada as compared to select G7 countries, Australia, and key east Asian countries



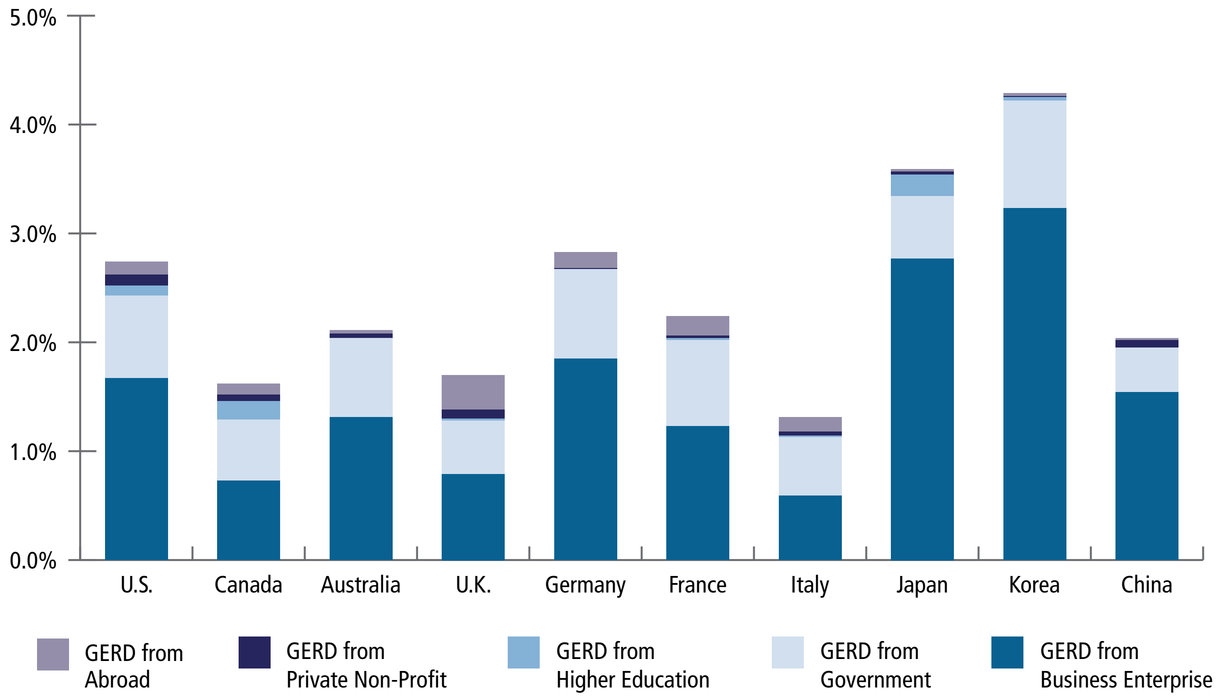
B. Canada as compared to smaller peer countries



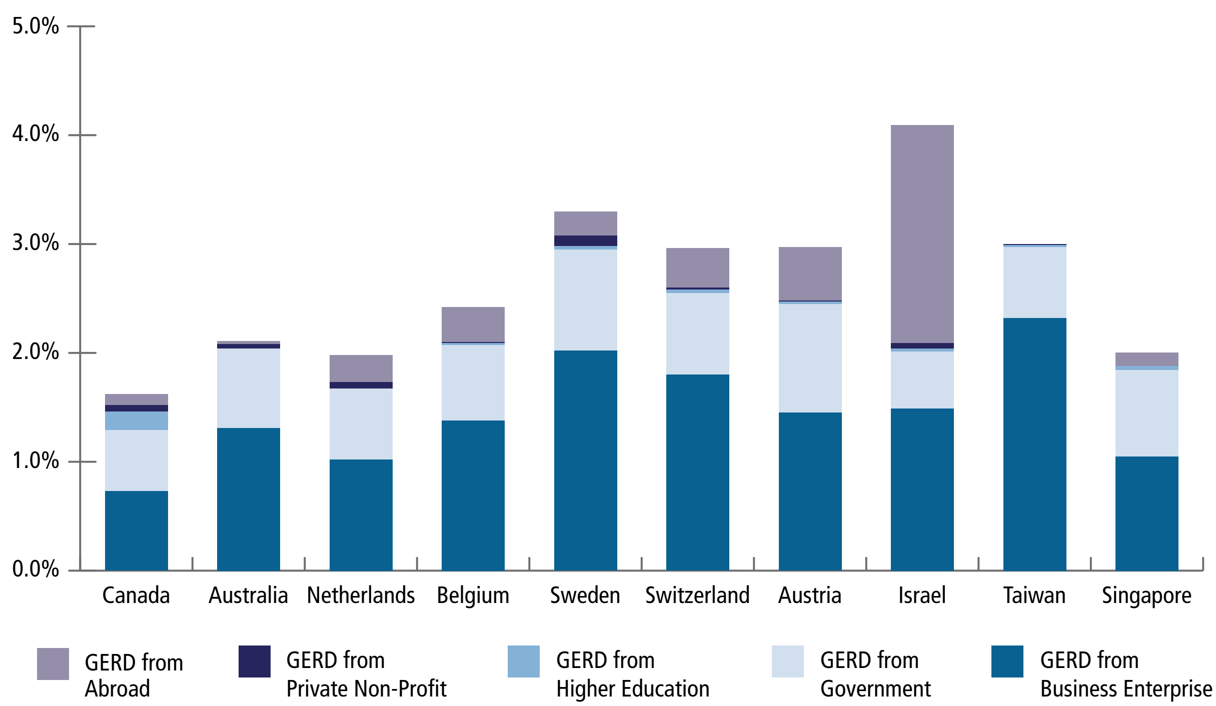
Source: OECD, Main Science and Technology Indicators. Available from: http://stats.oecd.org

Exhibit 3.2: GERD Intensity by Sector of Funding Source

A. Canada as compared to select G7 countries, Australia, and key east Asian countries



B. Canada as compared to smaller peer countries



Note: In most cases the data are from 2013 or 2014; please see this chapter's Annex for details and values. The breakdown of GERD from Higher Education and from Private Non-profit is not available for China. See this chapter's Annex for further details.

Source: OECD, Research & Development Statistics, Expenditure. Available from: http://stats.oecd.org colleges is almost double that of the U.S., with its renowned private and public research universities. The R&D subsidy by universities in most other nations is negligible.

Based on HERD intensity, Canada ranked as high as fourth among the 41 OECD nations in 2007. By 2014, as federal research funding flat-lined, Canada had fallen to seventh place. However, the group ahead of Canada is dominated by small Nordic nations (e.g., Iceland, Denmark, Finland, Norway, and Sweden), and Canada is actually first in HERD intensity among the G7 nations. This high standing is partly due to the fact that Canada, more than many OECD nations, relies heavily on the higher education sector to conduct research. The more pertinent issue is that in Canada, 50 per cent of HERD comes from universities subsidizing the national research effort, while the federal government's share of HERD is less than 25 per cent and falling.

To elaborate: Total HERD is calculated from multiple sources. The subsidy for R&D from universities is currently derived largely from the proportion of time that faculty are estimated to spend on research (approximately 45 per cent in Canada) multiplied by the number of faculty and estimated average salaries. A further subsidy is imputed for facilities and administration (F&A) costs, sometimes called "indirect costs", incurred as universities host external research grants.[iii] When HERD is examined over time and disaggregated by source of funding, as shown in Exhibit 3.3, it becomes clear that this subsidy has grown dramatically.

HERD increased from $5.79 billion in 2001 to a peak of $12.95 billion in 2012, and thereafter declined slightly to $12.87 billion by 2015.[1] About 27 per cent came from the following sources: contract research and/or matching funds from business (7.2 per cent), grants from the non-profit sector (9.7 per cent), provincial government research grants (8.9 per cent), and foreign grants and awards (0.8 per cent). The federal government more than doubled its funding of R&D to the higher education sector from $1.29 billion in 2001 to a peak of $3.17 billion in 2013, a remarkable period of expansion that provided a dramatic lift to Canadian science and scholarship. The total federal outlay declined to $3.00 billion by 2015.

> Maintaining and enhancing excellence requires investment. In recent years, other countries have been increasing their research and development (R&D) funding at a faster pace than Canada—a reality reflected in the erosion of Canada's relative ranking, i.e., its competitiveness, on R&D funding indicators. Canada must keep pace by boosting its investments, to protect and grow our knowledge and talent advantages.
>
> – State of the Nation 2014 report (STIC)

Impressive though the growth had been, the federal share in 2015 still represented only 23.3 per cent of all R&D funding for the higher education sector. Fifty per cent came from the higher education sector itself, amounting to $6.37 billion in 2015.[2]

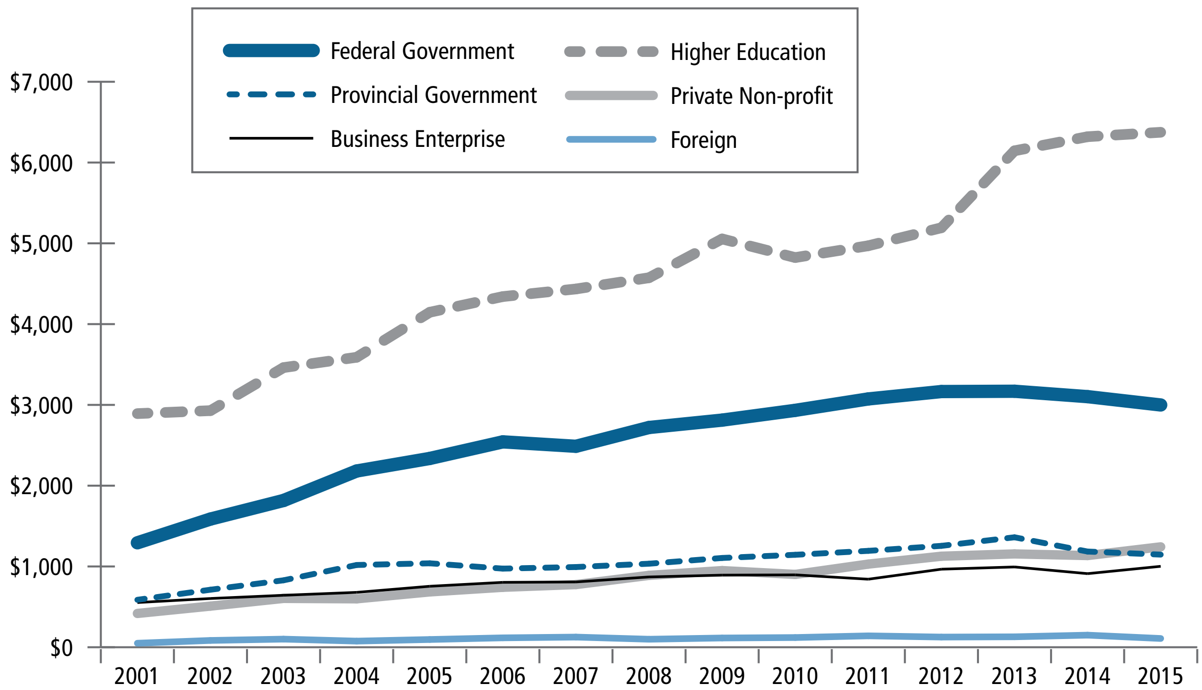
Federal officials sometimes argue that this subsidy can be viewed as a form of provincial and territorial matching offset by federal transfers that support health and education programs in the 13 subnational jurisdictions. Provinces and territories, currently engaged in difficult negotiations with Ottawa over the level of health transfers, are unhappy with the federal government's position that in higher education R&D as in healthcare, Ottawa should provide only a quarter of the relevant funding.

The Panel's preoccupations are different.

First, in contrast to healthcare, which is overwhelmingly under provincial jurisdiction, research represents a shared constitutional jurisdiction where the federal government has asserted a leadership role. This is eminently reasonable given the nationwide impacts and globalized nature of contemporary science and scholarship. We believe this reality argues strongly for the federal government to raise its share.

iii As we will examine in Chapter 7, the actual indirect costs of research incurred by PSE institutions are in the 40–60 per cent range, but current federal government compensation is 21.6 per cent. The balance is a subsidy provided by PSE to the national research effort.

Exhibit 3.3: Sources of R&D Funding to the Higher Education Sector, by Funding Sector, 2001 to 2015 ($ Millions)



Source: Statistics Canada, CANSIM table 358-0162.

Second, we have observed that in many provinces, undergraduate tuition fees and class sizes have been rising, and the proportion of university budgets attributable to provincial operating grants has been falling. Universities are clearly struggling to balance budgets stretched by various factors, not least among them the price of recruitment and retention of top-flight scholars and scientists, and the cost of providing facilities and services for their research efforts and support for their doctoral students. This situation is precarious and has created an environment that undermines excellence in both research and education. One could reasonably argue that students through their increased tuition fees are being asked to subsidize federal research grants—a situation mitigated in other nations by coverage of both the actual (direct) project costs and the facilities and services (indirect) charges borne by the institution hosting the research.

In brief, it is hard to imagine how Canada can compete with the top tier of research-intensive jurisdictions when federal public policy for decades has been predicated on the assumption that the higher education sector would be the locus for basic and applied research, even as the federal government is a minority financial contributor to that same research sector. An emphasis on total HERD has distorted the discourse about R&D funding in Canada, while too little attention has been paid to more relevant comparisons, taking into account research funding envelopes and funds per researcher. We turn next to those analyses.

3.1.3 Growing Demand, Declining Dollars

While total HERD greatly overstates the federal role, a meaningful multi-year increase has clearly occurred in federal spending on extramural R&D. The Panel accordingly sought to reconcile this observation with the frustration about funding levels expressed by so many members of the research community in their submissions and in our meetings with them. This situation becomes much clearer after factoring in diminishing purchasing power, growth in the size of the research community, and shifts in funding envelopes within the tri-council framework.

Total federal spending in support of HERD grew by some 80 per cent in real terms between 2000 and 2013.[3] In the same period, the number of researchers at Canadian universities and colleges reported by Statistics Canada grew at the same rate.[4] In fact, yearly tracking shows that in constant 2000 dollars, granting council funding per full-time equivalent (FTE) researcher rose by about 48 per cent to a peak in 2007-08, wobbled down slightly but returned close to the peak in 2009-10, and then commenced a steady decline, falling by over 30 per cent in real terms from the peak by 2015-16.[5] Following a significant increase in the 2006 Budget, total spending was essentially capped through 2015, leading to a modest erosion of real funding, even as the numbers of postsecondary education (PSE) researchers grew by a further 20 per cent. This jarring halt to growth, followed by a drop in per capita funding with ongoing expansion of the applicant pool, helps explain the disturbances observed within the research ecosystem in the latter years of the Harper government's mandates.

The same period saw a shift in funding away from investigator-led research, be it basic or applied, that allows individuals or teams to define their topics and/or the structure of the research collaboration, variously termed "unfettered", discovery-oriented, inquiry-driven, or simply "independent" research.[iv] To estimate the impact of this phenomenon, we defined two kinds of direct funding for research grants: investigator-led (as described above), which includes open operating grant competitions; and priority-driven, which we define as grants effectively targeted to specific disciplines or themes (and therefore not open to competition from all) and grants that require securing a partner (e.g., government, business, non-profit) or otherwise imposing a structure, even if there is considerable freedom to choose a topic (NCEs are therefore included).

Between 2007-08 and 2015-16, the inflation-adjusted budgetary envelope for investigator-led research fell by 3 per cent while that for priority-driven research rose by 35 per cent; this issue is analyzed in detail in Chapter 6. Our calculations suggest that as the number of researchers grew during this period, the real resources available per active researcher to do investigator-led research declined by about 35 per cent. As well, two new programs, the Canada Excellence Research Chairs and the Canada First Research Excellence Fund, are further concentrating resources in the hands of smaller numbers of individuals and institutions than would have been the case with open operating grants.

The Panel did consider the possibility that growth in the numbers of researchers in Canada might be disproportionate. We examined 2013 data on numbers of researchers in the workforce, adjusted for population and relative to OECD averages, as well as breakdowns of OECD data for higher education researchers specifically.[6] We also examined growth rates for a number of peer jurisdictions. On balance, we found no basis to argue that there was either unusually fast growth or that there is now a uniquely Canadian glut of university-based researchers. In fact, development of the knowledge-based economy suggests a growing need for such people in many sectors.

That said, the Panel emphasizes that indefinite expansion of professorial demand for research dollars is not defensible as a matter of public policy or reasonable given demographic trends. Better human resource planning is needed in the research sphere, with multi-sectoral and multi-jurisdictional collaboration.

For now, however, while numerical analyses are the focus of this chapter, we would be remiss not to acknowledge the human toll taken by these changes in funding—when independent research is relatively underfunded, success rates in competitions fall, amounts granted are reduced, time is wasted writing multiple grant applications, "safe" proposals become more likely to succeed than truly innovative or "risky" ones, and those early in their careers have a difficult time becoming established. The Panel believes that there is a particular imperative to ensure fair funding opportunities for younger researchers, based on considerations of intergenerational fairness, delayed retirements of senior investigators, gender equity, and optimal use of highly-qualified personnel already in employment. We return to these issues in more detail in Chapter 5.

iv See also the prefatory Terminology and Abbreviations.

3.2 Output Measures

The Panel acknowledges that investment in research should be motivated, at least in part, by a desire to improve the lives of others. However, any attempts to link these investments directly to specific improvements in defined time periods would be foolhardy given the non-linear, often indirect and unpredictable impacts of most forms of research, above all basic research and inquiry. As but one of scores of examples: Who would have predicted that the studies of electromagnetic fields by Faraday, Maxwell, and Hertz would eventually underpin the revolution in telecommunications and information technology? What we can conclude with reasonable confidence, however, is that research of a high quality is the most likely to have a high impact. Therefore, the bar we set for our investment in research should be the quality of its output.

This section looks at a number of measures of the quality of research done in Canada. Publication counts in indexed journals are a useful indicator because, as we observed in our guiding principles, the quality test of peer review must be met. The influence of a publication on the development of a field can also be followed by examining how often the work is cited by others. Finally, recognition, in the form of major prizes and awards, is a signal of where particularly influential work is being done.

3.2.1 Sources and Caveats

The health of a research ecosystem and the quality of the people working in it can be inferred to a meaningful extent by performance measures such as publications and citations of publications by other researchers. The material below draws on an update prepared under the auspices of CCA in advance of its 2017 comprehensive report on *The State of Science and Technology and Industrial Research and Development in Canada*,[7] [v] as well as national profiles prepared pro bono by the institutional analysis group at the University of Toronto, with a special focus on emerging research areas. These two yielded complementary insights from two distinct and well-regarded bibliometric databases.[vi]

The CCA report includes cautions about bibliometric indicators that can be summarized as follows:

- Greater emphasis on natural and health sciences, given the prevalence of publications in indexed publications as contrasted with publication patterns in the social sciences and humanities;
- Bias towards publications in English owing to database coverage;
- Upward temporal trends in publications and citations owing to growth in the number of journals/ indexed sources;
- Instability and incommensurability of comparisons owing to variable construction of research fields and sub-fields, with associated under- and over-weighting of disciplines; and
- Obscuration of inter- and multidisciplinary fields (e.g., Arctic science) that cut across multiple traditional fields and sub-fields.

CCA's more general caveat is eloquently framed and worthy of quotation:

> Finally, and most critically, bibliometric analysis captures only one form of research impact: effects on current and future knowledge generation as demonstrated through past publications. Research in some fields may accord a greater priority to other types of socially beneficial impacts. In applied

v The Panel was intrigued by the results from the latest survey of highly-cited researchers (top 1 per cent) undertaken by CCA, but has elected not to draw on them because of the low response rate (13.4 per cent) and attendant probability of response biases.

vi Both analyses draw heavily on OECD data. For bibliometrics, CCA relies on Scopus/Elsevier data and the analytical skills of Science-Metrix, while the University of Toronto report draws on InCites and Web of Science, provided by Clarivate Analytics.

> research domains (e.g., engineering, computer science, design), publications may be less important when compared with technological advances and measures based on other outputs such as patents. Much social science and humanities research is also oriented towards other objectives. As one example, the activities of the Truth and Reconciliation Commission of Canada used research methods from many humanities and social sciences disciplines, as well as oral testimony and Indigenous ways of knowing, to produce its report. This research prioritized informing public policy, contributing to cultural discussion and dialogue, and improving individual and social well-being in Canada's Indigenous communities. Other examples could be drawn from legal scholarship and education research. Numbers of publications and citations will always be partial and insufficient measures of the impact and importance of research in such cases.[8]

3.2.2 Publications and Collaborations

Examining indexed publications across a very wide range of fields, the CCA update finds that Canada produced 3.8 per cent of the world's research publications in 2009–2014, a decline from 2005–2010. CCA attributes the drop to the explosive growth of publications from China and notes that the shares for many nations had similarly declined. However, Canada's rank in total research output also dropped, from seventh in 2005–2010 to ninth in 2009–2014, as Italy and India moved past us (see Exhibit 3.4).

Emerging economies (Iran, China, India, and Brazil) along with the Republic of Korea show the largest increases over the last 10 years. The exhibit includes three indices of interest. The growth rate (GR) score reflects the growth by nation relative to its own baseline. Canada had a 26 per cent growth in publication output over this period. This relative growth against baseline is encouraging. However, national growth can also be indexed against global growth (the growth index or GI score). Comparing 2003–2008 to 2009–2014, Canada's GI score at 0.88 is consistent with our drop in total share of world output; the higher GIs of many other nations suggest a potential threat to our position.

The CCA update also includes a detailed breakdown of Canada's changing share of global publications in major bibliometric fields relevant to all three granting councils. The recent overall share of 3.8 per cent is associated with field-specific variation from a low of 2.4 per cent in Chemistry to 7.5 per cent in Psychology and Cognitive Science. CCA's assessment follows:

> Production of publications in most fields of research in Canada grew more slowly than the world average in 2003–2014. This is a change from the 2012 report, which noted that half of the fields grew more quickly than the world average in 1999–2010. The fields with the lowest GI scores include Mathematics and Statistics, Enabling and Strategic Technologies, Communication and Textual Studies, Engineering, and Agriculture, Fisheries and Forestry.[9]

Enabling and Strategic Technologies is defined as encompassing "sub-fields related to new or emerging technologies such as Energy, Biotechnology, Bioinformatics, Nanoscience and Nanotechnology, and Optoelectronics and Photonics"[10]—areas that could be vital to growth in Canada's subscale high-tech sector. CCA observes specifically that these are "areas in which Canada's research output is low relative to other countries."[11] We return to a more detailed examination of strategic technologies below.

The collaboration index (CI) is commonly calculated to examine how often publications have co-authors from multiple jurisdictions. It is adjusted for total publication output by nation because large countries, such as the U.S. or China, engage in less international collaboration given their domestic capacity. Canada's share of indexed publications with one or more international authors rose from 41 per cent in 2003–2008 to 46 per cent in 2009–2014. However, among several nations with stronger international CI scores are powerhouses such as the U.K. and Germany, as well as smaller nations such as the Netherlands and Sweden.

Exhibit 3.4: Top 20 Countries by Number of Scientific Publications Produced

Rank (2009–2014)	Country	Number of Publications		Share of World Publications (%)		CI		GI	GR
		2009–2014	2003–2008	2009–2014	2003–2008	2009–2014	2003–2008	2003–2014	
1	United States	3,136,910	2,633,098	24.3	29.2	1.00	0.89	0.80	1.15
2	China	2,600,858	1,207,471	20.1	13.4	0.48	0.46	1.50	2.15
3	United Kingdom	869,569	682,941	6.7	7.6	1.39	1.26	0.83	1.19
4	Germany	837,314	651,436	6.5	7.2	1.34	1.29	0.86	1.23
5	Japan	728,582	685,686	5.6	7.6	0.68	0.65	0.72	1.04
6	France	611,138	479,262	4.7	5.3	1.35	1.27	0.84	1.21
7	India	545,655	246,898	4.2	2.7	0.46	0.51	1.56	2.24
8	Italy	499,039	364,427	3.9	4.0	1.13	1.06	0.92	1.31
9	Canada	496,696	377,779	3.8	4.2	1.26	1.20	0.88	1.26
10	Spain	431,204	281,290	3.3	3.1	1.14	1.01	1.01	1.46
11	Australia	398,375	252,189	3.1	2.8	1.22	1.09	1.03	1.49
12	Republic of Korea	388,387	234,694	3.0	2.6	0.69	0.71	1.15	1.64
13	Brazil	321,960	177,451	2.5	2.0	0.65	0.71	1.28	1.84
14	Netherlands	280,459	201,344	2.2	2.2	1.37	1.28	0.91	1.30
15	Russia	256,825	208,439	2.0	2.3	0.74	0.91	0.89	1.27
16	Iran	211,646	63,321	1.6	0.7	0.46	0.49	2.37	3.41
17	Switzerland	207,018	146,791	1.6	1.6	1.59	1.53	0.91	1.31
18	Turkey	199,421	122,841	1.5	1.4	0.45	0.42	1.11	1.60
19	Poland	194,570	140,014	1.5	1.6	0.72	0.81	0.98	1.41
20	Sweden	180,825	137,728	1.4	1.5	1.38	1.28	0.83	1.19
	World	12,935,138	9,006,984	100	100			1.00	1.44

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

Share of World Publications (%)	The share of world publication is calculated from whole counts. Each author receives full credit for the publication regardless of the number of authors. Using fractional publication counts, Canada's share of world publications would be 2.8%. Countries are ranked by the total number of publications for the 2009–2014 period. Full counts overstate the output for countries with a higher propensity to collaborate and/or with more research in fields with a high propensity to collaborate. Canada ranks ninth both in full and fractional counts.
Collaboration Index (CI)	Based on publication co-authorships, the CI indicator measures a level of collaboration of a given entity with others in the context of the index 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.
Growth Index (GI) and Growth Rate (GR)	GI score measures the growth of publications between two periods of time (i.e., 2003–2008 and 2009–2014) relative to the world for the same period of time. A GI above 1.0 means that the relevant publication output is growing faster than the world average. The Growth Rate (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.

Source: The Expert Panel on the State of Science and Technology and Industrial Research and Development in Canada. Preliminary Data Update on Canadian Research Performance and International Reputation. Ottawa: Council of Canadian Academies; 2016. Available from: http://www.scienceadvice.ca/uploads/eng/assessmentspublicationsnewsreleases/stird2016/st_interimdataupdate_en_web.pdf

For several large Canadian provinces, CI scores for interprovincial collaboration from 2003 to 2014 were much lower than their corresponding international CI scores (Exhibit 3.5). Moreover, the provincial CIs were lifted by multi-provincial collaborations and smaller denominators. The Canada-wide proportion of interprovincial papers stood at a mere 9.8 per cent—a fraction of the international CI score for this period.[vii] The Panel obviously supports the right of Canadian researchers to collaborate as excellence and opportunity dictate. However, we are puzzled by the lack of interprovincial collaboration. From the standpoint of global impact, it may well make a relatively small nation even smaller and could therefore be unhelpful from the standpoint of overall Canadian competitiveness.

Exhibit 3.5: Interprovincial and International Collaboration Rates by Canadian Province and Territory, 2003 to 2014

Province	Collaboration Rates	
	Interprovincial	International
Alberta	24.5	42.5
British Columbia	23.0	48.2
Manitoba	33.5	39.7
New Brunswick	35.7	38.0
Newfoundland and Labrador	33.6	38.7
Northwest Territories	86.9	32.5
Nova Scotia	34.7	40.9
Nunavut	85.7	34.5
Ontario	14.8	43.4
Prince Edward Island	46.7	40.6
Quebec	16.9	43.8
Saskatchewan	33.9	41.7
Yukon	79.4	39.0
Canada	9.8	43.7

Source: The Expert Panel on the State of Science and Technology and Industrial Research and Development in Canada. Preliminary Data Update on Canadian Research Performance and International Reputation. Ottawa: Council of Canadian Academies; 2016. Available from: http://www.scienceadvice.ca/uploads/eng/assessmentspublicationsnewsreleases/stird2016/st_interimdataupdate_en_web.pdf

3.2.3 Citations as Proxies for Impact

Citation indices can be useful indicators for the scholarly and scientific impact of published work. Two indices covered by CCA are summarized here: average relative citation rates (ARCs) and median relative citation rates (MRCs). Both have statistical limitations. ARCs can be pulled up by a small number of very highly-cited papers, while MRCs are less likely to delineate fractional differences owing to rounding. Both measures, moreover, are likely to show growth over time among nations with well-established research

vii This may at first seem mathematically implausible given the scores for each of the provinces. However, interprovincial collaboration is concentrated in a small number of papers with multiple provinces participating. Thus, a single publication with authors from six provinces counts as one for each of the provinces, but only one instance of interprovincial collaboration.

machinery for two reasons. The first is simply the growth in numbers of publications and journals. The second is the disproportionate amount of growth concentrated in China. As we have seen, China's massive boom in academic publishing has pulled down relative growth rates for other nations. However, because papers from China still draw below-average citation counts, measures such as ARC and MRC for other countries are pushed upwards.

The CCA's update[12] reports that Canada's ARC score rose from 1.36 to 1.43 across the two periods of interest. In other words, Canadian papers were cited at a rate 43 per cent higher than the global average in 2009–2014. This change is unlikely to be significant, given the overall upward trend noted above. The MRC was stable, not unexpectedly given its reduced sensitivity. On one level, it is encouraging that Canada seems to be steadily in fifth or sixth place worldwide based on all three markers. Our secondary analysis, however, shows grounds for concern. Examining the top 20 countries, Canada's relative growth in ARC ranked 15th, with only the U.S., Japan, India, Brazil, and Turkey climbing more slowly. Again, our interpretation is that Canada is stalling relative to peers.

Returning to bibliometric fields, the declining outputs highlighted above could arguably be offset if Canadian research showed rising impact as measured by citation analysis. Unsurprisingly, Canada remains above average across the board. This is expected since the global bar is low and, as noted, has been lowered further by the below-average impact of China's massive volume of publications. Canada continued to be a strong performer in fields such as Clinical Medicine and Physics & Astronomy, with additional strengths apparent in Biology, General Science & Technology, and General Arts, Humanities, & Social Sciences. However, Canada's citation ranking fell in 13 of 22 fields assessed—an unsettling trend when coupled with slowing rates of growth in publication outputs relative to other nations.[13]

3.2.4 Nature Index

The Panel supplemented the CCA analysis with a review of the Nature Index,[14] which can be searched online. Data are collated from some 50,000 research articles in 68 high-quality science journals. The index is updated monthly to capture the preceding 12 calendar months. Our search was conducted in the fall of 2016 and therefore included the 12 months from September 1, 2015 to August 30, 2016. The index focuses on basic natural and health sciences, with all the resulting limitations. However, it has the advantage of using both whole author counts, as is done by CCA, and fractional counts that take into consideration numbers and national affiliations of authors. It provides a snapshot of outputs in highly-cited journals. The fractional count is also reweighted to adjust for the mix of specialty journals, leading to the rankings described below.

Overall, Canada ranked seventh, well ahead of Switzerland but behind the U.S., China, Germany, the U.K., Japan, and France in that order. Germany, the U.K., and China all advanced in their respective shares of publications based on weighted fractional counts. Examining publications only in the two flagship journals of basic science, *Nature* and *Science*, Canada ranked eighth, trading places with Switzerland. Among Canadian institutions, only 1 was in the top 20 worldwide, and only 2 more were in the top 100. Examining disciplines, Canada was 9th in Chemistry, 6th in Earth and Environmental Sciences, 6th in Life Sciences, and 10th in Physics/Physical Sciences.

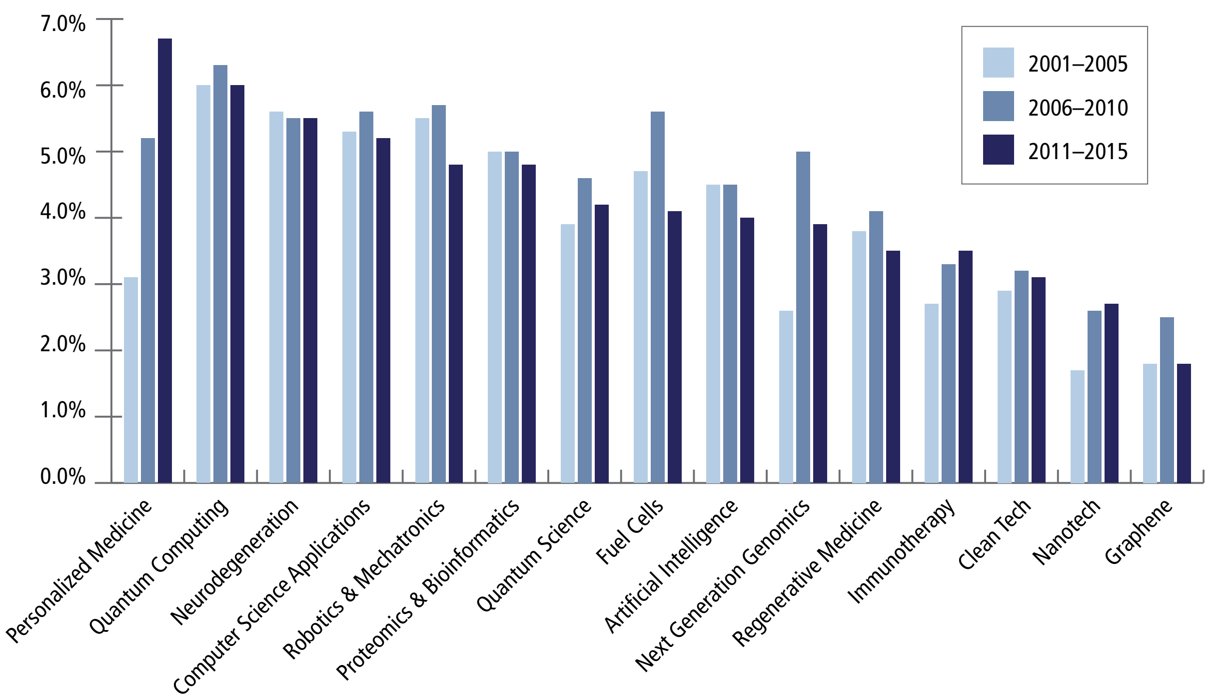
3.2.5 Emerging Areas of Basic and Applied Science and Technology

As noted above, the Panel commissioned a limited analysis of emerging research areas. These areas were deliberately biased towards those with potential for early application, identified by peer nations as priorities or targets for enhanced funding, and showing rapid citation growth worldwide. The themes were Artificial Intelligence (AI), Clean Tech, Fuel Cells, Computer Science Applications, Graphene, Immunotherapy, Nanotechnology, Neurodegeneration, Personalized Medicine, Proteomics & Bioinformatics, Quantum

Science, Quantum Computing, Regenerative Medicine, Robotics & Mechatronics, and Next Generation Genomics. Relevant material from that report can be found in Appendix 4.

Canada's recent share in about two-thirds of these fields is above the overall 3.8 per cent reported by CCA for the entirety of indexed publications across all disciplines (Exhibit 3.6). However, recent trends are masked by the roll-up into five-year brackets. For example, the fastest growing area with the highest share is Personalized Medicine, but total publication output is modest and has more or less stalled through 2013–2015, as is true for a number of fields.

Exhibit 3.6: Canada's Share of Global Publications in Emerging Research Areas



Source: Clarivate Analytics, Web of Science.

A recurrent finding is very fast growth in output from China, but a quality gap is also sometimes evident. As one instance, China has pulled ahead of the U.S. in Quantum Computing output, but trails many nations, including Canada, in citations per publication. In other areas, such as AI, citation traffic on Chinese publications is highly competitive. AI holds special interest because Canada can claim a truly disproportionate influence in building the discipline. The detailed profile shown in Exhibit 3.7 illustrates our national challenge. We broke the ground. However, others have cultivated it and are busily engaged in commercial-scale agriculture, and China has a widening lead.

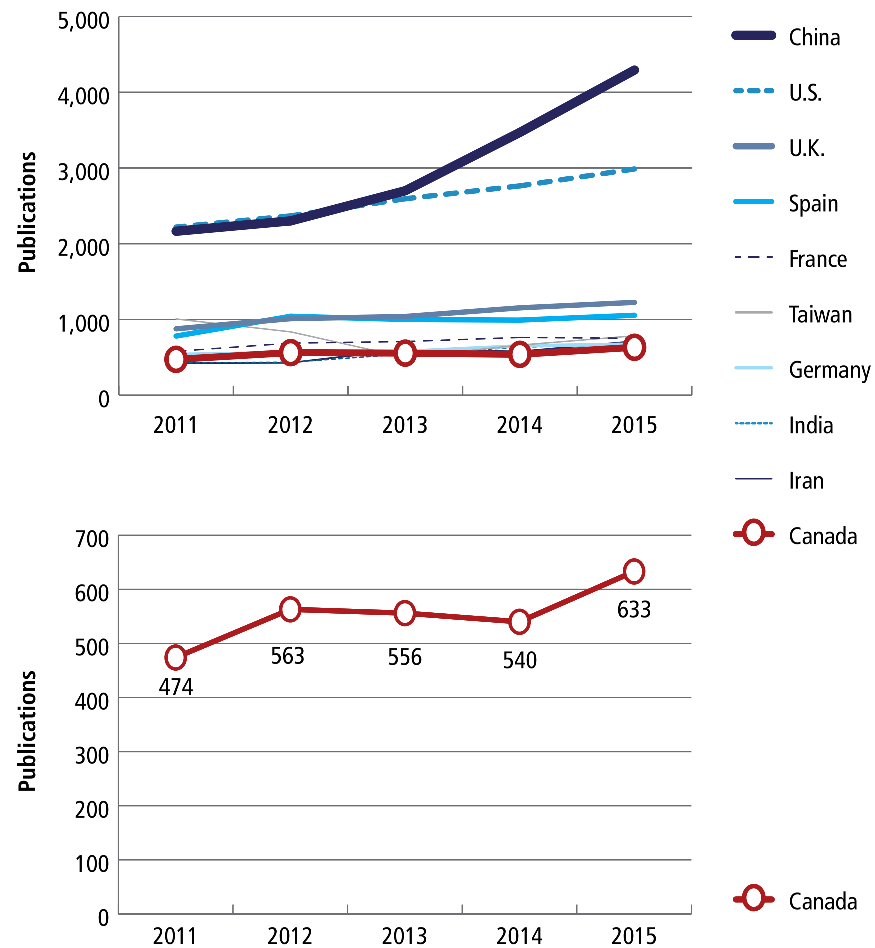
The same could be said of Regenerative Medicine. Canadian scientists have made multiple seminal contributions to the discovery and characterization of stem cells since the 1960s. We have prided ourselves on continuing breakthroughs in regenerative medicine, stem cell research, and tissue engineering. Nonetheless, we now sit eighth globally in total output of indexed publications based on the last five years of research. Neither the numbers of highly-cited publications nor the average citation counts suggest that our ranking undervalues our current standing.

Exhibit 3.7: Bibliometric Analysis of Artificial Intelligence Research, 2011 to 2015

This data set includes all publications containing the terms *Artificial Intelligence, Machine Learning* and *Neural Networks* (only when relevant to non-biological systems), combined with all articles from journals relating to Artificial Intelligence (as defined by the Web of Science subject category). This hybrid search strategy includes research into the field of artificial intelligence and research topics that utilize artificial intelligence techniques.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
China	14,930	120,442	8.1	2,715	34%
U.S.	12,933	110,957	8.6	2,074	48%
U.K.	5,308	49,206	9.3	949	61%
Spain	4,872	33,524	6.9	700	47%
France	3,492	27,563	7.9	494	53%
Taiwan	3,790	24,460	6.5	476	16%
Germany	3,009	24,852	8.3	455	57%
India	2,724	17,434	6.4	332	24%
Iran	2,751	17,621	6.4	403	43%
Canada	2,766	21,446	7.8	401	52%
Italy	2,650	17,074	6.4	359	51%
Australia	2,303	22,754	9.9	376	46%
Korea	2,201	12,580	5.7	253	36%
Turkey	2,120	13,789	6.5	259	22%
Japan	2,006	10,592	5.3	171	45%
Hong Kong	1,821	19,316	10.6	377	37%
Singapore	1,457	17,963	12.3	330	70%
Netherlands	1,304	10,897	8.4	204	49%
Brazil	1,270	6,504	5.1	141	32%
Poland	1,123	6,211	5.5	152	47%



Note: Data from Web of Science/InCites, provided by Clarivate Analytics. See Annex A of Appendix 4 for data sources, methodology and indicator definitions, and Annex B of Appendix 4 for keywords and search syntax.

Robotics and Mechatronics are strategically important if Canada is to rebuild its manufacturing capacity. The full profile in Appendix 4 shows that our outputs are growing and our citation indices are respectable. However, manufacturing powerhouses such as the U.S., China, Republic of Korea, and Germany are well ahead with the U.K. and Italy showing surprising strengths. Canada can also claim breakthroughs in Neurodegeneration whose relevance is dramatically evident given global demographic trends. However, as is arguably true for all 15 profiles, it is hard to make a case for better than a fifth or sixth place standing given the available measures of quantity and quality of research.

In a nutshell, it appears that Canada has briefly claimed bragging rights in certain fields based on excellence in one or two centres, but systematically failed to build national capacity that would create an enduring advantage.

3.3 Talent Development

If, as we have argued, the innate talents of the people of Canada are ultimately our most important natural resources, then the development of that talent through higher education is integral to the nation's future. Measures such as domestic graduation rates and international student recruitment may not correspond tightly with the strength of Canada's extramural research ecosystem. However, the Panel's considered view is that weakness in these indicators should be cause for concern about whether the nation is reaping the full benefits of its investments in research. In this vein, another relevant measure downstream from education is the size of the research workforce overall and by sector. Finally, the analyses in the previous section gave us some sense of the overall quality and outputs of the research ecosystem through aggregate bibliometrics, including shares of global publications and summary measures (averages and medians) of citation analyses. The highly competitive nature of research means that outliers matter. Top-tier scholars and scientists draw top-flight domestic and international talent and, in many cases, develop top-flight teams. Thus, this section also considers highly-cited researchers and publications, and Canada's success in winning major international research prizes.

3.3.1 Graduation Rates and Researcher Density

Canada's college-level graduation rates were the highest in the OECD[viii] for some years when all graduates of Quebec's Collèges d'enseignement général et professionnel (CEGEPs) were included, regardless of whether they were in occupational or university transfer streams. When the classification was changed in 2010 to exclude CEGEPs, our rank dropped. In 2013, Canada ranked sixth for college-level graduation rates among 26 OECD comparator countries at 21.0 per cent.[15] Australia registered the highest level at 28.3 per cent.

For bachelor's-level graduation rates, Canada ranked 15th among 29 comparator OECD countries at 38.3 per cent in 2013. Again, Australia registered the highest level at 61.3 per cent. A number of countries that are strong research performers have higher completion rates of these cornerstone degree programs. Canada's performance was lower still for doctoral-level graduation rates where, in 2013, Canada ranked 22nd among 35 OECD countries, falling behind many peer nations with strong records of research productivity.[16]

The ability to attract international students speaks to the international reputation of the postsecondary institutions in a given jurisdiction and the funds available to support them. It is important to talent development based on simple mathematics: Canada's domestic talent pool is deep, but small as contrasted with the many millions of brilliant young people around the world who are looking to pursue tertiary

viii Graduation rates for tertiary education across OECD countries are defined using a highly standardized classification system and are largely self-explanatory. College-level graduation rates typically represent programs with a practical or specific occupational orientation, designed to prepare students to enter the labour market.

studies abroad in any given year. It is notable that the numbers of international graduates from all levels of university in Canada rose from 16,101 students in 2006 to 33,003 in 2014—an average annual growth rate of 13.1 per cent over those years.[17] Moreover, while domestic doctoral enrolments and graduation rates are much lower than optimal, international recruitment is growing steadily. In 2014 international students made up at least 21.1 per cent of university doctorate degree graduates in Canada, for an average annual growth rate of 18.6 per cent since 2006, rising in absolute numbers from 609 graduates in 2006 to 1,515 graduates in 2014.[18]

While this growth is encouraging, the Panel is aware that in a number of peer nations, fully half of doctoral students in research-intensive universities are international recruits. Enrolment data from Statistics Canada show marked interprovincial variation.[19] For the four westernmost provinces, the proportion of international recruits among doctoral students is approximately 33 to 47 per cent. The share in Quebec registers about 33 per cent in total, and the Maritime provinces are similar at around 30 per cent. Newfoundland and Labrador ranks second in the country at more than 45 per cent. The outlier is Ontario, with by far the largest doctoral enrolment in the country. It appears that the provincial government has provided little or no per student funding for international doctoral enrollees over the course of almost 20 years. As a result, the overall proportion of international doctoral students is 22 per cent and universities report turning away thousands of qualified applicants due to lack of funding.

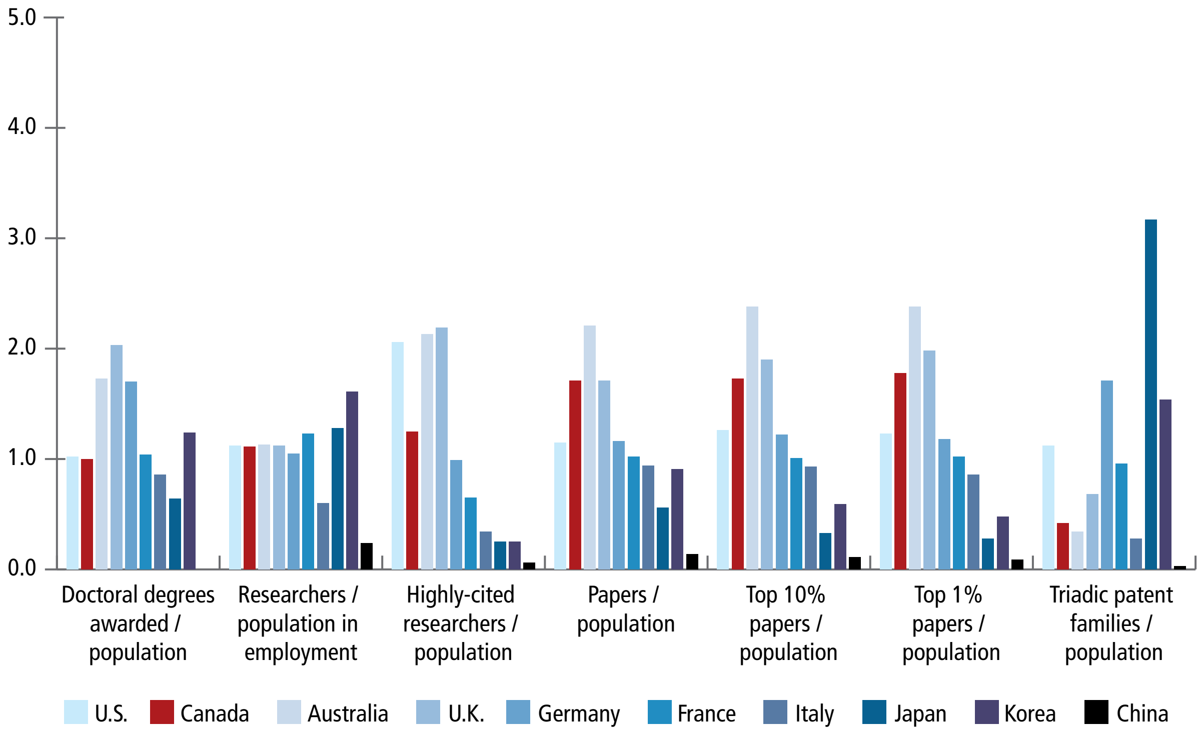
The Panel has heard various concerns that Canada is producing and importing too many doctoral graduates. The usual argument advanced to support this view is that universities are saturated and their growth rates may be diminishing due to demographic trends. A 2015 Conference Board of Canada report[20] dissected this issue precisely, observing that while approximately 40 per cent of PhDs hold positions in the PSE sector, the majority are employed outside academe and less than 20 per cent become full-time professors. The report found PhD career satisfaction to be high and that graduates had a lower unemployment rate than master's and bachelor's degree holders. It also observed and encouraged acceleration of a trend across Canadian universities to ensure that doctoral-stream students and postdoctoral fellows were equipped with skills relevant to employment outside the PSE sector and exposed to those employment opportunities.

We repeat here a theme from the first two chapters: Immersion in research changes the way people think and solve problems, and doctoral graduates are particularly well-equipped to help improve our lagging productivity and innovation indices. Exhibit 3.8 provides a useful multidimensional snapshot in this regard. It highlights not only Canada's trailing status in numbers of doctoral degrees awarded on a per capita basis, but also our lower density of employed researchers, particularly as compared to other nations with small populations that have higher innovation and productivity indices. Consistent with our earlier argument that Canada's extramural funding crisis is not due to over-production of academic researchers, sectoral breakdowns from OECD data show that Australia and the U.K. have substantially higher numbers of researchers employed in the higher education sector on a per capita basis. Germany, France, and Australia all have greater numbers of researchers employed by government. It is unclear from the OECD data how much of this latter phenomenon reflects intramural research capacity in those nations as opposed to civil service appointments for scholars and scientists in free-standing research institutes or such appointments extended to full-time professors, as is the case in Germany.

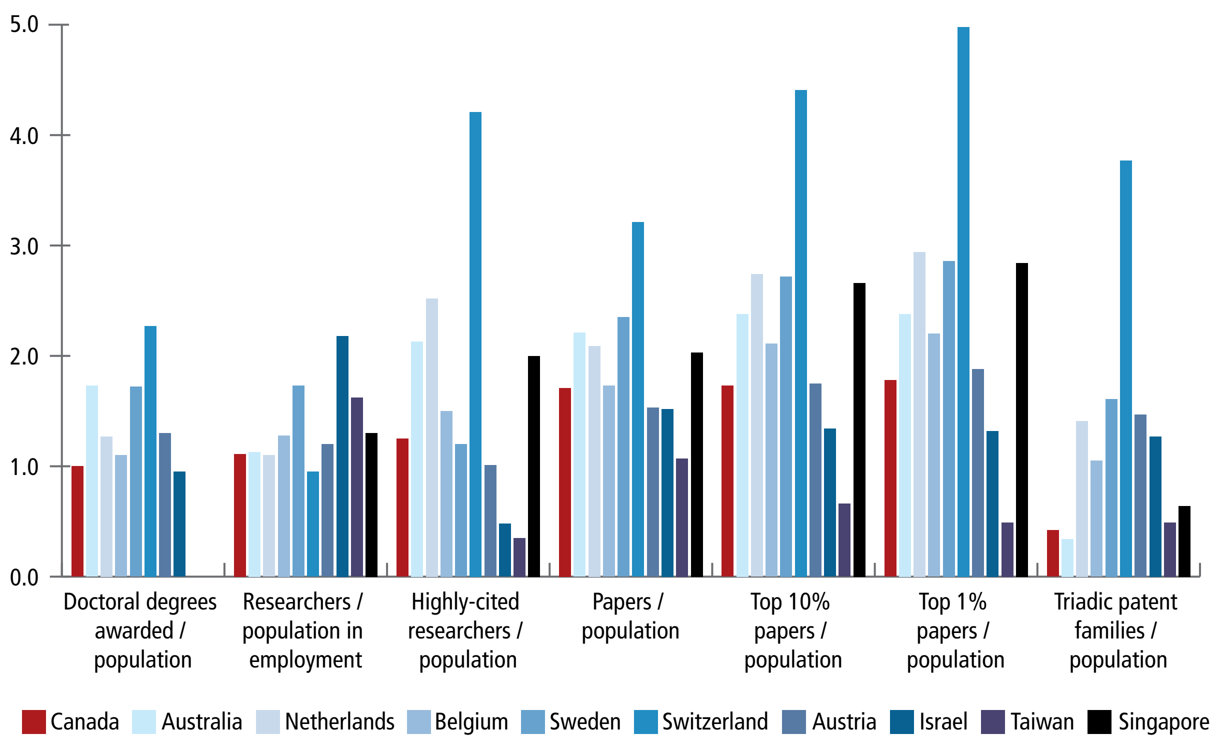
Finally, the data demonstrate that Canadian businesses are internationally competitive in the number of researchers they employ. Our secondary analyses suggest that the number of doctoral graduates employed in industry is still lower than that in some peer nations, but assuming that this will remain the case seems both pessimistic and self-fulfilling. As the Conference Board recommended: "To achieve maximum benefit from the knowledge and skills of PhDs, changes are needed to ensure that all PhD graduates have the skills to find good jobs and build successful careers. Employers must recognize the value of a PhD education, and effectively employ PhDs, to take full advantage of their knowledge and skills."[21]

Exhibit 3.8: Research Capacity, Activity, and Output (Normalized to OECD Averages)

A. Canada as compared to select G7 countries, Australia, and key east Asian countries



B. Canada as compared to smaller peer countries



Note: In most cases the data are from 2013; please see this chapter's Annex for details and values. Data on doctoral degrees awarded not available for China, Taiwan, or Singapore. Bibliometric data are from Clarivate Analytics, InCites; see this chapter's Annex for full list of sources. Data are normalized relative to the OECD averages, which are set to 1.0.

3.3.2 Highly-cited Researchers and Prizes

The importance of top-tier talent and high-impact research was noted earlier. Exhibit 3.8 is again informative, showing proportions of highly-cited researchers on a per capita basis and publications per capita. It also shows two categories of highly-cited papers. The number of papers per capita that a given jurisdiction places in the top 1 per cent of highly-cited publications is a useful measure. However, the small numbers for very small countries can yield unstable results and be almost meaningless from a statistical perspective. Papers in the top 10 per cent of the distribution of citations are of somewhat lower impact, but still noteworthy; this measure is also much more stable.

None of these three high-citation indicators plays strongly in Canada's favour. The comparisons with the G7 and east Asian nations show Canada to be competitive, but we clearly lag the U.K. and Australia. The U.S. comparison is also telling in one respect. The number of highly-cited researchers on a per capita basis in the U.S. is sharply higher than ours—indeed, almost as large as the U.K. and Australia, both meaningfully smaller than the U.S. in total population (Exhibit 3.8). The inference is that the U.S. has large numbers of world-class scholars and scientists, and its dominance of major research prizes, discussed further below, is not an accident.

Another observation relates to Germany, which has a weaker performance in these indices than might be expected. In recent decades Germany's storied universities have become less prominent in global rankings, perhaps because of the extent to which the German government has concentrated funding in over 200 free-standing research institutes. The German "Excellence Initiative" in the last few years, with its recurrent rounds of major investment in a subset of strong German universities, may well represent a national hedge against what has been a big bet on a free-standing institute strategy.

Turning from these comparators to the set of smaller nations on the lower panel of Exhibit 3.8, the comparisons become much less favourable, with Canada's metrics overshadowed by the performance of the Netherlands, Sweden, and Switzerland, among others.

Moving from highly-cited researchers and papers to the realm of major international research prizes takes us further into the realm of outlying talent. Major international prizes for research are relevant measures because they bring great prestige not just to individuals and teams, but also to institutions and nations. They are also the culmination of years of excellence in research and, particularly when prizes are won repeatedly across a range of disciplines, they send strong signals to the world about the health of a nation's basic research ecosystem.

Unfortunately, Canada's performance in winning international prizes is also lagging. In 2013 the Right Honourable David Johnston, Governor General of Canada, and Dr Howard Alper, then chair of the national Science, Technology and Innovation Council (STIC), observed that Canadians underperform "when it comes to the world's most distinguished awards", e.g., Nobel Prize, Wolf Prize, and Fields Medal. They added: "In the period from 1941 to 2008, Canadians received 19 of the top international awards in science—an impressive achievement, to be sure, but lacking when compared with the United States (with 1,403 winners), the United Kingdom (222), France (91), Germany (75) and Australia (42)."[22] [ix]

There is an interesting wrinkle to the dominance of the U.S. in Nobel prizes.[23] Over 30 per cent of all U.S. Nobel laureates since 1950 were foreign-born, with that proportion rising over time. From 2007 to 2016, the 54 Nobel prizes awarded to U.S.-based researchers included 20 immigrants. Sources differ as to whether more of the U.S. Nobel laureates originated from Canada or Germany, but the best estimate is that, since 1901, there have been 15 Canadian-born, and in many cases Canadian-educated, Nobel laureates based

ix Of interest, in 2003 the Norwegian government established the Holberg Prize, a Nobel-level award, to recognize excellence in the humanities, social sciences, literature, law, and theology. Two of 14 Holberg laureates to date are Canadians.

in the U.S.—double the total number of Nobel prizes awarded to Canadian-based researchers in the same period.

From the standpoint of international recognition, 2015 was an exceptional year. Canadians won two of the pinnacle awards: a Nobel prize (Arthur McDonald for Physics) and a Wolf prize (James Arthur for Mathematics). Those prizes celebrate work that exemplifies two very different models of discovery. As a theoretical mathematician, Dr Arthur's pioneering papers in automorphic forms have been overwhelmingly sole-authored; his long-term support has come from modest NSERC Discovery Grants. As a particle physicist, Dr McDonald has led a large team in developing and operating the renowned Sudbury Neutrino Laboratory, a major science facility purpose-built deep in an active nickel mine, where startling observations have been made that are forcing a reconsideration of The Standard Model for Elementary Particles. In both cases, however, what matters is that the work began decades ago, and Canada provided long-term support at the levels and in forms required to enable path-breaking discoveries to be made.

Canada cannot assume that there will be a series of other pinnacle prizes awarded based on discoveries that tap into work initiated in the 1970s and 1980s. To ensure a continuous pipeline of successful nominations for international awards, research institutions must be supported consistently to recruit and retain outstanding scholars and scientists. They in turn must be supported to create world-class research environments through meritocratic adjudication processes that offer fair access to appropriate levels of consistent funding for scientific inquiry. Our assessment thus far has not given us great confidence that these winning conditions are being created, let alone enhanced.

3.4 Some Reflections on Canada's Performance and Prospects

On balance, the Panel finds this array of measures sobering. Canada's level of extramural research funding has been misunderstood owing to an overemphasis on total HERD intensity without regard for source of funding. Gains in funding per researcher made in the first few years of the 21st century were completely reversed by 2013 in real per capita terms. Shifts in funding towards targeted or priority-driven research, rather than independent or unfettered research funded through open competitions, compounded these changes, such that basic researchers faced a drop in the available funds on the order of 35 per cent on a per capita basis. These indices leave the Panel certain that meaningful augmentation of federal funding is required for Canada to compete, even with smaller peers such as Australia and Switzerland, let alone with the research machinery in larger and better established nations.

It seems clear that the drop in per capita funding for basic research is having adverse effects. Canada's numbers of scholarly publications have indeed grown meaningfully in recent years, but those of many peer nations have grown faster in relative terms or further in absolute terms. Aggregate citation profiles have held up reasonably well, with Canada holding on to fifth or sixth place worldwide—a commendable showing. However, the breakdowns by bibliometric fields show that Canada's advantages are being eroded by slower growth in many disciplines and by degradation of field-specific citation rankings. International collaboration remains strong, but Canadians appear oddly averse to collaborating with their fellow citizens from other provinces and territories. Furthermore, the indices of performance in strategic and enabling technologies, or key emerging areas of scientific and technological research, underscore Canada's ongoing inability to set priorities and build national capacity alongside an enduring Canadian advantage.

As to the talent pool, there are again grounds for unease. While college-level graduation rates are high, baccalaureate graduation rates are about average in the OECD and doctorate graduation rates are decidedly below average. International enrolments in Canadian universities are growing strongly, not least at the doctoral level, but there is considerable room for further growth. Canada is also well-positioned to recruit from abroad at this point in global history. The interprovincial variation suggests that improvements in funding formulae may be needed in some jurisdictions if Canada is to capitalize fully on the enormous numbers of potentially mobile graduate students worldwide. Our density of researchers across sectors overall is suboptimal, and our densities of highly-cited researchers, highly-cited papers, and major prize winners are far lower than one would expect from a comparatively wealthy nation with so many natural advantages.

The Panel appreciates, of course, that the various measures compiled here tell an incomplete story, and many of them are surrogates for outcomes rather than hard outcomes in themselves. However, we believe that these measures point to the need for bold federal leadership and a significant renewal of funding for independent, investigator-led research. They also support continued growth in output of doctoral graduates, a greater emphasis on international recruitment of talented students and trainees, and policies that give preference to admitting highly educated immigrants. We believe Canada should aim to become the best-educated nation in the world with a reputation for generating startling discoveries across a range of scientific disciplines, breakthroughs in applied natural, health, and social sciences, and transformative insights from the humanities. To achieve those aspirations, a course correction is urgently needed, starting with improved oversight and governance—the focus of the next chapter.

ENDNOTES

1 Statistics Canada. Provincial estimates of research and development expenditures in the higher education sector, by funding sector and type of science (CANSIM table 358-0162). Ottawa: Statistics Canada; 2016.

2 Ibid.

3 Statistics Canada. Gross domestic expenditures on research and development, by science type and by funder and performer sector (CANSIM table 358-0001). Ottawa: Statistics Canada; 2015.

4 Statistics Canada. Personnel engaged in research and development, by performing sector, occupational category and type of science (CANSIM table 358-0159). Ottawa: Statistics Canada; 2016.

5 Based on secretariat calculations using the above-referenced Statistics Canada data (CANSIM tables 358-0001 and 358-0159).

6 Based on secretariat calculations using data from OECD Main Science and Technology Indicators (MSTI 2016-1), June 2016. Available from: http://www.oecd.org/science/msti.htm

7 The Expert Panel on the State of Science and Technology and Industrial Research and Development in Canada. Preliminary Data Update on Canadian Research Performance and International Reputation. Ottawa: Council of Canadian Academies; 2016. Available from: http://www.scienceadvice.ca/uploads/eng/assessmentspublicationsnewsreleases/stird2016/st_interimdataupdate_en_web.pdf

8 Ibid.

9 Ibid.

10 Ibid.

11 Ibid.

12 Ibid.

13 Ibid.

14 Nature Index [Internet]. Available from: http://www.natureindex.com/

15 OECD. Education at a Glance 2016: OECD Indicators. Paris: OECD Publishing; 2016. Available from: http://download.ei-ie.org/Docs/WebDepot/EaG2016_EN.pdf

16 Ibid.

17 Statistics Canada. Postsecondary graduates, by Pan-Canadian Standard Classification of Education (PCSCE), Classification of Instructional Programs, Primary Grouping (CIP_PG), sex and student status (CANSIM table 477-0020). Ottawa: Statistics Canada; 2016.

18 Ibid.

19 Statistics Canada. Postsecondary enrolments, by registration status, Pan-Canadian Standard Classification of Education (PCSCE), Classification of Instructional Programs, Primary Grouping (CIP_PG), sex and student status (CANSIM table 477-0019). Ottawa: Statistics Canada; 2015.

20 Edge, J., Munro, D. Inside and Outside the Academy: Valuing and Preparing PhDs for Careers. Ottawa: The Conference Board of Canada; 2015. Available from: http://www.conferenceboard.ca/e-library/abstract.aspx?did=7564

21 Ibid.

22 Johnston, D., Alper, H. We Need to Celebrate our Scientists and Researchers. The Globe and Mail. 2013 February 18. Available from: http://www.theglobeandmail.com/opinion/we-need-to-celebrate-our-scientists-andresearchers/article8728552/

23 Shim, E. The U.S. Leads the World in Nobel Laureates Thanks to One Surprising Factor. Mic Network Inc. [US]. 2014 October 8. Available from: https://mic.com/articles/100750/the-u-s-leads-the-world-in-nobel-laureates-thanks-to-one-surprisingfactor#.DuYH9LJ5b; Bruner, J. American Leadership in Science, Measured in Nobel Prizes. Forbes. 2011 October 5. Available from: http://www.forbes.com/sites/jonbruner/2011/10/05/nobel-prizes-and-american-leadership-in-science-infographic/#220f9d9d52a9; Matthews, D. Laureate Land: Nobel Prizewinners by Country of Origin. Times Higher Education. 2016 October 27. Available from: https://www.timeshighereducation.com/news/laureate-land-nobel-prizewinners-by-country-of-origin

Annex: Data Tables

Data tables for Exhibit 3.2: GERD Intensity by Sector of Funding Source

A. Canada as compared to select G7 countries, Australia, and key east Asian countries

	U.S.	Canada	Australia	U.K.	Germany	France	Italy	Japan	Korea	China
GERD from Business Enterprise, % of GDP	1.67%	0.73%	1.31%	0.79%	1.85%	1.23%	0.59%	2.77%	3.23%	1.54%
GERD from Government, % of GDP	0.76%	0.56%	0.73%	0.49%	0.82%	0.79%	0.54%	0.57%	0.99%	0.41%
GERD from Higher Education, % of GDP	0.09%	0.17%	0.00%	0.02%	0.00%	0.02%	0.01%	0.20%	0.03%	[b]
GERD from Private Non-profit, % of GDP	0.10%	0.06%	0.04%	0.08%	0.01%	0.02%	0.04%	0.03%	0.01%	0.07%
GERD from Abroad, % of GDP	0.12%	0.10%	0.03%	0.32%	0.15%	0.18%	0.13%	0.02%	0.03%	0.02%
Representing the Year	2013	2014	2013[a]	2014	2013	2013	2013	2014	2014	2014
Total GERD as % GDP	2.74%	1.61%	2.11%	1.70%	2.83%	2.24%	1.31%	3.59%	4.29%	2.05%

B. Canada as compared to smaller peer countries

	Canada	Australia	Netherlands	Belgium	Sweden	Switzerland	Austria	Israel	Taiwan	Singapore
GERD from Business Enterprise, % of GDP	0.73%	1.31%	1.02%	1.38%	2.02%	1.80%	1.45%	1.49%	2.32%	1.05%
GERD from Government, % of GDP	0.56%	0.73%	0.65%	0.69%	0.93%	0.75%	1.00%	0.52%	0.65%	0.79%
GERD from Higher Education, % of GDP	0.17%	0.00%	0.00%	0.02%	0.03%	0.03%	0.02%	0.03%	0.02%	0.04%
GERD from Private Non-profit, % of GDP	0.06%	0.04%	0.06%	0.01%	0.10%	0.02%	0.01%	0.05%	0.01%	[c]
GERD from Abroad, % of GDP	0.10%	0.03%	0.25%	0.32%	0.22%	0.36%	0.49%	2.00%	0.00%	0.12%
Representing the Year	2014	2013[a]	2014	2013	2013	2012	2013	2013	2014	2013
Total GERD as % GDP	1.61%	2.11%	2.00%	2.43%	3.31%	2.97%	2.96%	4.09%	3.00%	2.00%

Notes:

[a] Total GERD for Australia is based on 2013 data, but the breakdown by funding sector is based on 2008 data pro-rated to the 2013 total GERD value.

[b] The breakdown of GERD from Higher Education and Private Non-profit is not available for China. Estimate is derived from the shortfall between the sum of other sectors and the total GERD; the estimate is assigned to Private Non-Profit only.

[c] Data for Singapore relating to GERD from Private Non-Profit are unavailable; however, the sum of the other sectors is equal to the total and therefore it can be inferred that the value is close to zero.

Source: OECD, Research & Development Statistics, Expenditure. Available from: http://stats.oecd.org.

Data tables for Exhibit 3.8: Research Capacity, Activity, and Output[a]

A. Canada as compared to select G7 countries, Australia, and key east Asian countries

	U.S.	Canada	Australia	U.K.	Germany	France	Italy	Japan	Korea	China
Doctoral Degrees Awarded[c] (1,5)	1.02	1.00	1.73	2.03	1.70	1.04	0.86	0.64	1.24	b
Researchers in Workforce (2)	1.12	1.11	1.13	1.12	1.05	1.23	0.60	1.28	1.61	0.24
Highly-cited Researchers[d] (4,5)	2.06	1.25	2.13	2.19	0.99	0.65	0.34	0.25	0.25	0.06
Scholarly Papers (3,5)	1.15	1.71	2.21	1.71	1.16	1.02	0.94	0.56	0.91	0.14
Top 10% Most Cited Papers (3,5)	1.26	1.73	2.38	1.90	1.22	1.01	0.93	0.33	0.59	0.11
Top 1% Most Cited Papers (3,5)	1.23	1.78	2.38	1.98	1.18	1.02	0.86	0.28	0.48	0.09
Triadic Patent Families (2)	1.12	0.42	0.34	0.68	1.71	0.96	0.28	3.17	1.54	0.03

B. Canada as compared to smaller peer countries

	Canada	Australia	Netherlands	Belgium	Sweden	Switzerland	Austria	Israel	Taiwan	Singapore
Doctoral Degrees Awarded[c] (1,5)	1.00	1.73	1.27	1.10	1.72	2.27	1.30	0.95	b	b
Researchers in Workforce (2)	1.11	1.13	1.10	1.28	1.73	0.95	1.20	2.18	1.62	1.30
Highly-cited Researchers[d] (4,5)	1.25	2.13	2.52	1.50	1.20	4.21	1.01	0.48	0.35	2.00
Scholarly Papers (3,5)	1.71	2.21	2.09	1.73	2.35	3.21	1.53	1.52	1.07	2.03
Top 10% Most Cited Papers (3,5)	1.73	2.38	2.74	2.11	2.72	4.41	1.75	1.34	0.66	2.66
Top 1% Most Cited Papers (3,5)	1.78	2.38	2.94	2.20	2.86	4.98	1.88	1.32	0.49	2.84
Triadic Patent Families (2)	0.42	0.34	1.41	1.05	1.61	3.77	1.47	1.27	0.49	0.64

Notes:

[a] If OECD data for 2013 were unavailable, the most recent year available was used as a substitute.

[b] Data not available for China, Taiwan or Singapore.

[c] "Doctoral degrees awarded" is equivalent to ISCED 2011 Level 8 – Doctoral or Equivalent (http://www.uis.unesco.org/Education/Documents/isced-2011-en.pdf).

[d] The Highly-cited Researchers database may include multiple entries for the same person if they have qualified for Highly Cited status in more than one field.

Sources:

1 OECD, Education and Training, 2013. Available from: http://stats.oecd.org

2 OECD, Main Science and Technology Indicators, 2013. Available from: http://stats.oecd.org

3 Clarivate Analytics, InCites. For articles published in 2013.

4 Clarivate Analytics, website. Available from: http://hcr.stateofinnovation.com

5 Population data from United Nations Department of Economic and Social Affairs. Available from: https://esa.un.org/unpd/wpp/Download/Standard/Population/
Supplemented with data from the Taiwan Statistical Data Book, National Development Council. Available from: http://www.ndc.gov.tw/en/News.aspx?n=607ED34345641980&sms=B8A915763E3684AC

CHAPTER 4

OVERSIGHT, ADVICE, AND GOVERNANCE: OVERDUE COURSE CORRECTIONS

Chapter 3 offered a snapshot of Canada's position as a contributor to global science and scholarship, but raised serious concerns about the widening gap between Canada and international leaders and peer nations. We concluded that this was in part due to constraints on funding levels and questioned Canada's current capacity to recruit, develop, and support top-tier domestic and international talent, not just for academe or extramural research, but more broadly to galvanize innovation across all sectors.

While our approach in Chapter 3 was largely quantitative, the Panel's consultations and inquiries have also yielded substantial evidence of a more qualitative nature about the structure and function of our research ecosystem and some international comparators. The roundtables and submissions did not produce a clear consensus on all points. However, while funding levels were a consistent concern, what we also heard and read was evidence suggesting:

- poor coordination across the four pillar agencies;
- puzzling inconsistencies in program architecture;
- uneven decision-making on investments in national science facilities;
- discrepant success rates;
- blurred accountabilities; and
- a proliferation of disconnected entities arising from opportunistic decisions, some inspired and some not.

All of these represent gaps in the system and opportunities for improvement as well as obvious departures from the principles set out in Chapter 1. Many submissions also argued that Canada needed a high-level council or blue-ribbon committee to address these shortcomings and, more generally, to give the nation a truly coordinated strategy for research.

This chapter, in response, falls into three sections, all concerned with how to make federal supports for science and scholarship more effective and efficient. The first relates to oversight and advice at the federal system-wide level, and touches briefly on federal-provincial-territorial coordination. The next two sections focus on matters of structure and governance specific to the granting councils and CFI.

4.1 Federal System-level Oversight and Advice

4.1.1 History

Concerns about the lack of a coherent national science policy date to the 1960s. In the 1970s a Senate Special Committee on Science Policy produced three remarkable reports summarizing challenges with science oversight, advice, and coordination in Canada that it adroitly tracked back to the 1920s.[1] These reports, along with the special committee's brief "second-look" report in 1977,[2] are widely cited under the name of the committee chair, Senator Maurice Lamontagne. A recent article by Quirion, Carty, Dufour, and Jabr[3] brings developments fully up to date. Interested readers are referred to those reports for a full historical account.

Exhibit 1.3 in Chapter 1 captured many of these developments in a timeline of the evolution of the federal research funding system during the 20th and early 21st centuries. Exhibit 4.1 tabulates some of the key bodies inside and outside government that have been engaged in advising the federal government over the course of more than 100 years. For our purposes, it is helpful to track briefly the evolution of the role of Chief Science Advisor (CSA) and over time the formal bodies of external advisors organized under government auspices.

Exhibit 4.1: Science Advice: Canadian Institutional and Governmental Sources of Science Advice over Time

Time Period	Sources of Science Advice
1882–	Royal Society of Canada
1916–	National Research Council (Honorary Advisory Council on Scientific and Industrial Research)
1964–1971	Science Secretariat of the Privy Council Office
1964–1992	Science Council of Canada
1987–1996	National Advisory Board on Science and Technology
1988–1993	National Forum of Science and Technology Councils
1996–2007	Advisory Council on Science and Technology
1996–2007	Council of Science and Technology Advisors
2003–2008	National Science Advisor to the Prime Minister
2005–	Council of Canadian Academies (formerly Canadian Academies of Science)
2007–	Science, Technology and Innovation Council
2017–	Chief Science Advisor, Government of Canada

In 1964 the Government of Canada created an arm's-length Science Council of Canada (SCC) and a Science Secretariat inside the Privy Council Office (PCO). The director of that secretariat was appointed CSA to Cabinet in 1969. This function was superseded by creation of the Ministry of State for Science and Technology (MOSST) in 1971, ostensibly a step forward in internal capacity for science policy-making and oversight. By 1983 the Government decided that MOSST should emulate other departments and appointed a deputy minister-level CSA to the ministry.

The hope was that the CSA in MOSST might, as Quirion et al. write, "advise the government on: (1) the integration of a long-range scientific perspective into the policy development process and into specific proposals before the Cabinet; (2) the identification of areas that are science and technology intensive and that would have a significant impact on Canada; (3) the quality and effectiveness of science and technology policies."[4] In practice, however, the departmental CSA had no central authority and no responsibilities for reviewing, let alone coordinating, other departmental science and technology budget allocations.

Over the next 20 years, while many departments had their own CSA or CSO (chief science officer), there was still no one person to pull threads together until then Prime Minister Paul Martin appointed former NRC president and distinguished scientist, Dr Arthur Carty, to the recreated role of National Science Advisor (NSA) in 2004.

Quirion et al. highlight that, since the longstanding SCC was wound down in the 1990s, external advisory bodies have taken on various organizational forms with different life expectancies, reporting arrangements, and capacity to report publicly. The last 20 years are most relevant here. Former Prime Minister Jean Chrétien's team put in place two advisory bodies. The Advisory Council on Science and Technology (ACST, 1996–2007), appointed by the Prime Minister, was a smaller panel that offered largely private advice on measurement of Canada's research performance and identification of emerging trends and issues. The public-facing body, which focused on intramural science, was the Council of Science and Technology Advisors (CSTA, 1996–2007). Quirion et al. describe it as follows:

> The CSTA was to provide Cabinet with external expert advice on internal federal government science and technology issues. It was chaired by the Secretary of State for Science, Research and Development and its 22 members were nominated from their Advisory Boards/Councils by Ministers of science-based departments and agencies. The CSTA was initially asked to develop a set of principles for the effective use of science advice in government decision-making as well as an examination of the role of the federal government in performing S&T and its ability to fulfil this function. Over its 10-year life span, it produced and published several key reports on how to address these critical issues.[5]

As noted above, starting in 2004 Dr Arthur Carty served as NSA, working through the PCO and notionally reporting to then Prime Minister Paul Martin. Another innovation in the Martin years was the creation of CCA in 2005 to act as a clearinghouse for assembling expert advisory panels drawing on the three national academies (Royal Society of Canada, Canadian Academy of Engineering, and Canadian Academy of Health Sciences), and also to respond to commissions and compile metrics on Canada's research and innovation performance.

A new government led by Prime Minister Stephen Harper put its own stamp on these functions by moving the NSA's reporting line to Industry Canada in 2006. Commissioned in 2007 to report on science advice and advisory bodies, Dr Howard Alper of the University of Ottawa recommended closing both ACST and CSTA along with eliminating the position of NSA. These three functions were to be replaced by a new science and technology council chaired by the Prime Minister. Dr Alper's advice was followed with two important differences. When the new Science, Technology and Innovation Council (STIC) was created in 2007, Dr Alper was asked and agreed to chair it. STIC in turn was tasked with providing confidential advice to the Minister of Industry along with issuing "biennial, public State of the Nation reports that assess and benchmark Canada's STI progress and performance, particularly against that of international jurisdictions."[6] STIC continues today with 17 external members drawn from diverse constituencies, and the Deputy Ministers of Health and ISED. It has a small but skilled secretariat, and has issued four public reports on the state of science and technology in Canada and on science and technology sub-priorities. However, neither the CCA reports nor the STIC overviews contain granular policy recommendations to the Government of Canada.

Quirion et al. offer a summary assessment that is useful here: "An inevitable conclusion from this brief documentary history is that science and science advisory systems in Canada have come and gone on a whim and have rarely had the stability and support to make a lasting contribution to science policy."[7] Events of the last decade, in particular, highlight that an oversight body should ideally have sufficient independence to signal privately its concerns to the Prime Minister, and, as appropriate, to signal publicly—both to Parliament and the citizenry—its concerns about policy changes that damage the research ecosystem. Those considerations figure in the Panel's recommendations and elaborations, as do the role and pending appointment of a CSA.

In the Panel's view, the limited mandate of STIC as an external advisory body and the lack of an NSA have put Canada in an unusual and weakened position compared with many nations in the OECD. The need for a high-level overview and coordination of research efforts seems particularly urgent given the global trends, our weakening competitive position as outlined in Chapter 3, and the critical challenges cited in Chapters 1 and 2.

A further imperative for action is the growing complexity of the system itself due to the addition of many new entities and programs. Exhibit 4.2 graphically demonstrates this phenomenon with an overview of funding developments since 1960. This expansion phenomenon has many facets. In part, it is a pragmatic response to the quickening pace of research and the need to seize opportunities or respond to advocacy. It also reflects heightened politicization, a trend fuelled by political impatience with traditional research funding mechanisms.

Whatever the motivation, the net result is agencies and programs with overlapping mandates, orphaned disciplines as individual agencies rebalance their budgets, and duplication of overheads. Difficulties navigating this complex ecosystem also cause confusion and frustration among researchers as well as potential partners within the provinces and in charitable foundations, civil society, and industry.

4.1.2 Function and Role of a National Advisory Council on Research and Innovation

Given the critical global challenges and the complex research landscape in Canada, the Panel has concluded that it is timely to create a new advisory body to provide broad oversight and advice and foster coordination of the federal research effort: the National Advisory Council on Research and Innovation (NACRI).

With a membership drawing on leaders in research, civil society, and industry, NACRI would be well-positioned to offer non-partisan and strategic advice to the Government of Canada about emerging trends and priorities in research and innovation. Oversight of innovation policy and supports, both in general and specifically where innovation and research intersect, is timely on two scores. First, as mentioned in Chapter 1, the Growth Council appointed by Finance Minister Bill Morneau has very recently recommended that Canada's innovation ecosystem is in need of a thorough review and possible overhaul. That recommendation reflects the Growth Council's assessments that Canada's innovation performance is lagging behind international peers, an issue to which we return briefly in Appendix 3. On the research side, the Panel believes that NACRI's scope must embrace the full range of disciplines, including the social sciences and humanities, a position that explains why "research" rather than "science and technology" figures in its proposed title.

A structure such as NACRI would align Canada with several other OECD countries that have similar types of structures, including the U.S. and Australia. In arriving at a potential structure and mandate for this body, the Panel has examined a variety of Canadian precedents, as well as international approaches such as the U.S. President's Council of Advisors on Science and Technology model, Australia's evolving arrangements, and the German Wissenschaftsrat. Docking or reporting structures for similar international bodies vary: some connect to the most relevant government department; others report to the Cabinet or a Cabinet committee; others again report to the Prime Minister's Office (PMO), Privy Council, or equivalent; and multiple reporting lines are not uncommon. A review of international examples led us to recommend a hybrid model that is closest to the U.S. but not perfectly analogous.

> We encourage the government to appoint a national science advisor or science advisory council/panel to provide expert advice and input on research programs, emerging research areas, and strategic initiatives.
>
> – University of Waterloo

Exhibit 4.2: Key Initiatives in Federal Support for Canadian Postsecondary Research

Core Initiatives	Year	Diverse Non A-base Initiatives
Period of structural change and growth	1960s	
MRC (Medical Research Council) split off from the National Research Council (NRC) 1969		
New funding for research in areas of national interest 1977	1970s	
NSERC (Natural Sciences and Engineering Research Council) split off from the NRC 1978		
SSHRC (Social Sciences and Humanities Research Council) split off from the Canada Council 1978		
Period of significant growth in budgets of the funding agencies follows their creation through the 1980s	1980s	
NCE program (Networks of Centres of Excellence) launched. Tri-agency program administered by NSERC 1989		
Restraints hit	1990s	
Program review & budget reductions for all granting councils 1995		
The reinvestment period starts in 1997		
CFI (Canada Foundation for Innovation) created 1997		
CIHR (Canadian Institutes of Health Research) replaces MRC 1999		
GC (Genome Canada) created 1999 – regional structures as well as HQ		
Talent – Canada Research Chairs (CRC) program launched ($900M over 5 yr)	2000	Genome Canada ($160M); an additional $140M allocated 2000-01
Infrastructure – CFI ($900M)		Precarn Inc. ($20M)
		Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) ($60M)
Tri-councils – Major increase to CIHR ($75M)	2001	Canadian Institute for Advanced Research (CIFAR) ($25M over 5 yr)
Tri-councils – Smaller increases to NSERC & SSHRC ($36.5M; $9.5M)		
Indirect costs program – One shot allocation ($200M)		Genome Sciences Centre BC ($10M) – honouring M. Smith
		CA*net 4 (CANARIE) ($110M)
		Pierre Elliott Trudeau Foundation ($125M endowment)
Tri-councils – Increases to the core budgets ($125M per yr)	2003	Polar Continental Shelf Program (PCSP) ($6M over 2 yr)
Indirect costs program made an ongoing initiative ($225M per yr)		
Talent – Canada Graduate Scholarship (CGS) program created ($105M at equilibrium)		Genome Canada ($75M)
		Rick Hansen Leadership Fund ($15M)
Infrastructure – CFI ($500M)		MaRS ($20M)
Tri-councils – Increases to the core budgets ($90M per yr)	2004	Genome Canada ($60M)
Indirect costs increase ($20M)		
Restraints hit once again		
Federal funding reductions of 5% (over 3 yr) for NSERC and SSHRC		

Exhibit 4.2: Key Initiatives in Federal Support for Canadian Postsecondary Research (continued)

Core Initiatives	Year	Diverse Non A-base Initiatives
Tri-councils – Increases to the core budgets ($75M per yr)	2005	TRIUMF ($126M over 5 yr)
Indirect costs increase ($15M)		Terry Fox Foundation ($10M)
		Genome Canada ($165M)
		Precarn Inc. ($20M over 5 yr)
		Assessment – Council of Canadian Academies ($30M over 10 yr)
Tri-councils – Increases to the core budgets ($40M per yr)	2006	
Indirect costs increase ($40M)		
Infrastructure – CFI for Leaders Opportunity Fund (LOF) ($80M)		
Era of tightly targeted investments begins	2007	
Tri-councils – Increases targeted to government priorities ($85M per yr)		Genome Canada ($100M)
Indirect costs increase ($15M)		Rick Hanson Foundation ($30M)
Talent – Increases to CGS ($27M per yr at equilibrium)		CANARIE ($120M over 5 yr)
Infrastructure – CFI ($510M)		CIFAR ($25M over 5 yr)
Colleges – New College and Community Innovation Program ($49M over 5 yr)		Perimeter Institute ($50M over 5 yr) Seven Centres of Excellence ($105M over 5 yr)
Commercialization – Centres of Excellence for Commercialization and Research (CECRs) created ($195M over 2 yr)		
Talent – New Industrial R&D Internship (IRDI) program through NCE ($4.5M over 2 yr)		
People and economic levers	2008	
Talent – Vanier Graduate Scholarships created ($25M per yr)		Gairdner Awards ($20M endowment)
Talent – Canada Excellence Research Chairs (CERCs) created ($21M over 3 yr)		Genome Canada ($140M) Canadian Light Source ($10M over 2 yr)
Talent – Stipends for CGS studying internationally ($3M over 2 yr)		
Tri-councils – Increases targeted to government priorities ($80M per yr)		
Commercialization – Business-led NCEs created ($11M)		
Infrastructure & people	2009	
Infrastructure – CFI ($750M)		Institute for Quantum Computing (IQC) ($50M for building)
Infrastructure – Knowledge Infrastructure Program (KIP) ($2B over 2 yr)		
Talent – IRDI ($3.5M over 2 yr)		
Talent – Temporary expansion of CGS ($87.5M over 3 yr)		
Budget cuts to the core resulting from Strategic Review		
Tri-councils – $147.9M reduction per yr phased in over 3 yr		
Indirect costs – $14.65M reduction per yr phased in over 3 yr		

Exhibit 4.2: Key Initiatives in Federal Support for Canadian Postsecondary Research (continued)

Core Initiatives	Year	Diverse Non A-base Initiatives
Increased investment	2010	
Talent – Banting Postdoctoral Fellowships created ($45M over 5 yr)		TRIUMF ($222M over 5 yr)
Tri-councils – Increases to core budgets ($32M)		Genome Canada ($75M)
Indirect costs increase ($8M)		
Colleges – College & Community Innovation Program ($15M increase)		
Targeting economic priorities	2011	
Talent – 10 new CERCs ($53.5M over 5 yr)		Brain Canada ($100M)
Colleges – Industrial Research Chairs ($5M per yr at equilibrium)		Genome Canada ($65M)
College-University I2I commercialization partnerships ($12M over 5 yr)		Perimeter Institute ($50M over 5 yr)
Tri-councils – Increases targeted to partnership funds ($37M)		Canada-India Research Centre of Excellence ($12M over 5 yr)
Indirect costs increase ($10M)		
NSERC – Climate and atmospheric research ($35M over 5 yr)		
Continuation of economic trend	2012	
Infrastructure – CFI ($500M)		Genome Canada ($60M)
Tri-councils – Increases targeted to University-Industry partnerships ($37M)		CANARIE ($62M over 3 yr)
Commercialization – BL-NCEs made permanent ($12M)		CIFAR ($25M over 5 yr)
		McMaster (healthcare delivery $6.5M over 3 yr)
		Talent – IRDI transferred to Mitacs and increased funding ($14M over 2 yr)
Continuation of economic trend	2013	
Tri-councils – Increases to core budgets ($37M; including $12M for Colleges)		Genome Canada ($165M)
Infrastructure – CFI ($225M)		
Core increases	2014	
Tri-councils – Increase to core budgets ($37M)		TRIUMF ($222M over 5 yr)
Indirect costs increase ($9M)		IQC ($15M)
Excellence – Canada First Research Excellence Fund (CFREF) established. Forecast to grow to $200M per yr at equilibrium		Talent – Internship funding (IRDI) to Mitacs $8M ($2M per yr)
Economic trajectory continued	2015	
Infrastructure – CFI ($1.33B over 6 yr)		CANARIE ($105M over 5 yr)
Tri-councils – Increases targeted to partnership programs ($37M)		Thirty Meter Telescope (TMT) ($243.5M)
Indirect costs increase ($9M); rename program to Research Support Fund		TRIUMF ($45M over 5 yr)
		Talent – Internship funding (IRDI) to Mitacs ($56.4M over 4 yr)
		Assessment – Council of Canadian Academies ($15M over 5 yr)

Source: Janet Halliwell, J.E. Halliwell Associates, and ISED.

Recommendation 4.1

The Government of Canada, by an Act of Parliament, should create a new National Advisory Council on Research and Innovation (NACRI) to provide broad oversight of the federal research and innovation ecosystems.

Among NACRI's responsibilities would be:

- advice to the Prime Minister and Cabinet on federal spending as well as broad goals and priorities for research and innovation;
- improving the coordination and strategic alignment of different elements of federal support for research and innovation;
- evaluation of the overall performance of the extramural research enterprise;
- public reporting and outreach on matters determined by the Council;
- confidential or public advice on other matters as requested by the Government of Canada;
- a foresight function for research and innovation;
- in concert with the CSA, ongoing advice on (i) the effectiveness of extramural research agencies and the intramural research groups, and (ii) the facilitation of collaboration among them and with the extramural research realm;
- advice on large-scale domestic and international research infrastructure projects, and on unusual requests for research support that fall outside the usual remit of the granting councils and CFI; and
- liaison with parallel bodies in provinces and territories and internationally as appropriate.

The Panel envisages that NACRI's early priorities could include overseeing the resolution of issues in the extramural research realm identified in this report, and, consistent with the recommendation of the Growth Council and this report (see Chapter 1), providing input as requested on a review of the innovation programming inside ISED and the three granting councils.

The uneven coordination across the four pillar agencies (SSHRC, NSERC, CIHR, and CFI) is a particular concern. To be clear, the Panel does not believe that coordination can be effected by an advisory body per se; that is a function for governance and management, as outlined below. However, NACRI, working in close conjunction with the new CSA, can maintain a watching brief on the overall research funding system and report on problems and progress, or lack thereof, to relevant ministers and deputies as well as to the PMO as required.

The Panel believes that the CSA, in close consultation with NACRI, should review the research-related elements of budget submissions made by all major government departments. We think that there is simply no way to create a coherent research and innovation policy unless there is broader oversight of not only extramural but also intramural science and research spending, as has been envisaged since the 1960s. This in turn means that the Department of Finance should consider making such reviews an integral part of the budgeting process.

4.1.3 Improving Evaluation Processes

As recommended, NACRI could facilitate review of one-off programs and entities that have been introduced into the extramural research system over the past several years, and adjudicate ad hoc requests for funding. This charge tracks back to the Panel's mandate, as delineated in Chapter 1, and the importance of continuity and expertise in assessing contribution agreements with third parties. These agreements (not including CFI) now account for some $143 million per year of federal spending, and may grow over time depending on how national laboratories, platform technologies, and major science initiatives are organized.

In this regard, the Panel has observed three evaluation practices in the federal government that are less than ideal.

The first is the reliance on assorted consulting and accounting firms to evaluate grant-making entities and scientific institutes. Although these firms may gather useful information, they are no substitute for serious peer review by content experts, nor do they have any unique expertise in evaluating the administration of research programs.

The second is the conflation of self-study with external review. Internal self-study is a time-honoured and valuable part of the quest by most organizations for continuous improvement. But when the agency itself is the commissioning body, picking external reviewers and defining the scope and questions, the likelihood of critical scrutiny is constrained.

The third is the most pervasive and problematic, and might be called "mission tautology". This occurs when reviews take the existence of the entity or program as a given and focus on whether it is achieving its stated mission. Such reviews fail to ask whether the program or entity should have been established in the first place, how the funds might be deployed more efficiently to achieve similar objectives, and, more fundamentally, whether the pursuit of those objectives still makes strategic sense.

In this spirit, the Panel would simply add that NACRI itself should undergo a rigorous review after a period of five years.

4.1.4 Reporting

A capacity to issue regular public reports and engage in outreach is integral to sustaining the credibility of NACRI with Canadians across diverse sectors, not least given recent history as reviewed earlier. The Panel acknowledges the fine work done by both STIC and CCA in reporting on Canada's research and innovation performance. CCA should remain a resource for the government and for the work of NACRI. However, as noted, NACRI should be provided with a degree of autonomy in giving concrete advice and recommendations, along with responding on demand.

The Panel emphasizes that an appropriate degree of independence does not in any way equate to an oppositional approach. NACRI would have ties to the government of the day on many levels, particularly through the close involvement and leadership role of the new CSA, outlined in more detail below; through interaction with federal agencies and councils involved with research and innovation; and through engagement with ministers and deputy ministers in federal departments with strong research mandates. Furthermore, while the CSA would be the close and confidential day-to-day advisor on research matters for many senior officials, NACRI must also be in a position to collaborate with the CSA in providing confidential advice as requested.

4.1.5 Priority Setting

The priority-setting and "foresight" functions set out above are intertwined. The Panel expects them to be closely linked to the evolving mandate of Canada's new CSA. However, we believe greater clarity is needed about priority setting. Integral to our concept of NACRI is that it should bridge and provide advice on two fronts: research and innovation. This is reflected in our membership recommendations below. In the research realm, we anticipate NACRI monitoring the ecosystem to comment on emerging trends (e.g., "Open Science" or novel research technologies) as well as to pinpoint areas where Canada has existing and developing strengths that may warrant additional support. However, we strongly emphasize the need for restoration of support for independent investigator-led research and the expansion of open competitions where merit adjudicated by effective peer review is the key criterion in resource allocation.

On the other hand, NACRI should be in a position to advise on priorities for innovation, including innovation-facing programs within the funding agencies and related entities funded by the federal government (see Exhibit 1.2).

Canada made a start in the priority-setting direction in 2007 when the Harper government declared four priorities: Environment, Natural Resources and Energy, Health and Life Sciences, and Information and Communications Technologies. Unfortunately, these categories were used as much to target research funding as to focus investments in innovation. That approach, coupled with the breadth of these categories, meant that their primary effect was to emphasize science, technology, engineering, and math (the so-called STEM disciplines) at the expense of the social sciences and humanities, and not much more.

In 2014, after consultation with stakeholders, Advanced Manufacturing was added as a major category, and Agriculture was added to Environment. STIC was then engaged to identify focus areas within these five categories. Exhibit 4.3 shows the resulting matrix with a much finer-grained result. These priorities may be reasonable for federal innovation policy, but applying such granular priorities to research would create serious distortions.

Exhibit 4.3: Federal Science, Technology, and Innovation Priorities, 2014

Research Priorities	Focus Areas
Environment and Agriculture	Water: Health, Energy, Security Biotechnology Aquaculture Sustainable methods of accessing energy and mineral resources from unconventional sources Food and food systems Climate change research and technology Disaster mitigation
Health and Life Sciences	Neuroscience and mental health Regenerative medicine Health in an aging population Biomedical engineering and medical technologies
Natural Resources and Energy	Arctic: Responsible development and monitoring Bioenergy, fuel cells, and nuclear energy Bio-products Pipeline safety
Information and Communications Technologies	New media, animation, and games Communications networks and services Cybersecurity Advanced data management and analysis Machine-to-machine systems Quantum computing
Advanced Manufacturing	Automation (including robotics) Lightweight materials and technologies Additive manufacturing Quantum materials Nanotechnology Aerospace Automotive

A deeper issue of priority setting with regard to overall research funding also requires attention. The Panel perceives that over the course of some two decades, Canada has operated on the assumption that investments in basic and applied research should somehow cascade quickly into more goods and services along with healthier and happier populations. This is tied back, obviously, to the naïve linear model critiqued in Chapter 2 and a lack of appreciation of the timeline for returns on basic research and the extent to which highly-qualified personnel working in industry and civil society are the key "innovation" outputs from such investments.

Frustration of these expectations led the Harper government to redirect research funding towards innovation-related programming under the auspices of the granting councils—as if these academic grant-making bodies could suddenly become effective engines of commercialization. The resulting imbalances in funding have clearly had adverse effects on independent research. What is needed now are strategies to foster both world-class research and world-class innovation (understood to involve not just business but civil society and governments), along with imaginative strategies to bridge but not conflate these two realms. The Panel believes that NACRI can and should be an integrative vehicle to advise on and facilitate those critical strategic shifts. (Chapters 6 and 7 examine the magnitude of the current imbalances and the reinvestments needed to rectify them.)

This duality of NACRI's mandate, its obvious overlap with that of STIC, and other considerations reviewed earlier lead to a further recommendation. NACRI should supersede the existing STIC, which has a more limited and purely responsive mandate. We offer this advice with no disrespect to the distinguished individuals who have served or are currently serving on STIC.

Recommendation 4.2

The Science, Technology and Innovation Council should be wound down as NACRI is established.

4.1.6 Relationship of NACRI to the Chief Science Advisor

The Trudeau government has highlighted its commitment to strengthening federally funded intramural and extramural research in diverse ways. These have included appointing an academic to the role of Minister of Science; upgrading this position from Minister of State to full Cabinet status; signalling that federal scientists are no longer restricted in publishing their research and discussing the results of peer-reviewed research findings; increasing the base budget of the three granting councils by $95 million in the 2016 Budget, directed explicitly to open competitions; and, if we may, appointing this Review Panel. A particularly important move, both symbolically and practically, was the announcement of the reinstatement of the post of CSA.

Minister Duncan has finished her consultation on the role, secured approval of a position description, and recently released publicly a sketch of the mandate of CSA to be appointed in 2017 (see summary in Exhibit 4.4). The Panel offered its recommendations on that position in an October 2016 update to the Minister and strongly supports the mandate and reporting lines announced by the Minister.

In that update we envisaged a close relationship between the CSA and NACRI, described below. We also acknowledged that the realm of intramural science needed attention, but emphasized "our strong view that the portfolio should have a mandate that includes elements of overarching strategy, coordination and evaluation for extramural science, including major science initiatives and platform technologies, liaison to the innovation sphere, and coordination of extramural science with internal scientists (e.g., in NRC and various federal departments)." We added: "The National Science Advisor could play a particularly important role in facilitating inter-council collaboration to support trans-disciplinary research and researchers."

Exhibit 4.4: Summary of Mandate of the Chief Science Advisor (CSA)

Reporting and Office
• Reports to both Prime Minister and Minister of Science on government-wide scientific matters • Office of CSA within Innovation, Science and Economic Development (ISED)
Mandate
• Examine the role and function of existing science advisory bodies across government; • Assess the merits of a network of departmental Chief Science Advisors, with a decision based on this advice to follow; • Play a primarily advisory and coordinating role, not a governance and decision-making role; • Advise on the development and implementation of guidelines so that government science is fully available to the public, and scientists are free to speak about their work; • Provide advice and implement processes so that scientific analyses are considered when government makes decisions; • Assess and recommend ways for government to better support quality scientific research within the federal system; • Provide annual reports on the state of federal government science; • Provide expert advice to Minister of Science and Cabinet as requested on key scientific issues, including research and foresight papers for public dissemination; and • Promote a dialogue between federal scientists and academia, in Canada and abroad, and raise awareness of scientific issues among the Canadian public.

Source: Compiled by the secretariat based on information from ISED.

4.1.7 NACRI Membership, Structure, and Reporting Lines

Integral to our concept of NACRI is that the council should bridge and provide advice on two fronts: research *and* innovation. This viewpoint is reflected in our proposed membership and reporting lines (see Recommendation 4.6).

Membership

The Panel believes that the membership of NACRI must be primarily external to government. Members should have the standing, experience, and breadth and diversity of vision to ensure that the council begins as, and remains, a foundational organization for advice on research and innovation in Canada. It should be large enough to reflect a breadth and depth of expertise spanning geography, sectors, and disciplines, and encompass both frontline and administrative/policy perspectives. Terms should last no longer than three years with an option to renew once only, with staggered first appointments per usual for continuity. The Panel assumes that search processes for these seats would follow the template established thus far by the government. Inclusion of a small number of international and/or expatriate members is encouraged, but all appointees must be committed to attending multiple meetings each year and reviewing substantial amounts of material. The Panel expects that NACRI, in any case, would frequently involve international experts as needed in its deliberations and assessments.

Recommendation 4.3

NACRI should have 12 to 15 members, appointed through Orders in Council, comprising distinguished scientists and scholars from a range of disciplines as well as seasoned innovators with strong leadership and public service records from the business realm and civil society. Domestic members should be drawn from across Canada and reflect the nation's diversity and regions.

Leadership and Secretariat

The Panel's review of practices in peer nations shows that a CSA equivalent often holds a leadership role on advisory councils such as NACRI. We agree, per the recommendation below, and see clear-cut advantages regarding coordination with government. However, given recent history and to underscore the independence of NACRI, its Chair should be an external appointee.

Neither the CSA nor NACRI can function without dedicated resources. The Panel has not recommended that NACRI be established as an independent agency or Crown corporation, to avoid isolating it from the machinery of government. This also enables a single secretariat to serve both NACRI and the CSA. The location of the secretariat within ISED has the further advantage of helping the CSA and NACRI in bridging to innovation programming.

Recommendation 4.4

An external member should hold the Chair of NACRI with the CSA serving as Vice Chair. NACRI should be supported by a dedicated secretariat working within the larger expert team supporting the CSA.

Privy Council Review of Machinery

The Panel assumes that a CSA/NACRI secretariat would connect with other internal coordinating structures such as the current Deputy Ministers' Committee on Intramural Science, perhaps with staff working across both secretariats in a "work-share" mode. The CSA's mandate includes the possibility of creating a network of departmental CSAs, which the Panel views prima facie as an excellent concept. More generally, however, we appreciate that details of these internal machinery issues are best determined by those who must navigate the heavy workloads and varied demands on senior officials and departmental chief scientists in the Government of Canada.

Recommendation 4.5

The Privy Council Office, working with departmental officials and the newly appointed CSA, should examine mechanisms to achieve improved whole-of-government coordination and collaboration for intramural research and evidence-based policy-making.

Reporting Lines

Reporting lines also merit consideration. This term, on one level, is a misnomer. NACRI would be advisory, and not a governing body per se or a group of government employees. It might therefore be better to describe these as formal channels for two-way communication.

As a first impression, one could argue for these channels to mirror those of the CSA, connecting NACRI to both the Prime Minister/PMO and the Minister of Science. However, this model would be inconsistent with the role envisaged for NACRI in the innovation sphere. Dual reporting by NACRI to the current Minister of ISED and the Minister of Science seems more appropriate. Other considerations include:

- The Science Minister's role is in transition from Minister of State to full Cabinet status. It may take some months for the role of the position to be fully clarified and established.
- While ISED itself may be restructured as both the Science Minister and the Minister of Small Business and Tourism transition in their roles, the current Minister of ISED will retain authority for industry, innovation, and overall economic development. Thus, NACRI must obviously have a close link to the ISED Minister.
- Assuming that Recommendation 4.5 is accepted, it will also take time for any changes in intra-governmental machinery to be determined and implemented.
- The Panel is not recommending movement of reporting lines of CIHR from Health Canada to ISED. Thus, connections to the Health Minister are also essential.

These considerations inform the next recommendation.

Recommendation 4.6

As a council of senior volunteers with a broad mandate of national importance, NACRI should have a publicly acknowledged working connection to the Prime Minister/PMO, parallel to that established for the CSA. NACRI should report to and interact most directly with both the Minister of Science and the Minister responsible for Innovation and Economic Development. It should also have open channels of communication with the Minister of Health and other ministers of key departments involved in intramural and extramural research.

To elaborate on the last point, while interpersonal relationships involving NACRI's members and senior government officials are important, more organized channels for interaction are needed. Various options to facilitate those interactions can be imagined and are not mutually exclusive. They include:

- creation of a Cabinet committee or modification of an existing one to enhance overall coordination while also serving as a specific point of connection for NACRI;
- constitution by the key ministers of a working committee to meet with NACRI or its Chair on a quarterly basis;
- regular interchanges with senior Finance officials; and
- ex-officio membership on NACRI for relevant ministers or their deputies.

The Panel envisages that the role of the CSA will ideally evolve on a government-wide basis such that s/he is a conduit and facilitator for both interactions and integration in the research realm. NACRI would support and reinforce those functions, and benefit from the CSA's role as both bridge-builder and Vice Chair.

4.1.8 Formation of a Standing Committee on Major Research Facilities

We heard from many who recommended that the federal government should manage its investments in "Big Science" in a more coordinated manner, with a cradle-to-grave perspective. The Panel agrees. Consistent with NACRI's overall mandate, it should work closely with the CSA in establishing a Standing Committee on Major Research Facilities (MRFs).

CFI defines a national research facility in the following way:

> We define a national research facility as one that addresses the needs of a community of Canadian researchers representing a critical mass of users distributed across the country. This is done by providing shared access to substantial and advanced specialized equipment, services, resources, and scientific and technical personnel. The facility supports leading-edge research and technology development, and promotes the mobilization of knowledge and transfer of technology to society. A national research facility requires resource commitments well beyond the capacity of any one institution. A national research facility, whether single-sited, distributed or virtual, is specifically identified or recognized as serving pan-Canadian needs and its governance and management structures reflect this mandate.[8]

We accept this definition as appropriate for national research facilities to be considered by the Standing Committee on MRFs, but add that the committee should:

- define a capital investment or operating cost level above which such facilities are considered "major" and thus require oversight by this committee (e.g., defined so as to include the national MRFs proposed in Section 6.3: Compute Canada, Canadian Light Source, Canada's National Design Network, Canadian Research Icebreaker Amundsen, International Vaccine Centre, Ocean Networks Canada, Ocean Tracking Network, and SNOLAB plus the TRIUMF facility); and
- consider international MRFs in which Canada has a significant role, such as astronomical telescopes of global significance.

The structure and function of this Special Standing Committee would closely track the proposal made in 2006 by former NSA Dr Arthur Carty. We return to this topic in Chapter 6. For now, we observe that this approach would involve:

- a peer-reviewed decision on beginning an investment;
- a funded plan for the construction and operation of the facility, with continuing oversight by a peer specialist/agency review group for the specific facility;
- a plan for decommissioning; and
- a regular review scheduled to consider whether the facility still serves current needs.

We suggest that the committee have 10 members, with an eminent scientist as Chair. The members should include the CSA, two representatives from NACRI for liaison, and seven others. The other members should include Canadian and international scientists from a broad range of disciplines and experts on the construction, operation, and administration of MRFs. Consideration should be given to inviting the presidents of NRC and CFI to serve as ex-officio members. The committee should be convened by the CSA, have access to the Secretariat associated with the CSA and NACRI, and report regularly to NACRI.

Recommendation 4.7

A Special Standing Committee on Major Research Facilities should be convened by the CSA and report regularly to NACRI. The committee would advise NACRI and the Government of Canada on coordination and oversight for the life cycle of federally supported MRFs.

On the international front, NACRI's MRF Standing Committee, working alongside the CSA, could be a particularly useful resource for advice and oversight regarding Canada's participation in international Big Science projects. The portfolio of broader international relations or "science and innovation diplomacy" would require leadership by political representatives (e.g., the Prime Minister and ministers such as those for science, innovation, health, and global affairs). The CSA would be an essential contributor to these functions that have taken on growing importance in an era of major global challenges and globalized scientific discourse. NACRI could play a supporting role on request, not least by engaging in bilateral and multilateral interchanges with the many national advisory bodies that have similar mandates.

4.1.9 Federal-Provincial-Territorial Cooperation and Coordination

Although the Panel's mandate did not explicitly refer to federal-provincial-territorial (FPT) matters, some reflection on these important relationships seems pertinent. FPT collaborations were raised in some of the consultations and submissions from researchers. We also received several thoughtful submissions from provincial and territorial officials, highlighting the reality that the provinces and territories are key partners with the federal government in support of university and college research.

The Constitution itself is silent on research. However, support for extramural research has clearly evolved over time into a shared area of jurisdiction, albeit one where the federal government has asserted a leading role. For their part, the provinces have constitutional responsibility for the universities in which most extramural research takes place and are significant direct funders of research as well.[i] Surely this is an area where close cooperation and shared planning would make sense, but that is not what the Panel found. Since the early 2000s, FPT ministers have met infrequently as a group, if at all.[ii] The same is true at the

i For 2014, Statistics Canada reports $3.1 billion in direct federal funding of higher education research and $1.2 billion from provincial governments. Data from Statistics Canada: Gross domestic expenditures on research and development, by science type and by funder and performer sector (CANSIM table 358-0001). Ottawa: Statistics Canada; 2015.

ii According to ISED records, the last formal intergovernmental ministerial meeting on innovation was held in 2003. The provinces and territories convened a meeting of their own in 2010 with federal ministers attending some sessions.

deputy ministers' level. While both ministers and officials have maintained active bilateral and ad hoc relations, these are unlikely to generate the kind of cooperation needed to obtain the best performance from the system.

Submissions to the Panel from provincial and territorial governments highlighted potential opportunities to increase the impact of public investments in research through greater program alignment. Those opportunities cover the spectrum from how individual research programs are structured and competitions scheduled, to dealing with major shared challenges such as the funding of infrastructure and the development of digital research infrastructure (issues dealt with in more detail in Chapter 6). Despite the lack of high-level contact, the tone of what we heard from the provinces and territories was positive: They are open to working together more closely and are cognizant of the opportunities for improvement that this could bring.

Our optimism is tempered by the fact that consultations also revealed areas of growing tensions between the orders of government. These include the increasing tendency at the federal level to seek intergovernmental matching and cost sharing as part of its programs. As one indicator of non-alignment, a pattern has emerged in some provinces where CFI funding in some disciplines, most under the SSHRC umbrella, is not routinely matched with provincial funds. Another area of concern is the failure of the federal government to provide adequate F&A support for the research that it funds. As Chapter 3 outlined, the provinces are increasingly attuned to the reality that although the federal government has a strong steering influence in extramural research, this is clearly a shared responsibility with substantial provincial contributions. Conversely, again as noted in Chapter 3, the Government of Canada has legitimate concerns about the fact that provincial governments and universities together determine the number of university-based researchers who seek personnel and operating support from federal agencies. We therefore re-emphasize the need for improved human resource planning in the research realm and believe that a national roadmap would be extremely helpful. More generally, the Panel believes that as the federal government puts its research house in better order, it should intensify its interactions with the provinces to improve coordination across an ecosystem in which all three orders of government play significant roles.

At present only Quebec has a Chief Scientist, but Ontario is moving forward with a similar appointment, and, as noted, Ottawa's CSA will be appointed in 2017. Various advisory bodies on research and innovation also exist across the provinces. Both the CSA and NACRI accordingly could promote FPT dialogue in the years ahead.

Recommendation 4.8

Ongoing interactions and annual in-person meetings should be established to strengthen collaborative research relationships among federal, provincial, and territorial departments with major intramural or extramural research commitments. The CSA, with advice from NACRI, should take the lead in promoting a shared agenda on matters of national concern, such as human resource planning to strengthen research and innovation across Canada.

The Panel also observes that Canada's sesquicentennial in 2017 provides a moment in history when it may be possible for federal, provincial, and territorial ministers of science, innovation, and health to converge on ambitious national goals. A First Ministers' Conference on Research Excellence could reset FPT relations on this front and reinvigorate national collaboration.

Recommendation 4.9

The Government of Canada should propose and initiate planning for a First Ministers' Conference on Research Excellence in 2017. The conference would celebrate and cement a shared commitment to global leadership in science and scholarly inquiry as part of Canada's sesquicentennial celebrations.

The Panel imagines that such a First Ministers' Conference would also be a sesquicentennial summit on science and research, with working sessions involving ministers and deputy ministers in research-intensive departments from the federal government and their counterparts in provincial and territorial departments. These sessions would be outstanding opportunities to begin working through issues such as shared human resource planning and a more collaborative and consistent framework for research funding, including federal-provincial/territorial matching programs. Above all, the summit would signal that Canada is determined to play a global leadership role in generating important new insights into human and non-human nature and the human condition more broadly.

4.2 Consolidation or Coordination of the Four Pillar Agencies?

Much of the foregoing material has been concerned with oversight and advice—with oversight defined as a broad and integrative outlook on a complex and segmented system. In this section, we narrow our focus to issues of governance and accountability in the four pillar agencies for research support: CFI, CIHR, NSERC, and SSHRC.

Before proceeding, we should repeat a point made in Chapter 1. Our mandate is to focus on gaps and shortcomings, and the observations and recommendations that follow are in no way meant to criticize individuals or to question the fine work and high ideals of those who work in the four agencies. On the contrary, the accomplishments of recent generations of researchers across a range of disciplines have been meaningfully facilitated in most instances by funding from one or more of these agencies.

That said, a recurrent theme in the Panel's consultations was disparity in program architecture, funding models, and governance strategies across the three granting councils. Exhibit 4.5 provides a telling snapshot of such imbalances in "open competitions". Other common challenges include uneven support for multidisciplinary operating grants, orphan disciplines that do not align with current boundaries on eligibility set separately by the councils, gaps in funding for infrastructure and equipment between the councils and CFI, and, despite some commendable efforts on all sides, continuing serious problems in aligning equipment and research operating grants.

While NACRI and the new CSA may enhance coordination across the four agencies, a logical question that can be raised is whether some consolidation should also occur. That question seems reasonable given the fact that other nations have made or are making bold changes to align their funding systems more closely with the changing landscape of science and scholarship.

Exhibit 4.5: Characteristics of Major Granting Council Programs Supporting Investigator-led Research

	Program Name	Applications (per year)[a]	Grants Awarded (per year)[a]	Success Rate[a]	Active Grants[b]	Average Annual Grant Value[b]
SSHRC	Insight Development and Insight Grants	3,112	778	25.0%	2,529	$37,701
NSERC	Discovery Grants	3,214	2,039	63.4%	10,315	$34,876
CIHR	Open Operating Program, Foundation, and Project Grants	4,681	688	14.7%	3,468	$143,514

[a] Average of the four-year period 2012-13 to 2015-16.

[b] Data for 2015-16 only.

Source: Calculations by the secretariat based on detailed program expenditures provided by the granting councils.

4.2.1 Background and Analysis

The Panel has taken note of the growth in the number and value of tri-council programs. As shown in Exhibit 1.2, the annual turnover in these programs is now roughly $1 billion, substantially more than the remaining budgets in any individual council. Rather than serving as a spur to consolidate back-office functions, however, each of these tri-council programs has been assigned back to one of the three councils. Headquarters for two of the agencies are housed in the same building (NSERC and SSHRC), but CFI and CIHR each have office space in different locations.

The Panel therefore asked itself whether consolidation of the councils and CFI into a single entity should take place. We examined international experience closely, but will only summarize our findings briefly here.

As one model, we noted that in addition to the significant amount of research activity taking place in some 240 free-standing institutes, Germany also funds extramural research through the German Research Foundation (Deutsche Forschungsgemeinschaft), widely known as DFG. DFG operates with a budget of €3 billion as a single portal supporting the extramural research and equipment needs of all disciplines. Australia maintains a separate health and medical research council, but provides extramural funding for all other disciplines through a single council.[iii]

On the other hand, consolidation may not lead to optimal coordination if a complex multidivisional structure is sustained. For example, the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (Netherlands Organization for Scientific Research, commonly referred to as NWO) is a single umbrella agency for extramural research and expert advice to the federal government. It has a complex internal structure, with disciplinary and specialized divisions, major science installations, time-limited initiatives, and separate institutes for sea, space, and energy research. In January 2017, NWO adopted a new organizational structure designed “to improve the harmonisation between instruments from different domains, to make cross-domain programming easier, and to make it clearer for researchers which part of NWO they can best approach with their research ideas.”[9]

The U.K. initiatives are also illuminating. The landscape there was complex, with seven separate research councils under Royal Charter. Even before the recent consolidation, these councils had created a strategic partnership with elements of harmonization, and were also coordinating the delivery of multidisciplinary research support across six priority areas. A review in 2015 by Sir Paul Nurse[10] recommended that all seven councils be brought “under one roof” with a single chief executive and consolidated back-office functions. However, the review supported continuation of internal council structures to facilitate a smooth transition and provide a “home” for disciplines and research communities. Since then, the U.K. government has gone further, adding to the consolidation both the national innovation agency, Innovate U.K., and the research funding functions of the Higher Education Funding Council for England. Consolidation is ongoing, and, as this report was in final stages of production, the U.K.’s outgoing Chief Science Advisor, Sir Mark Walport, has been appointed to lead the new umbrella agency, UK Research and Innovation.

A final piece of the structural puzzle is support for major equipment and strategic infrastructure. Here, too, there is substantial variation. Other nations do have better-established machinery for dealing with specialized MSIs and related domestic collaborations and international partnerships. This was evident in bodies such as Germany’s Helmholz Association or the U.K.’s Science and Technology Facilities Council. Those findings helped motivate our recommendation for the creation of a Standing Committee on MRFs under NACRI. However, we found repeatedly that, while various agencies in most jurisdictions offer generous extramural funding for equipment and small-scale infrastructure, there was no analogue for CFI, leading to challenges for others in making evidence-based decisions about the funding of large-scale research facilities located at universities or colleges.

iii Health and medical research is funded through the National Health and Medical Research Council (NHMRC), while the Australian Research Council (ARC) funds all other disciplines.

We concluded that the decision to create CFI was remarkable, given that it has allocated some billions of dollars not just to fund equipment, a less visible activity, but to co-fund construction of research buildings—the type of visible investment that governments commonly view through a political lens. However, many informants complained about a lack of coordination in the funding of infrastructure, equipment, and research operations. There are also elements of infrastructure that fall between CFI's capital mandate and the equipment mandates of the granting councils. Thus, while we were left in no doubt that CFI's independence from government had been a positive move, the interdependence of capital and operating funds has received too little attention from the four agencies.

4.2.2 Creation of a Coordinating Board

The Panel received disparate input on structural consolidation. Understandably, none of the four agencies proposed consolidation into a single entity or creation of a formal coordinating body. Universities Canada argued that the architecture of the federal system of support for research requires no serious changes and that the most persistent gap is in levels of funding. The U15 Group of Canadian Research Universities recommended that a high-level advisory panel be put in place (see NACRI above), but did not comment otherwise on the governance of the granting councils. Some individual submissions and roundtable conversations in contrast led to suggestions that a merger of the four agencies was the most logical way forward. The vision proposed was one multidisciplinary agency from which a researcher or research team could seek funding for personnel, research operations, and major or minor equipment.

The Panel's international review led us to conclude that there is no "perfect" agency structure for disciplines in a funding ecosystem, and that putting a large number of divisions and operations under one umbrella does not necessarily ensure coordination. While we quickly determined that full consolidation with abolition of council structures was likely to disrupt an already fragile ecosystem, we did weigh two options.

One was the U.K. hybrid structure. Here, we noted that the U.K. had started from a more complex landscape with a stronger imperative for simplification. Given our simpler starting point, it seemed prudent to watch the exciting U.K. experiment unfold over the course of two or three years, rather than rush to emulate it.

> Canada desperately needs an integrated mechanism to fund science and its applications. It is currently far too piecemeal, with multiple overlaps, gaps, and generally no overall policy, with each agency functioning on its own, and often competing with others for limited funding. … At the very least, a board overseeing all the various federal science funding agencies in the country would be a great start (an easy win), followed by much more integration of all the agencies and what they fund.
>
> – University of British Columbia

The second more appealing possibility was to take advice given in the 1970s, and recommend what amounts to an executive board with full authority to oversee coordination and collaboration across the four agencies. This would include authority to manage physical co-location, greater consolidation of back-office functions, and formalization of tri-council operations as the primary administrative model.

The latter solution remains a possibility from the Panel's perspective. Among its advantages is that it would drive immediate changes. The Panel observes, however, that this option can readily be held in reserve and its need can continue to be assessed. If the three granting councils and CFI are explicitly mandated to address issues raised here and throughout this report, their progress can be encouraged and facilitated by a new coordinating body with engagement of both a new CSA and NACRI. A stronger supervisory structure could be created in the future if need be.

Recommendation 4.10

The Ministers of Science and Health should mandate the formation of a formal coordinating board for CFI, CIHR, SSHRC, and NSERC, chaired by the CSA. The membership of the new Four Agency Coordinating Board would include the four agency heads, departmental officials, and external experts. Reporting to the Ministers of Science and Health, the Coordinating Board would expeditiously determine and implement avenues for harmonization, collaboration, and coordination of programs, peer review procedures, and administration.

External members would be distinguished individuals with an understanding of the extramural research ecosystem and deep experience with frontline research issues. Obvious priorities would be:

- improving overall coordination;
- addressing equity and diversity concerns and systemic biases in peer review;
- enabling more nimble support of multidisciplinary research;
- better aligning capital and operating support;
- addressing orphan disciplines that do not have a council "home";
- consolidating back-office functions to the greatest extent possible; and
- developing a coordinated approach to public outreach about exciting developments in Canadian research that informs citizens and inspires children and youth.[iv]

These issues and others are addressed in more detail in Chapter 5.

We would be remiss not to observe that the colleges and polytechnics made thoughtful submissions to the Panel about their place on the innovation side of tri-council programming. While outside the Panel's mandate, those programs and their place in them might also be usefully addressed not only by any review of supports for innovation per Recommendation 1.1, but also by the Coordinating Board.

The Coordinating Board should commit to timelines and deliverables, and its progress should be monitored by the CSA in close consultation with NACRI. In the event that progress is deficient, the CSA and NACRI would communicate concerns to the relevant ministers. If necessary, they could also recommend to the government that the Coordinating Board's composition be changed, and that it take on a supervisory role such that its recommendations would no longer require approval by the separate governing boards, but would instead constitute binding directions.

In this regard, the Panel took note of some sage advice given in a 2006 governance review of NSERC and SSHRC undertaken by James R. Mitchell on commission from Industry Canada. Mitchell commented on the lack of "alignment and coordination" between NSERC and SSHRC and other federal agencies involved with research. He wrote: "The general point here is not that the councils need coordination by the government, but rather that the government is entitled to expect a higher degree of collaboration and coordination *by the councils themselves* on a wide range of matters, ranging from common or overlapping areas of research interest."[11] He therefore proposed that, "at a minimum," the Government of Canada should:

> …encourage and support the creation of a new, stronger cross-agency coordinating mechanism (not a new organization) to facilitate:
>
> a) closer coordination of the activities, policies, programs and strategic plans of the three councils and the other federal research funding agencies;

iv See Principles in Chapter 1 and point c) from the Mitchell report, p. 77 (see endnote 11).

b) regular communication among the senior leadership and staff of the councils and the other research funding agencies and concerned federal departments; and

c) a more coherent presentation to Parliament, the government and the public of the research universe in Canada and of the contribution made to Canadian science and the larger Canadian interest by these federal agencies.[12]

One interpretation is that a decade has passed and the granting councils and CFI have again failed to act definitively. The Panel takes a more generous view. The recommendation was directed to the Government of Canada, not to the four agencies. We are repeating it now with greater emphasis, and with the addition of an accountability and oversight mechanism to help accelerate and assess the progress made by the four agencies. The Panel's strong hope is that collaboration and coordination will become the order of the day, without the need for more outside direction. However, we also urge the relevant ministers and deputies to be prepared to implement a supervisory board within 18 to 24 months if progress is limited. In this vein, the discussion below aimed at improving agency-specific governance is intended not to build stronger silos, but to drive better governance that will lead to bigger and stronger bridges connecting the four agencies and to clearer accountabilities.

4.3 Agency-specific Governance

Thus far, we have recommended that the four agencies maintain their identities but substantially improve their coordination on multiple levels, and emphasized the role of ministers in mandating these changes. What became clear to the Panel in our discussions with past and present leaders of the four agencies was that mandates from ministers were given inconsistently, and that lines of accountability in and around the three granting councils are blurred.

Consistent with the guiding principles set out in Chapter 1, we strongly concur that all four agencies should operate with a degree of independence from the Government of Canada, but clear accountabilities are also needed. It is one thing for the research community to be concerned if a minister interferes in ways that undermine the integrity of a specific competition. It is quite another for remedial direction to be given, as Minister Duncan did in the fall of 2016, when agencies or universities had repeatedly failed to make improvements in the continuing egregious gender imbalances in the awarding of Canada Excellence Research Chairs and Canada Research Chairs.

This section accordingly delves briefly into the relevant legislation, governance, and accountability provisions for the four pillar agencies, trying to determine what gaps exist and what steps might be taken to effect positive changes.

4.3.1 Agencies' Mandates and Structures

SSHRC and NSERC came into existence together in 1978, and their legislative provisions have been twinned ever since.[13] They currently share an internal audit committee to examine risks and risk mitigation. The 1985 governing legislation in force for both agencies was little changed from the original Acts, and amendments have been minimal. The NSERC and SSHRC Acts make the president a member of the governing council but do not mandate her or him to be chair. Indeed, there is no mention of a governing council chair. A "vice chair" is to be elected by members of the governing council and in practice leads the meetings. A particular quirk in the legislation is that in the event of the departure of the president, the volunteer vice chair assumes her or his duties. On plain reading, these Acts give the presidents substantial authority, and the governing councils serve largely an advisory function.

Mitchell's 2006 governance review of NSERC and SSHRC recommended not only enhanced coordination mechanisms between them and with other agencies such as CFI, but also the following steps:

- Give the two councils a clearer role as governing boards;
- Clarify the accountability of the Presidents;
- Clarify the relationship between the government (in the person of the Minister and his/her department) and the two organizations.[14]

Both agencies tried to improve governance in response, but the simple fact is that the legislation itself constrains the authority of the governing councils to govern.

Meanwhile, for strategic direction, a rather elaborate bureaucratic process exists under PCO authority to create performance agreements for heads of agencies such as granting council presidents. Individual objectives are determined at the beginning of the performance cycle and arise from various sources including the relevant minister or whole-of-government guidance applicable to the agency. Ministers are sometimes encouraged to send mandate letters directly to the council presidents or vice chairs, but this is done inconsistently. It appears that the evaluation process itself is focused primarily on rendering a decision about pay increments and "pay at risk" awards, with forms completed by the president, and ratings rendered by a committee of deputy ministers. The views of the relevant governing council and minister are sought, but considerable authority is vested in senior public servants, most of whom may have little understanding of the issues at hand. A package of forms is then sent to PCO, where a final decision on performance ratings is made at the highest levels of the Government of Canada.

In contrast to this cumbersome process, most for-profit and non-profit corporate boards would say that their most important job is to hire, advise/coach, evaluate, compensate, and, as necessary, terminate the president or CEO. Succession planning would be a related high priority.

The Panel appreciates that some may argue that the system is awkward but workable. However, in our view, the challenges at CIHR over the course of the past three years, and the particularly unhappy events of recent months, all suggest that these arrangements need an overhaul.

CFI, in contrast, has a governing structure more typical of a non-profit corporation. It was created through the Budget Implementation Act of 1997[15] with a governance scheme designed to put it at "arm's length" for fiscal management reasons that no longer apply. The board of directors is mandated simply and generally: "There shall be a board of directors of the foundation which shall supervise the management of the business and affairs of the foundation and subject to the bylaws of the foundation, exercise all of its powers."[16] The board meets three or four times a year and has clear authority to recruit, evaluate, and terminate the president. Thirteen people serve on the board with six, including the chair, appointed by the government and the remainder appointed by a self-renewing body known as the Foundation Members. Members, like shareholders, receive audited financial statements, appoint external auditors, and meet once a year to approve the annual report.

Panel members admire the continuing success of CFI, along with the quality of its leadership, directors, and members. We note that it has been a well-run agency that has largely depoliticized very large capital grants that sometimes become the subject of intense political jockeying in other jurisdictions. However, writing multi-million dollar cheques to institutions is generally less contentious than turning down thousands of grant applications from individual professors. Those key differences in mandate make the generalizability of these governance arrangements uncertain. Indeed, they will almost certainly need to be modified in some way if CFI switches to A-base funding as we recommend in Chapter 6. Thus, while our concerns about governance are limited in the case of CFI, its governance is also likely to need review if our recommendations are followed.

4.3.2 Membership of Governing Councils

CFI's mode of selecting directors makes for an interesting contrast with the membership processes of the three granting councils. The Panel can find no obvious template to explain the membership of their governing councils. All council members serving on SSHRC, NSERC, and CIHR are Governor-in-Council appointees. Their appointments are reviewed by PCO, and receive at least cursory scrutiny by the PMO. However, it appears that the presidents in all three cases have a pivotal role in advancing names for appointment to council. In addition, the numbers of frontline researchers on these councils vary, and mechanisms to solicit the views of diverse constituencies within the research community, not least early career researchers and trainees, are inconsistent.

As noted earlier, these governance arrangements are all embodied in Acts of Parliament. Thus, there are serious limitations to the measures that the granting councils themselves can take to remedy the situation in the absence of an Act of Parliament. Moreover, on the matter of legislation, a degree of similarity across NSERC, SSHRC, and the Medical Research Council was lost in 2000 when the CIHR Act was passed.

Both the SSHRC and NSERC Acts, for example, are and have remained skeletal. NSERC's functions are set out below:[17]

(a) promote and assist research in the natural sciences and engineering, other than the health sciences; and

(b) advise the Minister in respect of such matters relating to such research as the Minister may refer to the Council for its consideration.

SSHRC's functions are exactly parallel:[18]

(a) promote and assist research and scholarship in the social sciences and humanities; and

(b) advise the Minister in respect of such matters relating to such research as the Minister may refer to the Council for its consideration.

The CIHR Act[19] speaks to a different governance model, including its legislative micromanagement in specifying how the component Institutes should function. Most pertinent here, however, are the sections of the CIHR Act that describe CIHR's objectives, which are more numerous and wider in scope than the objectives of the other agencies, as seen in Exhibit 4.6. Furthermore, the expectation is that CIHR will be able to meet all of these objectives with a budget similar to that of NSERC. We return to the question of agency mandates and funding in Chapter 5.

4.3.3 Legislative Review for the Four Agencies

There is no doubt that the granting councils have made efforts to address limitations in their governance practices and mechanisms. SSHRC's submission to the Panel reported that it regularly assesses the effectiveness of its governance, using surveys and periodic international peer review. Its major governance review in 2008 led to the clear separation of the role of president and CEO from that of the chair of the governing council, and a decision to pursue a 50-50 balance between academic and non-academic members. To improve the acquisition of frontline perspectives, SSHRC initiated a Programs and Quality Committee to help ensure that the agency's suite of programs and policies was meeting objectives. For its part, NSERC conducts a self-evaluation every two to three years to assess its governance. Among its strong practices is the advice received by its governing council and the president from two standing committees with strong researcher representation—one on discovery research, and the other on research partnerships. Finally, CIHR has commissioned international reviews every five years as mandated by its legislation, with the 2006 review in particular making a number of recommendations on governance and management.

> The federal funding ecosystem has become too siloed. There are too many different agencies with narrow mandates, different funding structures and procedures and sometimes conflicting leadership visions.
>
> – Ontario Institute for Cancer Research

Exhibit 4.6: Objectives of CIHR as Set Out in Legislation (CIHR Act, 2000)

The objective of the CIHR is to excel, according to internationally accepted standards of scientific excellence, in the creation of new knowledge and its translation into improved health for Canadians, more effective health services and products and a strengthened Canadian health care system, by

(a) exercising leadership within the Canadian research community and fostering collaboration with the provinces and with individuals and organizations in or outside Canada that have an interest in health or health research;

(b) creating a robust health research environment in Canada, based on internationally accepted standards of scientific excellence and a peer review process, that will attract, develop and keep excellent researchers and provide them with the opportunity to contribute to the improvement of people's health in Canada and the world;

(c) forging an integrated health research agenda across disciplines, sectors and regions that reflects the emerging health needs of Canadians and the evolution of the health system and supports health policy decision-making;

(d) encouraging interdisciplinary, integrative health research through the creation of Health Research Institutes that

(i) together pertain to all aspects of health,

(ii) include bio-medical research, clinical research, research respecting health systems, health services, the health of populations, societal and cultural dimensions of health and environmental influences on health, and other research as required,

(iii) work in collaboration with the provinces to advance health research and to promote the dissemination and application of new research knowledge to improve health and health services, and

(iv) engage voluntary organizations, the private sector and others, in or outside Canada, with complementary research interests;

(e) promoting, assisting and undertaking research that meets the highest international scientific standards of excellence and ethics and that pertains to all aspects of health, including bio-medical research, clinical research and research respecting health systems, health services, the health of populations, societal and cultural dimensions of health and environmental influences on health;

(f) addressing emerging health opportunities, threats and challenges and accelerating the discovery of cures and treatments and improvements to health care, prevention and wellness strategies;

(g) fostering the discussion of ethical issues and the application of ethical principles to health research;

(h) promoting the dissemination of knowledge and the application of health research to improve the health of Canadians;

(i) encouraging innovation, facilitating the commercialization of health research in Canada and promoting economic development through health research in Canada;

(j) building the capacity of the Canadian health research community through the development of researchers and the provision of sustained support for scientific careers in health research;

(k) pursuing opportunities and providing support for the participation of Canadian scientists in international collaboration and partnerships in health research; and

(l) ensuring transparency and accountability to Canadians for the investment of the Government of Canada in health research.

The Panel remains concerned, however, that the self-assessments undertaken by the granting councils are all constrained by existing legislation, and that the major differences in legislation and ambiguities about accountabilities represent gaps that may only be remediated by legislative change.

Recommendation 4.11

The Government of Canada should undertake a comprehensive review to modernize and, where possible, harmonize the legislation for the four agencies that support extramural research. The review would clarify accountabilities and selection processes for agency governing bodies and presidents, promote good governance and exemplary peer review practices, and give priority to inter-agency collaboration and coordination.

One of the key goals of this review would be to reframe legislation with an enabling orientation that would allow for updating and improvements to governance without the need for a return to Parliament. Among other goals, the review should:

- address governing council/board composition, with appropriate attention to the balance of expertise and need to reflect the diversity of Canada and the research community;
- explicitly mandate that the agencies have mechanisms that yield and publicize unbiased and up-to-date evidence on the views of the accessibility and effectiveness of their programs from the perspective of researchers at distinct career stages (see also Chapter 5); and
- examine specifically what changes are appropriate to CFI's governance if and when that agency receives standard A-base funding rather than intermittent allocations of one-time funding.

It would be prudent for the establishment of the Four Agency Coordinating Board to precede the legislative review described above. This would prevent a focus on reforms to agency-specific governance from impeding progress on the more urgent issues of cross-agency collaboration and harmonization.

4.4 Moving to the Front Lines

The Panel appreciates that this focus on issues of oversight, governance, and accountability may seem irrelevant to some of our colleagues on the front lines of the research enterprise. As we began our deliberations, reviewed hundreds of submissions, and met with scores of researchers, focusing on such matters sometimes felt like a digression. However, what became increasingly clear to us were three hard realities that we can summarize as follows.

First, it is unlikely that there will ever be enough funding to support all researchers and institutions to the extent they would prefer. Nor will the funds ever be perfectly allocated: reasonable people will disagree unreasonably about where the funds flow. However, by creating an oversight body such as NACRI to provide advice to the Government of Canada and help set priorities, the chances of bad decision-making are attenuated.

Second, while the four agencies have all done yeoman service over the course of decades to support extramural research in Canada, issues of harmonization, simplification, and coordination were very much at the forefront of what we heard from the research community. Some commendable progress has been made, but some ground appears to have been lost as well. These goals cannot be achieved without a shift in culture, accountability, and governance. The Panel is keenly aware of the potential for doing more harm than good with major structural changes. Thus, we have recommended a graded approach to making those shifts, strengthening agency-level governance, while also putting in place a formal coordinating body (the Four Agency Coordinating Board) chaired by Canada's new CSA.

In particular, we have envisaged NACRI providing oversight and advice to the Government of Canada and its relevant ministers in close collaboration with the new CSA. We have also envisaged that, in the first instance, the new Four Agency Coordinating Board would work collegially and that the governing councils and CFI board would review and confirm recommendations arising from it. We have specified that it falls to ministers, deputies, and others to direct the four agencies to make improvements as recommended here and in Chapters 5, 6, and 7, with the Coordinating Board facilitating execution. If those directions are given, and if progress by the four governing bodies is inadequate, we believe that the membership of the Coordinating Board should be revised. It should then be given authority to direct the four agencies to take actions on specific timelines.

Third and finally, this approach puts a major onus on the four agencies to collaborate in effecting reforms. We are optimistic that this can be achieved with facilitation by the CSA, oversight by NACRI, and effective close consultation with the research community. In particular, most of the recommendations that follow in Chapter 5 address cross-cutting issues whose implementation depends on coordinated action driven by the decisions of the Coordinating Board. We now turn to those issues.

ENDNOTES

1 Senate Special Committee on Science Policy. A Science Policy for Canada, Volume 1 – A Critical Review: Past and Present. Ottawa: Queen's Printer; 1970; Senate Special Committee on Science Policy. A Science Policy for Canada, Volume 2 – Targets and Strategies for the Seventies. Ottawa: Queen's Printer; 1972; Senate Special Committee on Science Policy. A Science Policy for Canada, Volume 3 – A Government Organization for the Seventies. Ottawa: Queen's Printer; 1973.

2 Senate Special Committee on Science Policy. A Science Policy for Canada, Volume 4 – Progress and Unfinished Business. Ottawa: Queen's Printer; 1977.

3 Quirion, R., Carty, A., Dufour, P., Jabr, R. Reflections on Science Advisory Systems in Canada. *Palgrave Communications*, 2016; 2, article number 16048. http://dx.doi.org/10.1057/palcomms.2016.48

4 Ibid.

5 Ibid.

6 Science, Technology and Innovation Council Mandate [Internet]. Ottawa: STIC; 2015. Available from: http://www.stic-csti.ca/eic/site/stic-csti.nsf/eng/h_00005.html

7 Quirion, R., Carty, A., Dufour, P., Jabr, R. Reflections on Science Advisory Systems in Canada. *Palgrave Communications*, 2016; 2, article number 16048. http://dx.doi.org/10.1057/palcomms.2016.48

8 Major Science Initiatives Fund [Internet]. Ottawa: Canada Foundation for Innovation; n.d. Available from: https://www.innovation.ca/awards/major-science-initiatives-fund

9 New NWO: funding instruments [Internet]. Utrecht (The Netherlands): NWO; 2016. Available from: https://www.fom.nl/en/news/2016/06/28/new-nwo-funding-instruments/

10 Nurse, P. Ensuring a Successful UK Research Endeavour: A Review of the UK Research Councils. London (England): Department for Business, Innovation & Skills; 2015. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/478125/BIS-15-625-ensuring-a-successful-UK-research-endeavour.pdf

11 Mitchell, J.R. A Review of NSERC and SSHRC. Report prepared for Industry Canada, 2006.

12 Ibid.

13 *Social Sciences and Humanities Research Council Act*, R.S.C. 1985, c. S-12. Available from: http://laws.justice.gc.ca/eng/acts/S-12/; *Natural Sciences and Engineering Research Council Act*, R.S.C. 1985, c. N-21. Available from: http://laws.justice.gc.ca/eng/acts/N-21/

14 Mitchell, J.R. A Review of NSERC and SSHRC. Report prepared for Industry Canada, 2006.

15 *Budget Implementation Act, 1997*, S.C. 1997, c. 26. Available from: http://laws.justice.gc.ca/eng/acts/B-9.81/

16 Ibid.

17 *Natural Sciences and Engineering Research Council Act*, R.S.C. 1985, c. N-21. Available from: http://laws.justice.gc.ca/eng/acts/N-21/

18 *Social Sciences and Humanities Research Council Act*, R.S.C. 1985, c. S-12. Available from: http://laws.justice.gc.ca/eng/acts/S-12/

19 *Canadian Institutes of Health Research Act*, S.C. 2000, c. 6. Available from: http://laws.justice.gc.ca/eng/acts/C-18.1/

CHAPTER 5

ALLOCATION AND ADJUDICATION: SHARED CHALLENGES AND RECOMMENDED SOLUTIONS

Chapter 4 addressed oversight and governance, and recommended mechanisms for improved coordination of the four pillar agencies: CFI, CIHR, NSERC, and SSHRC. In this chapter we turn our attention to the high-level principles, policies, and procedures that shape the research environment. Our recommendations aim to strengthen the framework that determines where and how federal funding is distributed, with the goal of creating and sustaining a research ecosystem that delivers excellence. Our findings and general directions for change have been informed by strong input on these issues in our consultations. To arrive at specific recommendations, we weighed our guiding principles against those inputs as well as quantitative analyses undertaken by the secretariat and information helpfully shared by the four agencies.

We begin by examining general issues of resource allocation and adjudication processes. The opening question is conceptually challenging and politically sensitive: How do the granting council mandates relate to their funding allocations? We also provide observations on the strengths and challenges stemming from the variable breadth and scope of these mandates.

We turn next to the resource allocation within and by the granting councils themselves. This analysis follows from the treatment of questions about program architecture raised in Chapter 4 where we saw that the approaches and outcomes varied significantly by council. Decisions made within the councils fundamentally shift the funds available for different purposes, leading in turn to dramatic movement in whom and what gets funded and at what levels. Every dollar misallocated is a lost opportunity.

Similar to our recommendation for a lifecycle approach for MSIs and large-scale research facilities, we are advocating a lifecycle approach that considers the prospects of researchers at different stages of their careers, from graduate school through to the final years before retirement from the front lines of science and scholarship.

Within the programmatic envelopes of the four agencies, further allocations are made on the basis of peer review. If the review process does not adjudicate primarily on the merits of the proposal and systemic biases are introduced, then both excellence and equity are compromised. Thus, the Panel has considered how peer review is working currently and how it might be improved.

The third section carries the title “Achieving Potential”, although it could just as easily have been called “People and Fairness”. A thriving research enterprise effectively and efficiently mobilizes the talents, skills, and potential of those who are trained to contribute to it. Equity and diversity in research funding is therefore not only about the core principle of fairness to participants in the research enterprise. It is also integral to national aspirations for sustainable excellence in science and scholarship. This section addresses mounting concerns that the research funding system does not reflect the diversity of Canada’s communities, and that the allocation of funds is inequitable in some respects, even as it fails to take full advantage of our nation's talent pool. Gender gaps are a particular concern, as is the plight of early career researchers (ECRs). Given demographic trends, enhancing the opportunities for ECRs will also improve the prospects for women and other underrepresented groups, including racialized groups.[i] That said, the challenges confronting Canada's 1.5 million Indigenous people are particularly severe and will receive specific attention below.

All the recommendations in this chapter require coordinated attention across the four agencies. The responsibility for ensuring the agencies respond to them accordingly falls to the high-level Four Agency Coordinating Board recommended in Chapter 4. To repeat: That body must be empowered by the relevant ministers and then, under the chairmanship of the new CSA and with continuing oversight by NACRI, must design and effect a myriad of reforms in close collaboration with the four agencies and the research communities.

Our fourth section has a different vector. It relates to entities operating outside the direct jurisdiction of the four agencies. These "third parties" have diverse governance configurations and accountabilities, and are governed by term-limited contribution agreements with ISED. The current organizations have played useful roles in addressing gaps in the research funding ecosystem and some have effectively leveraged funding from other sources. The downside risk is that these arrangements can create duplication of funding, allow select groups of researchers to sidestep the intensity of peer review competitions, and facilitate unchecked mission drift as third-party partner organizations shift their mandates to justify their continuation.

Chapter 1 set out our basic approach: It made no sense for us to undertake a detailed review of each of these diverse agreements and entities. Our concern instead was to arrive at a depoliticized mechanism for ongoing review not only of the existing entities, but also of any proposals for new contribution agreements. Chapter 4 made the case that a new body, NACRI—with the CSA as Vice Chair—should have the mandate to oversee the reviews of proposals for new bodies and raised the possibility that it might be involved in examining renewals of existing entities. Here, we focus specifically on this last point, highlighting three such entities as examples. This section concludes with the Panel's brief reflections on the ongoing issue of the extent and applicability of requirements for matching funds to support federal research programs.

5.1 The Big Picture: Scope and Budgets of Granting Councils

5.1.1 Granting Council Legislative Mandates

The disciplinary division of Canada's research landscape is intuitively obvious from the titles of the granting councils. As outlined in Chapter 4, NSERC and SSHRC came into existence in 1978 with parallel legislation that assigned two concise functions: (i) to promote and assist research and scholarship in the natural sciences and engineering (other than health sciences), and the social sciences and humanities, respectively; and (ii) to advise the minister on matters related to the research areas they support. In contrast, the CIHR Act of 2000 sets out a highly detailed and prescriptive objective for the organization that includes 12 sub-points and a preamble of over 400 words. Exhibit 4.6 showed the preamble, with a mandate that ranges from generating and translating knowledge to specific responsibilities for improving the health of Canadians, and the effectiveness of Canada's healthcare system.

The NSERC and SSHRC Acts afford these organizations significant latitude to define their mandates and refine them over time as appropriate to a shifting research landscape. NSERC's vision is to help "make Canada a country of discoverers and innovators for the benefit of all Canadians", achieved through

i The term "visible minorities" continues to be used in various statutes and codes. However, current practice has moved to use of the term "racialized groups". See, for example, http://www.ohrc.on.ca/en/racial-discrimination-race-and-racism-fact-sheet.

"investments in people, discovery and innovation to increase Canada's scientific and technological capabilities for the benefit of all Canadians".[1] SSHRC's mission statement speaks of "focusing on developing talent, generating insights and forging connections across campuses and communities".[2] The level of detail in CIHR's legislation in contrast leaves little room for interpretation. Perhaps in consequence, the mission that CIHR sets out is simply a copy-paste from the CIHR Act: "to excel, according to internationally accepted standards of scientific excellence, in the creation of new knowledge and its translation into improved health for Canadians, more effective health services and products and a strengthened Canadian health care system."[3]

In 2015 the federal Advisory Panel on Healthcare Innovation compared CIHR's mandate with those of sister organizations abroad, and cautioned that CIHR's mandate was unduly broad relative to its resources.[4] That panel advanced an argument for consolidating existing small healthcare agencies in Ottawa into a healthcare innovation agency. With new funding, the agency could take on responsibility for much of what CIHR now funds through its Strategy for Patient-Oriented Research (SPOR), its partnership in applied health research involving Canada's provinces and territories and their healthcare systems. This would enable CIHR to focus its resources more narrowly on independent basic and applied research across disciplines related to human health. No action has been taken on those recommendations to date.

Comparisons in funding remain germane. CIHR has a broader mandate than the U.S. National Institutes of Health (NIH). Moreover, the U.S. funds a significant fraction of applied research in healthcare innovation and healthcare quality through two other federal agencies with a combined operating budget of close to US$1.50 billion per year. In 2016-17 the NIH budget was US$30.62 billion, while the CIHR budget was C$1.03 billion, including its share of spending contained in the relevant tri-council programs. The thirty-fold difference contrasts with a nine-fold difference in population. Adjustments for GDP per capita or purchasing power have only a minor influence on such large discrepancies.

The Panel also observes that the major per capita funding differential in favour of the NIH has not spared that agency from challenges similar to those faced by CIHR. The description by a small group of leading U.S. bio-scientists in a landmark 2014 paper in the *Proceedings of the National Academy of Sciences* encapsulates much of what the Panel heard about CIHR and the health research scene in this country:

> Now that the percentage of NIH grant applications that can be funded has fallen from around 30% into the low teens, biomedical scientists are spending far too much of their time writing and revising grant applications and far too little thinking about science and conducting experiments. The low success rates have induced conservative, short-term thinking in applicants, reviewers, and funders. … Young investigators are discouraged from departing too far from their postdoctoral work, when they should instead be posing new questions and inventing new approaches. Seasoned investigators are inclined to stick to their tried-and-true formulas for success rather than explore new fields. One manifestation of this shift to short-term thinking is the inflated value that is now accorded to studies that claim a close link to medical practice.[5]

For CIHR, the sentiments described in the last sentence were reinforced by the Harper government. In every budget from 2011 to 2015 inclusive, all new funding for the agency was earmarked for SPOR.

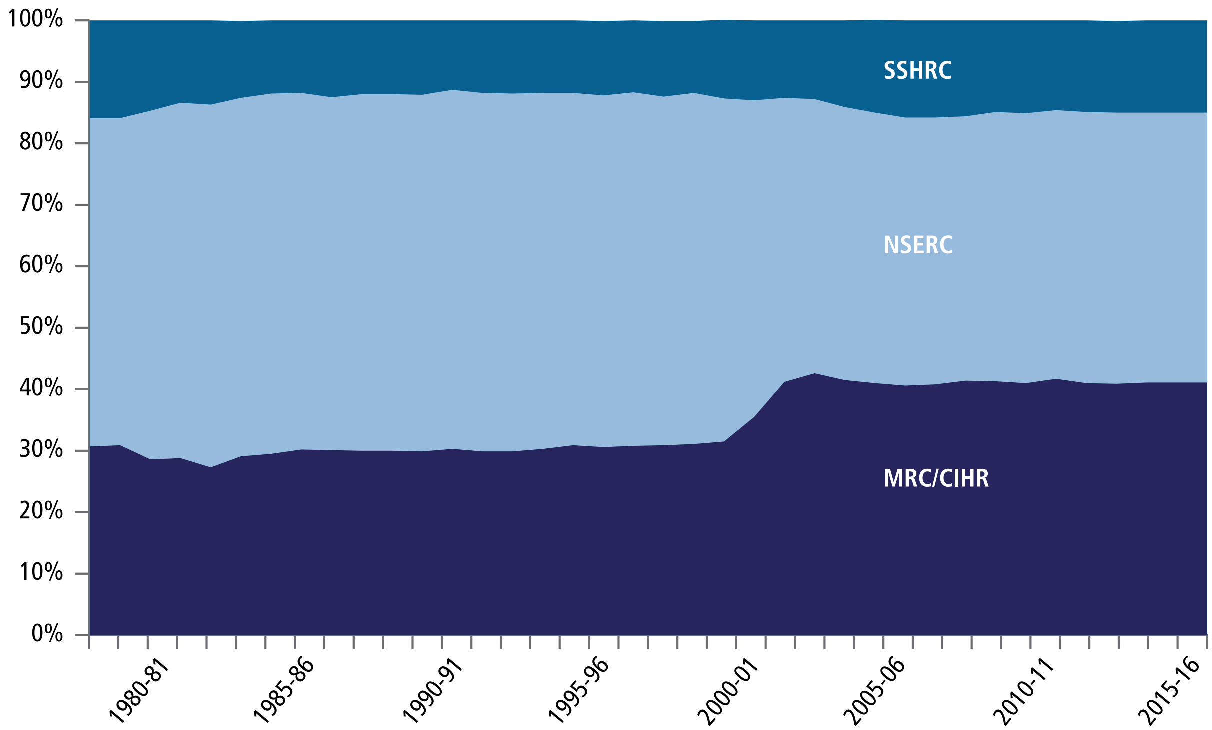
5.1.2 Allocation of Funding to Granting Councils

The relation of CIHR's expansive mandate to its constrained budget provides a segue to the broader issue of allocations to each granting council. The Panel has emphasized that the overall level of funding to the granting councils must be increased to maintain Canada's competitiveness on the international stage and to support excellent research that will address the needs and priorities of Canadian society. What is more challenging to determine is how federal research investments might best be distributed among the granting councils.

The trend lines in proportionate budget allocations since 1978-79 are shown in Exhibit 5.1. The lower share of funding for SSHRC has been more or less stable. That community of scholars remains the largest among the three councils. The usual and reasonable explanation for these differences in funding is differences in the costs of research. Comfort is also sometimes found in the fact that, broadly speaking, the social sciences and humanities in Canada have fared as well as other disciplines in scholarly outputs and global reputation. Furthermore, the council itself has not shown signs of the funding pressures, such as the precipitous decline in success rates, that have become an acute challenge for CIHR. However, some argue that this reflects long-term disengagement on the part of SSHRC scholars and scientists who are aware of the limited funds available.

The graph clearly shows the sharp uptick in funding after MRC gave way to CIHR in 2000. The more expansive mandate of CIHR was cited as the reason that its funding increased rapidly over the space of a few years to bring it closer to par with NSERC, where it remains.

Exhibit 5.1: Total Granting Council Expenditures by Council



Note: Our analysis of research funding trends in this figure excludes the Research Support Fund (RSF)—previously the Indirect Costs Program (ICP)—since it does not support researchers directly. Rather, it provides funding directly to institutions to help defray the costs associated with managing research funded by the three granting councils (e.g., electricity and administrative support).

Source: ISED.

The Panel was advised that, for more than a decade, there has been an implicit 40-40-20 rule in the allocation of new funding across the councils. In keeping with this rule-of-thumb, approximately 20 per cent of CRCs were allocated to SSHRC disciplines at the inception of the program in 2000. However, the application of this rule has been complicated by the growth in other tri-council programs, and the allocation of budgetary responsibility for those programs to specific councils. A large confounder is the fact that SSHRC manages the Research Support Fund (RSF) with approximately $369 million per year flowing to institutions rather than to individual researchers. Excluding the RSF and allocating spending to the relevant councils, it appears that the actual funding level for SSHRC has remained steady since its creation, not at 20 per cent but at approximately 15 per cent of the relevant funding allocated to the three granting councils. Absent any change in priorities, these proportions are likely to fall further in the years ahead.

Exhibit 5.2 breaks down tri-council program spending by council. It confirms that no CERCs have been awarded to scholars in SSHRC fields, and only 4 per cent of CFREF spending has flowed through SSHRC. NCE participation, contrary to popular beliefs, tracks closely to the current SSHRC share of total budgets, but is again below the putative target of 20 per cent and lower than would be expected given the size of the SSHRC research community.

Exhibit 5.2: Tri-council Program Expenditures by Granting Council, 2015-16

Program	CIHR		NSERC		SSHRC		Total
CRC	$86,658,332	35.5%	$108,982,861	44.6%	$48,528,538	19.9%	$244,169,731
CERC	$9,800,000	28.1%	$25,050,000	71.9%	$0	0.0%	$34,850,000
CFREF	$16,246,614	32.9%	$31,234,943	63.2%	$1,912,756	3.9%	$49,394,313
Vanier	$8,284,309	33.3%	$8,286,944	33.3%	$8,341,667	33.5%	$24,912,920
Banting	$3,786,418	38.8%	$2,970,528	30.5%	$2,995,420	30.7%	$9,752,366
CGS	$21,034,369	16.0%	$42,060,918	32.0%	$68,493,297	52.1%	$131,588,584
CCI	$24,408	0.1%	$45,950,592	99.9%	$25,000	0.1%	$46,000,000
NCE Suite	$36,504,697	35.5%	$49,272,287	47.9%	$17,049,789	16.6%	$102,826,773
Total	**$182,339,147**	**28.3%**	**$313,809,073**	**48.8%**	**$147,346,467**	**22.9%**	**$643,494,687**

Source: Calculations by the secretariat based on detailed program expenditures provided by the granting councils.

The minimal allocation of funds to SSHRC scientists and scholars from the CFREF and CERC programs reflects the application of the STIC priorities in determining eligibility. Shelving those priorities for both programs could be done quickly and would open the door to wider disciplinary participation. However, many of the CERCs have already been allocated. Two full rounds of CFREF are complete, and the investments in those projects are still rising. Furthermore, many of the current CERCs will hold their Chairs for some years to come.

One further lesson of this table is that CIHR has lost ground relative to NSERC in tri-council programming. On the other hand, a substantial amount of the funding to NSERC has arrived in priority-driven or earmarked programming. It is hard to escape an aggregate impression that these allocations lack a logic model, and that the biggest losers have been frontline researchers across all disciplines who wish to pursue an independent line of science or inquiry, and the students and trainees who elect to work with them.

In addition to the concerns we heard about the SSHRC budget, we learned about CIHR's challenges with low success rates and the rise in the average age of first-time principal investigators receiving CIHR operating grants. The flat-lining of the average value of NSERC's Discovery Grants was also drawn to our attention repeatedly by stakeholders, and is discussed below. These findings spoke to a wider shortfall in funding for independent research and open competitions, examined in detail in Chapter 6.

The Panel also examined the proportion of spending on graduate and training awards within each council in an effort to understand these allocation issues more fully. SSHRC was a significant outlier. SSHRC disciplines account for approximately 21,000 full-time doctoral students across Canada and 48,000 full-time master's students.[6] A substantial portion of the council's budget accordingly goes to doctoral students awards along with postdoctoral fellowship supports, amounting to $117.6 million in 2016-17. However, this allocation means that SSHRC operating funds for investigator-led research are further constrained: for 2016-17, the budget for the Insight competitions (SSHRC's knowledge generation program analogous to NSERC's Discovery Grant program) was $142.7 million for some 24,000 faculty members—almost half of all full-time faculty at Canadian universities. A further anomaly is that despite a much larger number of graduate students, SSHRC gets the same number of Vanier CGS awards as the other two councils, even as it receives just over half of the regular CGS awards.

Not unexpectedly in light of these findings, the Panel received thoughtful submissions arguing that the Government of Canada was underfunding SSHRC. The arguments made for these disciplines were lucid, and cited, *inter alia*, the cognitive competencies required by the next generation, the relevance of business education and economics, growth in the Canadian services sector, the importance of enriching culture and society, the pressing need for cross-cultural understanding in a globalized world, the importance of evidence-based public policy, and the fraying of the social fabric abroad and even here in our remarkably civil and pluralistic society. Different lines of argument focused less on relevance and more on need, i.e., emerging trends in SSH research that are driving up associated expenses, and the relatively greater dependence of this community of researchers on federal council funding, given its difficulty attracting funds from non-federal sources.

> Underfunding for SSHRC is particularly damaging to Canadian research because it represents the predominant source of funding for HSS [humanities and social sciences] researchers. In the natural and health sciences, for example, there is significant provincial and even non-governmental research funding available in addition to that provided by the federal granting councils. Meanwhile, the costs of HSS research continue to increase as research challenges and methods evolve. … The old presumption that research in the HSS disciplines 'doesn't cost much' is becoming increasingly inaccurate. Some big data analysis in political science or multi-party digital humanities programs of research, for example, cost every bit as much as some work in engineering or public health.
>
> – Federation for the Humanities and Social Sciences

The Panel further considered whether the quest for funding in a constrained environment had led researchers to migrate between granting councils. The movement that seemed most likely was from CIHR to NSERC. Our hypothesis in this regard reflected budgetary pressures on CIHR, the growth in size of the community of bio-scientists and biotechnologists, and the fact that researchers in these latter categories can readily present their grants as corresponding either to NSERC's life sciences mandate or CIHR's human health mandate. Funding of these disciplines within NSERC has grown since 2006-07 by $60 million, as shown in Exhibit 5.3. Their share of the overall NSERC budget has changed only modestly. We remain uncertain, however, as to what budgetary denominator is most appropriate for this calculation, and what impact, if any, this growth is having on funding for other NSERC disciplines. It is exactly these types of issues that struck us as requiring ongoing and closer scrutiny.

Recommendation and Elaboration

The Panel has noted a number of ambiguities about the mandates and funding of the three councils arising from the foregoing brief review. There was particular concern that, despite the supposed application of a 40-40-20 algorithm for adding new base funding to the councils, SSHRC's share of the tri-council budget envelope has remained at approximately 15 per cent for decades. With the growth in CFREF already set to continue for several years, and potential for more CERCs to be awarded outside the SSH disciplines in the years ahead, these discrepancies would likely grow even if the eligibility criteria for these programs widen. Our recommendations about NCEs in Chapter 6 may enable greater participation by SSHRC scholars in these networks, but the allocations are modest compared with those for the CFREF program.

Recommendation 5.1

NACRI should be asked to review the current allocation of funding across the granting councils. It should recommend changes that would allow the Government of Canada to maximize the ability of researchers across disciplines to carry out world-leading research. Particular attention should be paid to evidence that ongoing program changes have adversely affected the funding opportunities for scholars in the social sciences and humanities.

Exhibit 5.3: NSERC Expenditures for Life Sciences, 2005-06 to 2014-15 ($ Millions)

	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15
Neurosciences and Psychology	23.5	25.0	25.1	26.2	30.7	31.2	33.4	34.6	35.6	35.3
Biomedical Engineering and Medical Technologies	37.6	38.3	39.6	42.0	47.8	47.0	49.3	50.1	50.2	47.3
Regenerative Medicine	3.2	4.1	4.0	4.2	4.3	6.3	5.9	4.3	5.2	3.5
Health – Northern Communities	0.2	0.2	0.0	0.0	0.0	0.2	0.2	0.2	0.0	0.0
Human Diseases and Pharmaceuticals (incl. Food and Drug Safety)	33.8	37.6	59.0	44.6	56.3	54.3	47.5	55.4	51.7	56.9
Health Sciences[a]	24.9	26.8	26.1	26.5	29.8	29.7	28.9	29.4	27.6	29.5
Life Sciences[a]	20.9	23.0	26.6	25.4	24.6	27.0	24.2	26.9	27.7	31.0
Total Expenditures, Life Sciences	144.1	155.0	180.4	169.0	193.5	195.7	189.5	200.9	198.1	203.6
NSERC Total Expenditures	821.2	855.2	969.6	981.9	1004.2	1027.2	1036.2	1022.7	1018.9	1038.1
Life Sciences as % of NSERC Total Expenditures	17.5%	18.1%	18.6%	17.2%	19.3%	19.1%	18.3%	19.6%	19.4%	19.6%

[a] Not elsewhere classified.

Source: Calculations by the secretariat based on data provided by NSERC. Totals are roughly consistent with those published on NSERC's Dashboard (http://www.nserc-crsng.gc.ca/db-tb/index-eng.asp?province=0&category=5).

A key part of this review would be deliberations on the mandates of the councils in light of the concerns raised above. Such a review could inform any reconsideration of the legislation governing the three councils, as recommended in Chapter 4 (Recommendation 4.11). The Panel's overall view is that frontline scholars and scientists across all three councils face a significant shortfall in opportunities to pursue independent research, and operating budgets for all three councils should be increased. It would be premature for the Panel to pre-specify a particular ratio of funding across the three councils. However, we believe our later recommendations for major growth in operating grants and other supports (see Chapters 6 and 7) provide an important opportunity for the relevant ministers to consider whether, in the light of the foregoing, the support for SSHRC should be enhanced in advance of any analysis that NACRI might be asked to undertake.

5.2 Programmatic Allocation and Adjudication

5.2.1 Allocation of Funding to Researchers

Background and Analysis

For any given amount of money available, the allocation of funding to researchers by the granting councils must reflect a balance across numbers of applicants, success rates, and average levels of funding per grant. Different balances can be struck and, as we saw earlier in Exhibit 4.5, the funding rates and levels indeed vary significantly across the flagship open competitions convened by the granting councils.

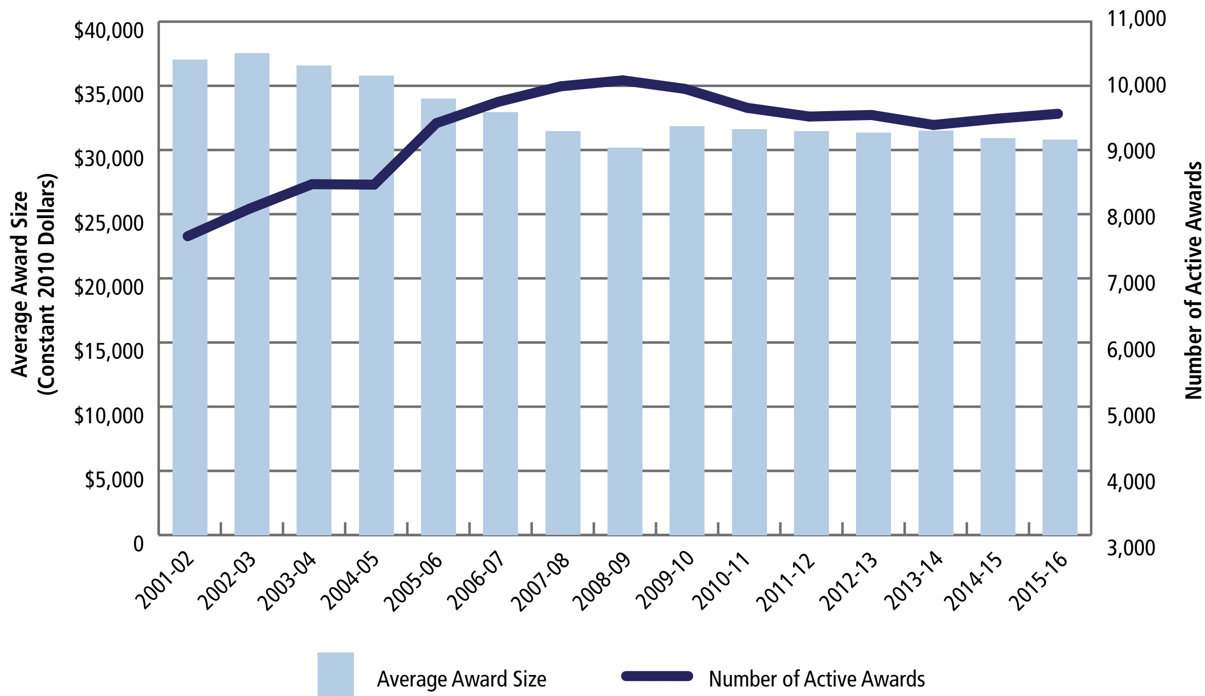
> My colleagues from Europe in particular seem to have lots more money that allows them to bring the latest technology to bear on research issues and that they can afford lots of students/post-docs. I can't compete with that if I have to rely on my basic science budget.
>
> – Active researcher, University of Waterloo

The NSERC Discovery Grant (DG) program has a long-standing tradition of awarding a large number of grants (around 2,000 per year), resulting in high success rates (60 to 70 per cent) but very low average grant values (less than $35,000 per year). The real dollar value of DGs has remained relatively unchanged for the past decade and is lower today than in the early 2000s (Exhibit 5.4). The Panel heard that many researchers are no longer able to support a graduate student or postdoctoral fellow from their grants. For its part, NSERC explicitly considers its DGs as "grants-in-aid" of research, and expects that researchers will find other sources of funding to pursue their full program of investigation. However, these grants are the principal source of funding for student and postdoctoral stipends for many areas of basic research where there is no immediate industry connection and therefore no ready opportunity in Canada for additional funding. Even in areas with possible connections to industry, this approach adds to the administrative burden of researchers and may restrict their ability to pursue diverse lines of inquiry if they are not of immediate interest to funding partners.

While the funding levels are low, the popularity of the DGs among researchers stems in part from their open architecture. A constrained project-based approach is deliberately eschewed. Researchers are free to shift focus so long as they have a credible research storyline and remain productive. The Panel observes that a similar model has been adopted by SSHRC with its Insight Grants. The new Foundation Grants at CIHR follow suit, albeit with a concentration of resources in a small number of grants and success rates at the opposite extreme from the DGs.

The very high success rates are also popular in the NSERC research community, and vociferous protests could be expected if the rates were to drop. This reflects the reality that a solo scientist/small team model is highly prevalent. Much reduced success rates would have adverse effects on laboratory continuity and on education and training of the next generation of researchers in NSERC disciplines.

Exhibit 5.4: NSERC Discovery Grants Program – Individual, 2001-02 to 2015-16



Source: Compilations by the secretariat based on estimates from NSERC, October, 2016.

The Panel supports high success rates for ECRs, but has mixed views on the DG approval rates that start and remain so high across the life cycle of NSERC researchers. These success rates are meaningfully higher than norms based on the Panel's understanding of statistics from open peer review competitions in several other nations. The obvious concern is that these success rates could lead to funding of a higher-than-usual proportion of lower-quality research and are certainly a factor in the unreasonably low per grant funding levels.[ii] A further concern is that the DG program not only reflects but also strongly reinforces a one-scientist-one-grant model, at a time when multi-investigator and multidisciplinary teams are becoming more important in many areas of science.

Several Panel members took the position that while DG funding levels in general were too low, it would be a suboptimal use of resources if all new funds provided to NSERC for open competitions were simply rolled out pro rata. A useful compromise seemed to be a blend of some general increases, a more clearly tiered allocation of DG funds based on merit to reinforce quality, and creation of a parallel track to support collaborative efforts. This would avoid unduly compromising the high core success rates that have effectively built capacity over many years.

CIHR grants awarded in open competitions (Foundation and Project Grants) are much larger (greater than $100,000 per year) than those of NSERC. CIHR grants list on average more than five investigators per grant, whereas the NSERC DGs typically support a single investigator. SSHRC equivalents (Insight Grants) are more variable albeit with a median of two. CIHR is also the only council to allow principal investigators (PIs) to hold multiple grants, but CIHR grants are fewer in number (typically 700 to 800 new awards per year), leading to much lower success rates (less than 15 per cent). Recent CIHR

ii The Panel was advised on occasion that the DG average grant size was misleading, and many successful investigators received much larger grants. This was mathematically unlikely, and examination of the distribution of grant values confirms limited high-end skew with a very thin and fairly short tail.

program reforms were in part meant to redress these low success rates. Results to date, particularly for the Foundation Grant program, unfortunately suggest an even greater concentration of funding among senior researchers. Among the arguments advanced in support of the CIHR model was that ECRs participate initially as co-investigators on team grants led by a senior PI. This does occur, as the average number of co-investigators indicates. However, the Panel was advised by ECRs that such practices limit their independent development and reduce their chances of obtaining permanent appointments at universities or hospital research institutes.

SSHRC falls somewhere between the other two councils, with slightly larger grants than NSERC and higher success rates than CIHR (see Exhibit 4.5). Due to constraints on its overall budget and the portion available for operating grants, it supports a much smaller portion of the relevant research community than do NSERC and CIHR. SSHRC has been successful in supporting its ECRs. Around 68 per cent of its Insight Development Grants went to this group in the most recent competition, but SSHRC is also facing declining overall success rates.

There is some evidence to suggest that 20 per cent is the minimum threshold of success needed for a competition to avoid turning into a lottery among the most meritorious proposals.[7] We also noted that success rates above 20 per cent but under 40 per cent are commonplace in international data, except in competitions targeting ECRs where a higher success rate is often an explicit goal. Low success rates lead to inefficiency for both researchers and research administrators because of the need for repeated resubmission of proposals. As noted elsewhere in this report, they create a bias against high-risk and multidisciplinary research in favour of traditional paradigms and "safe bets".

Low success rates also tend to disproportionately affect the ability of researchers from underrepresented groups and those early in their careers to become established, leading some to leave research altogether. The Panel here took note of growing evidence of imbalances in funding allocation across career stages, particularly in CIHR, and heard concerns about the rapidly rising age at which CIHR researchers receive their first competitive funding award as PIs. Several studies, not least a CCA report in 2012 entitled *Strengthening Canada's Research Capacity: The Gender Dimension*,[8] indicate that underrepresented groups, including women, Indigenous researchers, racialized groups, and people with disabilities are particularly vulnerable at these early stages. This consideration, examined further below, underscores the importance of reviewing the level of support across all career stages to ensure stability and predictability of funding while maintaining the degree of competition necessary to promote excellence.

Conversely, the DG experience led the Panel to ask whether there is some maximum success rate beyond which funds are not optimally allocated. While there is some evidence for minimum success rates as noted above, the Panel could find no ironclad evidence as to what maximum thresholds of success are required to avoid supporting research that may not represent a wise use of scarce resources. On the other hand, these contrasting situations and issues underscore the extent to which the three councils have diverged. Closer scrutiny is warranted.

The Panel perceives that implementation of a more rational strategy for allocating funds across career stages has been limited in part by a lack of comprehensive data due to the many sectors and players involved in research. In this respect, the Panel views Statistics Canada's University and College Academic Staff System (UCASS) survey as an important source that puts council-level data in a wider context. We commend the Government of Canada for reinstating this survey.

Recommendation and Elaboration

Based on evidence from Canadian and international sources,[9] we found that stable support for a larger number of researchers at moderate levels of funding results in greater overall productivity and high-quality impact compared with concentrated funding in a very small number of researchers or distribution of small amounts to a very large number of researchers. However, the right balance point is not easy to determine. A reasonably broad distribution of grant support helps ECRs develop their research programs, encourages greater risk-taking and novel research approaches (including more multidisciplinary research), and decreases barriers for underrepresented groups to succeed. An unreasonably broad distribution creates the "peanut butter problem": by spreading funds too thinly, it rewards mediocrity and handicaps excellent researchers by giving them unduly small grants.

Two things seem clear. First, this is a dynamic balance, one to be sustained by close attention and constant adjustment. Second, the Panel is concerned that the right balance point has not been found across the three councils, not only based on widely disparate success rates and funding levels, but also growing concerns about poor distribution of funds by career stages.

Recommendation 5.2

The Government of Canada should direct the new Four Agency Coordinating Board to develop and harmonize funding strategies across the agencies, using a lifecycle approach that balances the needs and prospects of researchers at different stages of their careers.

Integral to the development of such a strategy is improvement in information and collaboration.

- A common tri-council definition of ECRs should take into account gender differences in career paths (e.g., years since PhD or first independent research appointment must take into account parental leaves).
- The involvement of CFI is crucial so start-up capital for ECRs can be aligned with operating and personnel supports provided by the relevant granting council.
- The four agencies should collaborate to improve data collection and analysis to support a lifecycle funding strategy, and engage in standardized public reporting of results.
- Granting councils should connect with universities/research institutions seeking active collaboration to align their support of early and mid-career researchers, and ensure productive transitions for researchers in the final stages of their careers.
- Comparative analysis, benchmarking, and publication of success rates in competitions are essential.

We believe the advantages of a lifecycle approach are obvious. A healthy and sustainable research ecosystem depends on ample opportunities for new researchers to break into the system and establish themselves, avoids gaps as they transition to mid-career, and provides strong support for researchers in their peak years of output and impact. It also makes fair and balanced appraisals of proposals by senior researchers without overweighting their history or undervaluing their potential for further contributions regardless of age. One approach, among others, would be to aim for higher success rates for ECRs, and gradually shift that balance through career stages with lower success rates for established researchers who will often be pursuing much larger grants that bear closer scrutiny. As discussed further below, the abolition of mandatory retirement led to an increase in the number of faculty members still working full-time past age 65. This situation has increased the need for a comprehensive lifecycle plan.

> The weight of the application on previous expertise discriminates against new ideas and young scientists. At a time when innovation is critical in all aspects of our society, … the future of Canadian scientists [has been curtailed] by developing a system which rewards senior and established researchers and limits funding for new ideas and young researchers.
>
> – Active researcher, University of Toronto

As to definitions, all councils currently define ECRs based on the number of years since their first independent academic position that makes them eligible to apply to the council. However, the number of years varies by council. Inconsistent approaches to take account of parental leaves appear to disproportionately affect female applicants. There will obviously be some differences due to fields of study and research areas, but a more consistent definition of ECRs would improve tracking and reporting, and ultimately improve funding strategies.

We have thus far urged better and more comprehensive data collection and reporting related to the planning and implementation of a lifecycle strategy for research funding. However, this work is also integral to developing a more comprehensive human resources plan for research personnel in Canada. As emphasized in Chapter 3, the majority of PhDs will be employed in Canada's private sector, not academe or government. The provinces and territories support research and fund graduate studies at universities, and the federal government has an obvious stake given the reliance of extramural researchers on its four funding agencies. All this speaks to the need for a multi-sector collaboration in developing and implementing a national plan for human resources in the R&D realm. It also reinforces Recommendation 4.9; this issue should be on the agenda of a First Ministers' Conference on Research Excellence in 2017.

5.2.2 Peer Review

Background and Analysis

Maximizing the impact of federal investments requires a peer review system that works fairly and effectively to achieve its primary goal of funding excellent research. The peer review systems used by the four agencies historically have often been praised in national and international evaluations, due largely to the dedication and commitment of thousands of researchers who voluntarily contribute their time and energy to them. At the same time, changes in research and the way that research is done are forcing changes in peer review processes. The increasing shortfalls in funding are frustrating reviewers and straining the system.

A variety of reports, both domestic and international, have recognized a variety of issues, including:

- the growing burdens on reviewers and applicants as the number of grants increases;
- inadequate matching of reviewer expertise to applications;
- the growing cost to the four agencies of face-to-face reviews with large committees;
- slow responsiveness to changes in the research landscape;
- continuing difficulties in fairly assessing multidisciplinary research;
- finding effective ways to support risky or novel research; and
- mounting evidence that unconscious biases sometimes confound the assessment of researchers and proposals.

A more general challenge in improving peer review practices is the surprising paucity of rigorous evidence about how peer review can most effectively, efficiently, and equitably be carried out.

> CIHR's reforms to its peer review system demonstrate the extent of the harm which can occur when untested changes are applied by an individual agency to its range of programs. The federal government needs to put a mechanism in place to ensure proper oversight and accountability of such changes with high-impact potential.
>
> – University research administrator

The burden on reviewers and the costs to the four agencies, in particular, have sparked calls to improve the efficiency of peer review. All agencies have made efforts in response, with mixed results. CIHR, for example, introduced far-reaching reforms that included the near-complete elimination of face-to-face peer review for its two largest grant programs. The negative response from the research community drew considerable media attention and led CIHR to reverse some of the changes. A lack of effective two-way engagement with the research community in the planning and design stages of the peer review changes appears to have contributed to this unhappy situation. The Panel sees the increased level of engagement between CIHR and the research community and the recently announced CIHR International Peer Review Expert Panel[10] as positive steps on which to build.

Recommendation and Elaboration

In peer review, four agency collaboration and coordination is needed to strengthen the system, as is a partnership with the research community in designing and implementing any changes. There have already been some promising examples of tri-council coordination[11] including a harmonized conflict of interest policy for peer review. Further efforts to standardize policies should be encouraged.

Among the ongoing challenges for all four agencies is determining which measures best define excellence and ranking of applications for funding purposes. Efforts to define excellence more objectively and precisely have led to increased (and perhaps over-) reliance on metrics such as bibliometric data, number of trainees, and funding history.[12] Researchers in our consultations emphasized that while quantitative indicators can reveal useful information, they must be balanced with the qualitative assessments of expert judgment, tempered by dialogue among reviewers, and avoid implicit biases (e.g., penalizing small universities for smaller numbers of graduate and postdoctoral trainees).

Recommendation 5.3

The new Four Agency Coordinating Board should create a mechanism for harmonization as well as continuous oversight and improvement of peer review practices across the three councils and CFI.

Among the desired outcomes would be:

- a common set of guiding principles or values for peer review;
- mechanisms for more effective adjudication of multidisciplinary research;
- a streamlined process for submitting grants, starting with rapid and major improvements to the ease of use and agency harmonization of the Canadian Common CV; and
- support for experimentation and evaluation to study new approaches to peer review, including use of iterative review processes.

We consider in turn each point above.

A critical element for a successful peer review system is trust: trust that reviewers are fair, impartial, and true expert peers; that applicants have accurately and honestly presented their data and ideas; and that the agencies have created and managed a merit-based process in which proposals are assessed for excellence without bias. Establishing a common set of guiding principles or values for peer review would be a step towards sustaining that trust with the research community and public alike. Moreover, while many international granting agencies have clearly enunciated peer review principles, SSHRC is the only council in Canada to do so.[13] At a Global Summit on Merit Review in 2012, which included almost 50 heads of science and engineering funding agencies from around the world (including Canada),[14] participants endorsed six principles to provide a framework for increased international research cooperation and to convey accepted international standards for research funding agencies. These principles include expert assessment, transparency, impartiality, appropriateness, confidentiality, and integrity and ethical considerations. Gender equity is an additional principle that is particularly relevant in the Canadian context, as discussed below.

> In general, far too little risk is encouraged in fundamental science. Peer review panels recognize novel, risky ideas, but are risk-averse when making funding recommendations. A cultural change is required, and must be driven by the funder.
>
> – Ontario Institute for Cancer Research

Considering the value that the research community places on empirical evidence, it is surprising how little research has been done on the effectiveness of peer review and its ability to identify excellence. In collaboration with the research community, the four agencies should engage in rigorous research and careful experimentation to test new approaches for peer review and to provide an evidence base for system improvements.

The agencies should also create structures to accommodate and adjudicate multidisciplinary research fairly and efficiently, and to encourage high-risk, high-reward research that has the potential to be ground-breaking and paradigm shifting. Joint programs to support research that spans the mandate of more than one agency should be established to encourage and assess multidisciplinary proposals. The Collaborative Health Research program offered by NSERC and CIHR is a strong case in point. More generally, review panels should include a range of experienced individuals who are comfortable crossing disciplinary boundaries and have the confidence to support high-risk but potentially path-breaking proposals.

> The common CV process is horrific, and could only be dreamed up by a bureaucrat.
>
> – Active researcher, University of Waterloo
>
> At the time of writing, I must maintain active approximately 9 different versions of my CV for various grants, be they provincial, federal or other. … These maintenance activities are tedious and repetitive, and somewhat ridiculous for 3 federal agencies (two CV types within a single agency). The Canadian Common CV is a step in the right direction to address this, in principle, but fails in practice.
>
> – Academic faculty member, École Polytechnique de Montréal

Reference above to a harmonized system and its improved user-friendliness is self-explanatory. However, we feel it is appropriate to highlight the intense frustration of the research community with the Canadian Common CV (CCV), the single CV portal used by multiple agencies. Among the many and persistent problems cited include inconsistent information requested by agencies, a complex and user-unfriendly web interface, an unstable/unreliable IT infrastructure that frequently crashes around application deadlines, and a rigid architecture that precludes free-form entries that can accommodate atypical forms of scholarship and relevant creative professional activity. The Panel urges the granting councils to develop and communicate a plan by mid-2017 to fix the CCV, recognizing that a complete redesign and rebuild of the platform may be needed. The research community must be engaged closely in developing more user-friendly solutions that are fully standardized across all federal research funding entities. The Panel noted two proposals from the research community that may merit further investigation: making the CCV open source (or at least open to compatibility to outside developers), and adopting ORCID, a persistent and unique digital identifier that can simplify tracking of research activities.[15]

5.3 Achieving Potential

5.3.1 Equity and Diversity

Background and Analysis

Equity and diversity in research is commonly positioned as a matter of fairness such that people can make full use of their talents. In the Panel's view, it is also a very wise human resource strategy to maximize research excellence in a country like Canada with a small population. Not only does wider participation draw on a larger base of talent, but the inclusion of diverse perspectives has the further advantage of broadening horizons and improving interpretation of information and decision-making alike.

> Science has a diversity problem, and in the quest for new ideas and innovation, we cannot afford to exclude any bright minds, particularly when other areas of the world are making gains in this area.
>
> – Ryerson University

Similar to many other countries, Canada's academic system has been challenged to achieve proportionate representation in the professoriate of women, Indigenous peoples, members of racialized groups, and people with disabilities (the four designated groups in the Employment Equity Act[16]). Indigenous people face particular challenges and are the subject of separate discussion. That said, there has been a slow but encouraging trend towards more gender diversity in Canadian higher education and research over the past 30 years (Exhibit 5.5).

Exhibit 5.5: Distribution of Full-time University Academic Staff in Canada by Rank and Sex

Rank	Sex	1970	1980	1990	2000	2010
All Ranks Combined	Male	87.2%	85.4%	80.4%	72.0%	63.4%
	Female	12.8%	14.6%	19.6%	28.0%	36.6%
Full Professor	Male	96.6%	95.2%	92.4%	84.8%	76.6%
	Female	3.4%	4.8%	7.6%	15.2%	23.4%
Associate Professor	Male	91.9%	87.4%	80.5%	68.3%	61.7%
	Female	8.1%	12.6%	19.5%	31.7%	38.3%
Assistant Professor	Male	86.2%	76.5%	66.8%	58.8%	53.6%
	Female	13.8%	23.5%	33.2%	41.2%	46.4%
Other	Male	72.0%	64.8%	56.1%	48.5%	46.9%
	Female	28.0%	35.2%	43.9%	51.5%	53.1%

Source: Calculations by the secretariat based on Statistics Canada, CANSIM table 477-0017.

The lack of diversity in the Canadian research ecosystem stems from complex factors and engrained attitudes. Barriers in the primary and secondary educational systems, coupled with a lack of role models and mentors, can make it difficult for people from underrepresented groups to choose and succeed in fields leading to research careers, especially in the STEM disciplines. As well, the relevant talent pools are limited by policies and practices such as persistent underfunding of education for Indigenous people on reserves or insufficient accommodation of people with disabilities.

The Panel notes that progress has been made in addressing gender disparities. Women now outnumber men in many graduate programs. Growth in the proportion of female assistant professors, and the slow rise over time in proportions at the ranks of associate or full professor, are consistent with a generational shift that will become more obvious in the next decade. Some studies suggest similar patterns for other underrepresented groups as well. Simple demographics—the preponderance of white males at higher academic ranks, and the aging of the so-called Baby Boomers—make further diversification inevitable.

That said, it was difficult for the Panel to gain a full and accurate picture of equity and diversity within Canada's research landscape because of a dearth of data. Currently, there appear to be no consistent accountability frameworks and principles to guide policies, data collection, and reporting across the granting councils. For example, with respect to trainees, submissions to the Panel indicated that gaps in parental leave policies across the granting councils may pose barriers to transition from this stage to assistant professor. There is some variability in policies affecting postdoctoral fellows and students directly funded by the granting councils, but SSHRC stands out in its lack of such provisions when trainees are indirectly supported through a supervisor's grant. Further, conditions placed on parental leave policies for personnel awards may be untenable in practice unless institutions collaborate in enforcing these provisions. The latter point underscores the Panel's view that faster progress on these fronts will require better collaboration among all parties engaged in funding and managing research enterprises. The importance of data and evidence cannot be overstated. As a case in point, while gender-neutral parental leave policies are generally seen as a tool to improve equity, some studies show that men benefit disproportionately from parental leave by using the time to publish papers rather than for child care.[17] However, the Panel has been struck by the observation that even when evidence for bias is strong, remedial action has sometimes been slow and limited.

Experience with the two flagship personnel support programs—the CRC and CERC programs—is germane here. The CERC awards are new, prestigious, and generous, and have the goal of attracting top international talent to Canada. In the inaugural competition 19 Chairs were awarded, all to men. No university nominated a female candidate. The resulting outcry triggered the appointment of an Ad Hoc Panel on CERC Gender Issues that made recommendations on how to improve equity and diversity in the program.[18] Even in the second competition, however, only 2 of the 10 awards went to women, with a female candidate resigning her award after a year. Currently 26 of the 27 active CERCs are held by men.

The CRC program dates to 2000, and is well-established. Data do not suggest any gender bias in the selection of chairholders from the pool of nominees put forward by universities, but this is to be expected as nominees have a high approval rate. The nomination process itself is the critical step, and available evidence suggests continued biases. This problem is so long-standing that it led a decade ago to a complaint to the Canadian Human Rights Tribunal.[19] As part of the programmatic changes resulting from the 2006 settlement of that case, all participating institutions are expected to establish a fair and transparent recruitment and nomination process for their Chair awards, and to remove barriers to access for the four designated groups mentioned above. The secretariat for the CRC program has established guidelines on expectations of what such processes entail and has implemented measures to encourage equity, including monitoring of recruitment practices, setting of equity targets, and an exemplary equity practices recognition process.

Examples of Potential Peer Review Bias

- In CIHR's 2014 Foundation Grant competition, 37 per cent of Stage 1 applications were from women, yet women represented only 29 per cent of applicants at Stage 2 and just 27 per cent of successful applicants. [CIHR data.]
- A CIHR study found that grant applications from young male researchers were 40 per cent more likely to be funded than those from female researchers. Similarly, applications from larger research teams and institutions with a large critical mass also had a significantly higher likelihood of being funded. [Tamblyn et al. CMAJ Open, 2016; 4(2): E213.]
- An analysis of NSERC's Discovery Grant program showed that funding success and grant amounts are consistently lower for applicants from small institutions, suggesting systemic bias against them. [Murray et al. PLoS ONE, 2016; 11(6): e0155876.]

These measures have improved the situation for women who now sit at just under 30 per cent of CRC holders compared with a low of 14 per cent in the early years. More than half of Canadian universities, however, are still not meeting conservative gender targets 10 years after implementation of the equity guidelines.[20] The Panel applauds the recent announcement that the newest cohort of CRCs will include the largest proportion of women yet as a good step forward. However, more needs to be done.

As to the other four groups, the overall CRC program target of 15 per cent for visible minorities[iii] is being met. But without disaggregated data, it is impossible to know how specific groups, such as African-Canadians, are performing. Similarly, while the program is meeting its 1 per cent target for Indigenous researchers (discussed in the next section), the most recent information indicates that they account for 2.1 per cent of all university professors and 4.3 per cent of the overall labour force.[21] Finally, academics with a disability are below target levels by some 2 to 3 per cent.[22]

iii The CRC program uses the term "visible minorities" in setting targets.

How does one explain these persistent deficiencies? An important threat to the integrity of peer review is the potential for conscious and unconscious biases of peer reviewers to influence their assessments. Bias can also stem from intrinsic program elements such as eligibility rules, evaluation criteria, partnership requirements, and disciplinary focus. A small but growing body of evidence has documented the various forms and consequences of bias in peer review,[23] but there is less information on how best to address or remediate those biases—a factor that we weighed carefully in framing recommendations on this difficult issue.

Recommendations and Elaborations

Many factors affect diversity and equity in general and apply as well to the research realm. Changing the research demographic to improve diversity depends therefore not only on engaging more underrepresented people in research programs, but also on breaking down the barriers they face as they launch and progress through their academic and research careers. The complex nature of these challenges makes it unlikely that any one initiative will drive rapid systemic changes. Diligence is needed to ensure that measures taken strengthen the quality of researchers and research supported within the federally funded ecosystem. Significant gaps will also need to be addressed at all levels, including existing and future policies and processes that unintentionally impede access. For example, equity charters, such as Athena SWAN in the U.K.,[24] risk reinforcing inequities as members of underrepresented groups are asked to serve not only in their usual roles, but also as chairs and members of working parties charged with turning words in a charter into policies and practices. Progress, in other words, depends on accountability and commitment at all levels of the relevant administrations.

> The trend to delayed retirement hampers university plans to hire new professors, including women and visible minorities, with net staff turnover rates so low, that achieving equity in staff diversity become projects of geological timescale. Canada's PSE [postsecondary education] system needs to innovate new career and staffing models and quickly move away from a dated, one size fits all, single academic contract and workload model based around tenure.
>
> – Active researcher, University of Calgary

Recommendation 5.4

The Four Agency Coordinating Board should develop consistent and coordinated policies to achieve better equity and diversity outcomes in the allocation of research funding while sustaining excellence as the key decision-making criterion. This priority intersects efforts to improve peer review practices and requires a multipronged approach.

That multipronged and coordinated approach involves:

- education and training on bias for peer reviewers;
- diversity in peer review panels;
- better data collection and transparency;
- consistent metrics and reporting plans to detect bias;
- tailored peer review mechanisms for specific research groups; and
- constant evaluation for degree of attainment of desired objectives and any unintended adverse consequences.

The Panel appreciates that it is challenging to design targeted interventions without robust data to delineate where interventions are needed. Better data and public reporting are integral to determining first, if inadvertent biases exist, and then whether actions to address these biases are having the intended effect. While reinstatement of the Statistics Canada UCASS survey is a good start to improve data collection,

> Canada seems to lag behind other countries in collecting statistics related to diversity issues … Although it's not sufficient on its own, information is the first necessary step to improving retention of the diversity in scientists through the various career stages.
>
> – Postdoctoral researcher

> **Prohibited Grounds of Discrimination**
>
> (1) For all purposes of this Act, the prohibited grounds of discrimination are race, national or ethnic origin, colour, religion, age, sex, sexual orientation, marital status, family status, disability and conviction for an offence for which a pardon has been granted or in respect of which a record suspension has been ordered.
>
> (2) Where the ground of discrimination is pregnancy or child-birth, the discrimination shall be deemed to be on the ground of sex.
>
> – *Canadian Human Rights Act.* R.S., 1985, c. H-6, s. 3; 1996, c. 14, s. 2; 2012, c. 1, s. 138(E).

more systematic efforts by the four agencies, particularly the three granting councils, are needed. The Panel also sees an opportunity for the agencies to engage the broader research community by sharing data on equity and diversity, and by funding researchers to study the issues and propose evidence-informed solutions. We urge that metrics and reporting plans be developed in consultation with the research community by the end of 2017.

The Panel strongly endorses the principle that appropriate expertise is the key criterion for peer review panel membership. As such, diversity cannot be promoted at the expense of expertise, nor should a small number of members of underrepresented groups be overloaded with peer review duties in the name of diversity. Nonetheless, the four agencies can do more to develop recruitment strategies that help build peer review panels that are more reflective of the diverse composition of the Canadian research community.

The agencies should also develop and expand education and training of reviewers about bias. In this regard, a best practice already exists in CIHR's module on unconscious bias in peer review.[25] The CIHR module could be readily adapted and adopted by the other agencies.

We remain confident that continued progress will be made. The difficult history of the CRC and CERC programs, however, leads us to the next recommendation.

Recommendation 5.5

The federal ministers responsible should consider hard equity targets and quotas where persistent and unacceptable disparities exist, and agencies and institutions are clearly not meeting reasonable objectives.

It should be observed that some Panel members believe that the CRC and CERC situations were so egregious that quotas could defensibly have been imposed.

5.3.2 Early Career Researchers

Background and Analysis

Recommendation 5.2 emphasized that the four agencies should take a lifecycle approach that balances the prospects of researchers at different stages of their careers. Career paths of researchers in universities and institutes often show a steady transition—through undergraduate, graduate, and postdoctoral training, then growth with institutional supports during some years as an ECR, followed by a mid-career period with increasing levels of independence and achievement as well as mentorship and support for students, trainees, and ECRs. When the system works optimally and is well-funded, it is remarkably effective at nurturing discoveries, new ideas, and outstanding talent. We recognize that there are many exceptions to this linear path related to illness, family obligations, and other factors. Accommodating those exceptions is essential to realizing the potential of talent in the system. Moreover, some attrition inevitably occurs along the way. While that can be viewed adversely as an opportunity cost or opportunities lost, some attrition is healthy and may benefit other sectors of society as researchers retool and take on other jobs.

On the other hand, the Panel repeatedly heard about attrition caused by very low success rates in competitions and a sense of futility on the part of young scholars and researchers. We have become concerned about ECRs who are not making the transition to the greater independence and stronger research programs expected of mid-career scholars and researchers. Arguments were also made to the Panel that while ECRs are still mentored and supported by their institutions, those at the early mid-career stage have become particularly vulnerable. As grant success rates decline and funding is concentrated in more established researchers, "a valley of death" opens up between early career and established researchers.

> Early career investigators are a particularly vulnerable group. These individuals are the future and therefore, mechanisms need to be in place for ensuring they can get a running start.
>
> – Hospital for Sick Children Research Institute
>
> The situation is untenable and starting to look like a youngster's dream of playing in the National Hockey League: nothing is impossible, but the chances of making a real career out of it are slim.
>
> – Active researcher, Université de Montréal

We return here to demographics. Due to the elimination of mandatory retirement, a generation of healthfully aging Baby Boomers remains firmly in place in our universities, institutes, and research hospitals.[26] Much of the growth in numbers of researchers from 2000 to 2015 involved young recruits. Some are still finding their feet, and others are entering the mid-career stage. Our suggestion of lifecycle allocation of resources involves finding a precarious balance between capitalizing on the accumulated wisdom and continued productivity of the older cohort of researchers, and making funding available to support the up and coming generations who represent the future of Canadian research. The numbers in the older cohort, as noted above, will fall over the next 10 to 15 years. We must ensure that Canada has built a pipeline of talent for the long haul.

Recommendation and Elaboration

The Panel believes that, concurrent with a broad lifecycle approach and efforts to improve peer review processes in general, specific and immediate attention should be paid to improving the success rates of ECRs in granting council competitions. We are aware that the councils are making efforts in this direction, but our consultations indicate that further action is urgently needed. A number of effective strategies have been described and tested in Canada and internationally, including:

- establishing dedicated funding envelopes for ECRs;
- setting minimum success rates proportional to ECR application pressure; and/or
- modifying evaluation criteria to reduce emphasis on factors that may discriminate against ECRs such as training of highly-qualified personnel (HQP), leadership experience, and track record.

Recommendation 5.6

The four agencies should examine best practices in supporting early career researchers, augment their support of them consistently across disciplines, and track and report publicly on the outcomes.

The Panel is aware that different strategies may be appropriate for ECRs and for researchers in transition to mid-career. It may be more prudent to pre-specify higher success rates for ECRs in open competitions, as is done by at least one of the agencies, and/or give extra weight in every competition to first submissions by a researcher to the relevant agency, as is done in some other nations. ECRs appear more likely to engage in multidisciplinary research—highlighting another collaborative opportunity for the agencies. Whatever strategies are undertaken, ECR data should be closely tracked and reported so that success rates can be adjusted as needed.

The Panel also notes that NSERC does not provide a full suite of salary awards for ECRs, SSHRC no longer funds release time for grant recipients, and CIHR has shifted funds away from its suite of internal salary awards for ECRs and mid-career researchers. A recent external evaluation of CIHR's salary/career award programs recommended that CIHR "consider whether operational efficiencies and equivalent or greater research impacts could be achieved by replacing the new investigator open salary awards with operating grants targeted specifically at this group",[27] a reasonable concept but one predicated on a forced choice between options, rather than reallocating funds to support ECRs in both ways. It appears that the creation of the CRCs variously accelerated this process or reinforced existing practices as regards salary awards. However, the number of CRCs remains small relative to the size of the research communities supported by the three councils. The Panel believes that demographic trends mean that a higher priority must be given not only to improved operating grant access but also to enhanced salary supports for young researchers. We return to this issue in Chapter 7.

For now, the Panel would simply ask: Is there any reason why an outstanding young researcher starting her/his career should be forced to apply to multiple programs and even agencies to get a flying start? It would seem more rational for a whole-of-agency and inter-agency process to be put in place, with one application encompassing a personnel award to help fund the young researcher's salary, project operating costs, a stipend for a graduate student on the project, and any necessary infrastructure or equipment. We can only imagine how much more efficient and effective such a process would be in optimizing the potential of Canada's best and brightest young scientists and scholars. We encourage the four agencies to move in this direction in the months ahead.

5.3.3 Indigenous Research

Background and Analysis

Historically, research involving First Nations, Inuit, and Métis (referred to collectively as Indigenous) peoples in Canada has been defined and carried out primarily by non-Indigenous researchers. This stems in part from a culture and tradition of colonization. Significant barriers and discriminatory rules regarding participation in higher education also led to underrepresentation of Indigenous people in academe. The net result is that approaches to Indigenous research generally do not reflect Indigenous world views and many Indigenous people regard research with apprehension or mistrust.

> One of the main challenges faced by indigenous researchers is that Western-based science is often dismissive towards traditional ways of knowing as inaccurate and 'unscientific.' … Epistemological bias has a deterring effect …, most especially [for] indigenous students and researchers who may see many forms of study as either irrelevant or hostile to their communities and cultures. All federal funding agencies should be encouraged to support work led by indigenous communities themselves, since they are best suited to address their own research needs. Allowing these communities to secure funding through federal agencies is the only way to effectively and respectfully support indigenous knowledge on its own terms.
>
> – Lakehead University

At the same time, there is a pressing need for Indigenous research. Indigenous people continue to experience Canada's largest socioeconomic and health gaps, with life expectancies of up to 15 years lower than Canada's population as a whole.[28] The Truth and Reconciliation Commission has urged the federal government to eliminate employment and education gaps between Indigenous and non-Indigenous Canadians, and to integrate Indigenous healing practices within the healthcare system to treat Indigenous patients in collaboration with Indigenous healers. To this end, access to Indigenous-supported research findings about priority issues is important to inform the design of policies that will improve the quality of life in these communities.

The Panel was encouraged to learn about some relevant changes in the research landscape. We were apprised that attitudes, processes, and beliefs about the ethical responsibilities of researchers and funding agencies have shifted. Previously seen as working *on* and *for* Indigenous communities, they are moving towards a respectful partnership culture based on research *by* and *with* Indigenous researchers and communities. As relationships and greater trust are built, Indigenous communities are participating more actively in the design, implementation, and dissemination of research. These communities have also asserted better access to and appropriate control over how information is gathered, used, and disseminated so that they can benefit from outcomes.

Indigenous Approaches to Research and Discovery

Integrative Science is an initiative designed to bring together Indigenous and Western scientific knowledges and ways of knowing. It takes a much broader view of science that emphasizes the natural world and our human participation in it, cultural inclusivity, and the role of the agent in the knowledge system.

Two-Eyed Seeing is the guiding principle for integrative science. It refers to the achievements that can be gained by learning from the best of Indigenous ways of knowing, inherently tied to the natural world, and the best in Western (or mainstream) ways of knowing. In effect, it involves learning to use each eye to see the world through the lens of one tradition, and then using both eyes together for the benefit of all.

– From: www.integrativescience.ca

We note that highly credible colleagues have drawn on traditional Indigenous knowledge to improve their understanding of the workings of complex social and environmental systems. They argue that through methods for acquiring knowledge based on systematized observation and the formation and testing of hypotheses, Indigenous ways of knowing are not unlike the paradigms used within academe. Oral traditions represent reproducible, organized bodies of knowledge that are beneficial to answering specific questions within specific contexts, geographies, and timescales. Canadian researchers in this regard are now affirming what Indigenous people have known for centuries about geological events and human migrations.

Notwithstanding these signs of progress in cross-cultural understanding in the research realm, the Panel observes a pressing need to build and support Indigenous researcher capacity. Indigenous people remain underrepresented in the professorial ranks relative to their overall population. This lack of diversity impedes the ability to fully capitalize on the improved culture for Indigenous research and to advance research to address the health and social challenges and needs of Indigenous communities. Physical, geographic, and systemic barriers continue to prevent Indigenous researchers and communities from participating as equal partners with non-Indigenous researchers and research institutions.

Indigenous communities matter in Indigenous health research, without their involvement there can be no real benefit to communities nor any social value generated through indigenous health research and instead there is an increased potential of harm to Indigenous communities.

– Active researcher, University of Toronto and Forum for Indigenous Implementation Research and Evaluation (FIIRE) Network

In our consultations, the Panel heard that discussions on research priorities do not sufficiently recognize Indigenous leadership, governance, decision-making, institutions, and knowledge systems. Compounding the problem, poor internet connections in many Indigenous communities, prohibitive costs of travel from remote regions, language issues, capacity issues, lack of Indigenous people with postsecondary degrees, and cultural differences, among others, limit their voices in decision-making without specific concerted efforts.

The Government of Canada clearly has both a moral and constitutional obligation to improve this situation. The four agencies have taken a number of positive steps to create a better environment for Indigenous research. For example, in 2010 the Tri-Council Policy Statement: Ethical Conduct for Research

Involving Humans (TCPS 2) for the first time included a chapter on research involving First Nations, Inuit, and Métis peoples.[29] The preamble of that chapter wisely stated that it was "not intended to override or replace ethical guidance offered by Aboriginal peoples themselves. Its purpose is to ensure, to the extent possible, that research involving Aboriginal peoples is premised on respectful relationships. It also encourages collaboration and engagement between researchers and participants."[30]

Prior to the adoption of this framework, CIHR through its Institute of Aboriginal Peoples' Health had played a leadership role in creating its own Guidelines for Health Research Involving Aboriginal People,[31] developed in close collaboration with Indigenous researchers and communities. SSHRC also ran a successful pilot program in Indigenous research from 2004 to 2010, and subsequently developed policy and program measures in close consultation with its Aboriginal Advisory Circle to extend the equity and knowledge benefits of Indigenous research across its programming. A key result is SSHRC's Guidelines for the Merit Review of Aboriginal Research,[32] which emphasize key principles around Indigenous knowledge, reciprocity or co-creation in the development of knowledge, community involvement and interests, and respect for Indigenous protocols, approaches, and values. The Guidelines also ensure that Indigenous knowledge is recognized as a scholarly contribution that meets SSRHC's standards of excellence.

The Calls to Action of Canada's Truth and Reconciliation Commission, released in 2015, made specific reference to federal research funding in recommendation number 65: "We call upon the federal government, through the Social Sciences and Humanities Research Council, and in collaboration with Aboriginal peoples, post-secondary institutions and educators, and the National Centre for Truth and Reconciliation and its partner institutions, to establish a national research program with multi-year funding to advance understanding of reconciliation." [33] In response, SSHRC has broadly consulted to develop a framework for implementation and is promoting a broader scope for tri-council work by and with Indigenous researchers and communities, including support for research capacity and community self-governance.

> Inuit organizations who have the mandate, responsibility and qualifications to do research are often excluded from funding opportunities based on eligibility requirements. … There is an expressed irony by Inuit about having to sign on with a university in order to conduct research to benefit our own people.
>
> – Inuit Tapiriit Kanatami (ITK)

Notwithstanding ongoing progress, the Panel's consultations indicate that existing governance and machinery supporting research by and with Indigenous researchers and communities within the granting councils is constrained by contradictory funding mechanisms, systemic biases, and an overall lack of accountability to the Indigenous people and communities they are meant to benefit. For example, we observe that great strides were made in the first several years of CIHR's existence, largely through the innovative role of its Institute of Aboriginal Peoples' Health. With funding pressures mounting, however, CIHR terminated a capacity building program that the Institute had created to promote Indigenous research. The new peer review system and program reforms were also cited as obstacles to the conduct of Indigenous health research. NSERC continues to focus efforts on encouraging more Indigenous researchers to enter STEM fields, but the pipeline is small, and Indigenous representation in STEM disciplines is very thin. It is encouraging that, as noted earlier, the CRC program's 1 per cent equity target for Indigenous researchers has been met, but the target is based on approximation of the availability pool that is the lowest of the four designated groups.

In sum, progress could be accelerated by ongoing efforts between Indigenous organizations and researchers in cooperation with the granting councils. However, without clear mechanisms for coordination, the implementation of TCPS 2 is left to granting council-specific interpretation—a concern given evidence that discrepancies among the councils have already emerged.

Recommendation and Elaboration

> To improve transparency and accountability in research practice, [the granting councils should] establish a governing council of Indigenous elders, knowledge keepers, youth, and research scientists that provides guidance to the tri-councils in order to optimize the social value of Indigenous research and monitors them with respect to their adherence to existing rights, policy and ethics frames regarding Indigenous research.
>
> – Active researchers (joint submission), University of Toronto

The positive steps taken to date by the granting councils are an important and encouraging start, but more sustained effort and attention are required if the Government of Canada is to meet its goals to strengthen partnerships with Indigenous peoples, to cooperatively implement recommendations of the Truth and Reconciliation Commission, and to reduce health and economic outcome gaps. The Panel considered experience in countries such as Australia and New Zealand that have more fully recognized the long-term adverse impacts of colonization on Indigenous people. Notably, in Australia the proportion of research funding earmarked for Indigenous research is double the proportion of the Indigenous population as a whole. Initiatives such as the Australian Institute of Aboriginal and Torres Strait Islander Studies and programs to build the capacity and leadership of Indigenous researchers are changing the face of Australian research and improving the prospects for Aboriginal peoples in that country. Our conclusion is that updated governance, machinery, and equity practices, reflective of the goals of research by and with Indigenous researchers and communities, are needed across all three granting councils.

Recommendation 5.7

The three granting councils should collaborate in developing a comprehensive strategic plan to promote and provide long-term support for Indigenous research, with the goal of enhancing research and training by and with Indigenous researchers and communities. The plan should be guided by the Truth and Reconciliation Commission's recommendations on research as a key resource.

The Panel will not presume to elaborate on the recommendations of the Truth and Reconciliation Commission, but rather encapsulate specific elements and considerations as follows:

- development of a statement of principles for Indigenous research;
- working with Indigenous advisors to create mechanisms that build inclusiveness, recognition of distinctiveness, and accountability into the structures and processes of the four agencies and related institutions;
- increased support for research and training by and with Indigenous researchers and communities;
- improved recognition of efforts related to community-based research and clarity on the Indigenous knowledge process;
- reconsideration of research support mechanisms, such as the composition of peer review panels;
- greater understanding of the role of Indigenous knowledge;
- greater flexibility in eligible costs and timelines to enable strong and ongoing community engagement; and
- provision of opportunities for iterative proposal submissions in peer review.

5.4 Third-party Delivery and Matching Programs

5.4.1 Third Parties and the Mandate Conundrum

While the four pillar agencies are the principal conduits for distributing and administering the federal government's investments in extramural research, third-party organizations also administer funding from the federal government to research institutions and researchers as well as conduct research themselves and provide research services. Exhibit 1.2 showed the current set of organizations falling into this category. The relationship of each organization to the federal government is the subject of a tailored contribution agreement, usually renewable on five-year terms. Each organization has its own unique background and raison d'être. Each was created to fill an observed gap at the time or to seize a specific opportunity. There is little question that these organizations and mechanisms have added value to the research ecosystem, in part because their specialized mandates and structures allow them to respond to particular needs and operate more nimbly than the four agencies. Another benefit is their ability to leverage funding from a wide variety of other sources. They may, however, complicate the ecosystem, augment overhead expenditures, or outlive their original purpose. They may also converge with tri-council research activities to such an extent that the rationale for special funding and status becomes less apparent, or diverge such that questions can be asked as to whether they represent primary research programming or should be assessed for their impact in the sphere of innovation and commercialization.

Background and Analysis

Three bodies in particular are the largest of these third-party organizations and illustrate the challenges of evaluating contribution agreements: Genome Canada, Mitacs, and Brain Canada.

Genome Canada was created in 2000 at a time when many national genomics initiatives were being developed in the wake of the Human Genome Project. It emerged from a "bottom-up" design process driven by genomic scientists to complement existing programs by focusing on large-scale projects and technology platforms. Its funding model emphasized partnerships and matching funds to leverage federal commitments with the objective of rapidly ramping up genomics research in Canada.

> Genome Canada's extraordinary success in building DNA sequencing capacity has rendered this mainstream. Could an organization like Genome Canada, with already developed adjudication and application processes for big science projects be repurposed for special technologies?
>
> – HealthCareCAN

This approach has been successful: Genome Canada has received $1.1 billion from the Government of Canada since its creation in 2000, and has raised over $1.6 billion through co-funding commitments, for a total investment in excess of $2.7 billion.[34] The scale of Genome Canada's funding programs allows it to support large-scale genomics research that the granting councils might otherwise not be able to fund. Genome Canada also supports a network of genomics technology and innovation centres with an emphasis on knowledge translation and has built domestic and international strategic partnerships. While its primary focus has been human health, it has also invested extensively in agriculture, forestry, fisheries, environment, and, more recently, oil and gas and mining—all with a view to the application and commercialization of genomic biotechnology.

Mitacs attracts, trains, and retains HQP in the Canadian research enterprise. Founded in 1999 as an NCE, it was developed at a time when enrolments in graduate programs had flat-lined, and links between mathematics and industry were rare. Independent since 2011, Mitacs has focused on providing industrial research internships and postdoctoral fellowships, branching out beyond mathematics to all disciplines. It has leveraged funding effectively from the federal and provincial governments, industry, and not-for-profit organizations. It has also expanded internationally, providing two-way research mobility.

Budget 2015 made Mitacs the single mechanism of federal support for postsecondary research internships with a total federal investment of $135.4 million over the next five years. This led to the wind-down of NSERC's Industrial Postgraduate Scholarships Program. With matching from multiple other sources, Mitacs' average annual budget is now $75 to $80 million. The organization aims to more than double the number of internships it funds to 10,000 per year by 2020.[35]

Finally, Brain Canada was created in 1998 (originally called NeuroScience Canada) to increase the scale of brain research funding in Canada and widen its scope with a view to encouraging interdisciplinary collaboration. In 2011 the federal government established the Canada Brain Research Fund to expand Brain Canada's work, committing $100 million in new public investment for brain research to be matched 1:1 through contributions raised by Brain Canada. According to the STIC *State of the Nation 2014* report, Canada's investment in neuroscience research is only about 40 per cent of that in the U.S. after adjusting for the size of the U.S. economy.[36] Brain Canada may be filling a void left by declining success rates and flat funding at CIHR.

Recommendation and Elaboration

The Panel noted that, in general, third-party organizations for delivering research funding are particularly effective in leveraging funding from external partners. They fill important gaps in research funding and complement the work of the granting councils and CFI. At the same time, we questioned the overall efficiency of directing federal research funding through third-party organizations, noting that our consultations solicited mixed reactions. Some respondents favoured more overall funding concentrated in the agencies rather than diverting the funding to third-party entities. Others strongly supported the business models of these organizations.

We have indicated elsewhere that a system-wide review panel such as ours is not well-suited to examine these and other organizations subject to third-party agreements. We recommended instead in Chapter 4 that a new oversight body, NACRI, be created to provide expert advice and guidance on when a new entity might reasonably be supported by such an agreement. Here we make the case for enlisting NACRI in determining not just the desirability of initiating a new entity, but also whether contribution agreements should continue and, if so, on what terms.

> The MITACS program is a great start but requires matching funds from industry making it inaccessible for many areas of fundamental research.
>
> – Lakehead University

The preceding sketches of three diverse organizations subject to contribution agreements help illustrate the rationale for this proposal. To underscore the challenges of adjudication, we elaborate briefly. Submissions highlighted that funding from Genome Canada has enabled fundamental discoveries to be made and important knowledge to be disseminated to the Canadian and international research communities. However, other experts suggested a bifurcation with CIHR or NSERC funding research-intensive development of novel technologies, while Genome Canada would focus on application (e.g., large-scale whole genome studies) and commercialization of existing technologies. From the Panel's standpoint, these observations underscore the subtleties of determining where and how Genome Canada's mandate overlaps and departs from that of CIHR and NSERC as well as CFI. Added to the complexity of any assessment is Genome Canada's meaningful role in providing large-scale infrastructure grants and its commercialization program. Mitacs, even more than Genome Canada, bridges beyond academe to the private and non-profit sectors, again highlighting the advantage of having any review overseen by a body with representatives from both spheres. Finally, as did the other two entities, Brain Canada won plaudits, but some interchanges saw discussants ask when and whether it might be more efficient to flow this type of funding on a programmatic basis through CIHR.

We emphasize that the Panel's intent here is neither to signal agreement nor disagreement with any of these submissions or discussions. We simply wish to highlight that decisions about ongoing funding will involve expert judgments informed by deep expertise in the relevant research areas and, in two of these examples, an ability to bridge from research to innovation and from extramural independent research to the private and non-profit sectors. Under current arrangements, management consulting firms and public servants drive the review and decision-making processes. Our position is that oversight by NACRI and stronger reliance on advice from content experts would be prudent given the sums involved and the nature of the issues.

Recommendation 5.8

NACRI should be mandated not only to review proposals to create new third-party delivery organizations, but also to assess ongoing activities of all existing third-party organizations that receive federal support. It should guide their formal periodic review processes and advise the Government of Canada on the continuation, modification, or termination of their contribution agreements.

The Panel appreciates that external agencies may perceive that the relevant granting councils and CFI have an interest in consolidation rather than continuation. The Panel believes NACRI's arm's-length standing means that it can be seen as an impartial arbiter of whether the third-party organizations under review are making (or will make) a contribution that could be made through current agencies and programming, and can also fairly weigh the opportunity costs of channelling ongoing resources into these agreements. In those instances where the initiatives are deemed to be similar to MRFs, the assessments can be readily referred from NACRI to the Special Standing Committee on Major Research Facilities, as defined in Chapter 4.

5.4.2 Matching Funding

Federal agencies or third parties that support research are increasingly using a variety of mechanisms to leverage, cost share, or match funding. In Canada, the trend started with CFI in 1997, followed by Genome Canada, the CERC program, the Knowledge Infrastructure Program (KIP-2009), the Post-Secondary Institutions Strategic Investment Fund, and, to some extent, Mitacs and the recent CFREF.

Certain programs within the granting councils also require matching support, especially those with a commercialization or strategic intent but, in some cases, basic research programs as well.

Another form of matching support involves collaborations or partnerships between the federal government and non-federal donors to support specific research initiatives of mutual interest. The Institute for Quantum Computing, Perimeter Institute, and CIFAR are examples of such models of public-private partnerships.

In areas of shared jurisdiction, matching support is beneficial as it ensures strategic buy-in from other partners and contributes to system-wide coherence. It may also stretch or conserve limited program funds, allowing more projects to be supported and more support to be dedicated to particular efforts. Cost-sharing and matching requirements can also serve to leverage new sources of funding and help assure real commitment to projects by participants, which may be particularly true for commercially oriented programs where cost sharing can indicate that a company views a project as promising and valuable.

For example, from its launch in 1997, the CFI model for supporting capital grants has required 60 per cent of the total value of the project to be provided by other partners—usually the province or territory, the university or college itself, and/or business. This system has generally worked well. University research is a shared jurisdiction and capital awards can effectively determine priorities and directions of research; thus, it is appropriate that the provinces/territories and institutions have an active say in making these decisions. Requiring them to participate financially seems appropriate. Financially, CFI has invested more than $6.7 billion in capital projects since 1998 and levered close to $9.2 billion from partners.[37]

In contrast to these positive outcomes, there are also challenges with the matching requirement for federal investments in research performed in the higher education sector.

First, the rationale for provincial/territorial participation is diminished when a project is of national importance—with beneficiaries beyond the provincial/territorial borders. This is examined in more detail in Chapter 6.

Second, certain researchers, in particular those in the SSHRC disciplines, can find it more difficult to secure matching funding from the private sector. While non-governmental organizations may have an interest, they often have less cash available and matching tends to be more on an in-kind basis, which has its limitations. The result can be a skewing of research activities, forcing researchers to abandon lines of inquiry that are not of interest to potential partners.

Third, there is a wide variation across provinces/territories in the availability of public matching funds. This can make it harder for researchers in certain regions of the country to obtain matching funding and thereby the requirement can contribute to regional inequities. It is also adding to the challenges for SSHRC researchers, as noted earlier in this chapter.

Fourth, the process of recruiting funding partners can be time-consuming and burdensome for researchers. In many cases, if researchers cannot find a partner, they cannot apply for funding, potentially excluding excellent research. For example, at some organizations (e.g., Stem Cell Network, Brain Canada) cost sharing may be a condition of eligibility to apply for funds. From the partners' perspective, too many matching requirements can become a serious burden—both financially and in their ability to set their own priorities. For the private sector and non-profit communities who wish to partner, the opportunities to do so may either not always be evident or, due to the proliferation of programs, they may find it difficult to navigate the process of finding the research or project on which to partner. To this end, rules and processes for matching could be better harmonized and simplified across all federal research agencies, and more broadly in the research funding ecosystem.

Recommendation 5.9

When the intent is to support independent research, requirements for matching funds should be used sparingly and in a coordinated and targeted manner. In general, matching requirements should be limited to those situations where the co-funder derives a tangible benefit.

To elaborate: Co-funders are most likely to receive a tangible benefit in projects or in highly applied research involving elements of translation, product or process development, or commercialization. In addition, the Panel cautions that the increasing number of matching programs is contributing to a sense of "matching fatigue" among researchers and partners. In the case where provinces/territories have a stake, FPT meetings should include discussion of the range and arrangements of matching programs to ensure alignment, ease of administration, feasibility, and mutual benefit. The four agencies should also consider ways to facilitate the matching process both for researchers and for potential partners to reduce administrative burdens and maximize efficiencies.

5.5 From Design and Evaluation to Delivery and Resources

This chapter represented the logical progression of the Panel's review from oversight and governance in Chapter 4 to a consideration of various cross-cutting issues facing all four agencies, albeit with greater emphasis on the three granting councils. In effect, our focus was the design of the system, particularly where and how federal funding is distributed to researchers. Our review raises a number of concerns about the three granting councils' mandates in relation to their relative funding allocations, as well as the allocation decisions made by a succession of federal governments that have led to the current distribution of resources across councils and programs. In addition to urging a rethinking of program architecture and closer attention to both success rates and funding levels, we have recommended a lifecycle approach to budgeting, aimed at ensuring support for researchers at different stages of their careers. The peer review system, obviously, is the engine of frontline resource allocation. Here too, opportunities for improvement were identified and recommendations provided.

A more challenging issue for the Panel was the uneven performance of the extramural research ecosystem with respect to equity and diversity. To repeat the Panel's view: We see an equitable and diverse ecosystem as one that is more likely to have excellent performance. We recognize that the persistent underrepresentation of women, some racialized groups, Indigenous people, and people with disabilities involves factors well beyond the scope of the four pillar agencies to address, let alone fully redress. However, more can and should be done, as set out in several recommendations.

The ecosystem includes a number of third-party entities operating under contribution agreements with ISED. We have a broadly positive view of their contributions and admire their entrepreneurial energy in leveraging funding from other sources. However, the risks of duplication, poor coordination, politicization, and multiplication of overheads all escalate as these entities and arrangements proliferate. We have accordingly recommended a role for NACRI in assessing not just new proposals but in the intermittent reviews of these contribution agreements. The prevalence of matching in these agreements also led us to offer some reflections and to register some cautions about the use of matching requirements as a condition of federal research support, particularly in areas of independent research.

We turn now from these design considerations to more detailed consideration of the delivery of programs and the resourcing of research grants, infrastructure, people, facilities, and administration. The two chapters covering this ground are effectively one unit, divided more to facilitate assimilation of their contents than for any conceptual reasons. The two chapters conclude with a reconciliation of the financial implications and options arising from the recommendations therein.

ENDNOTES

1 NSERC's Vision [Internet]. Ottawa: Natural Sciences and Engineering Research Council; 2011. Available from: http://nserc.gc.ca/NSERC-CRSNG/vision-vision_eng.asp

2 About SSHRC [Internet]. Ottawa: Social Sciences and Humanities Research Council; 2016. Available from: http://www.sshrc-crsh.gc.ca/about-au_sujet/index-eng.aspx

3 Our Mandate [Internet]. Ottawa: Canadian Institutes of Health Research; 2013. Available from: http://cihr-irsc.gc.ca/e/7263.html

4 Advisory Panel on Healthcare Innovation. Unleashing Innovation: Excellent Healthcare for Canada. Ottawa: Health Canada; 2015. Available from: http://healthycanadians.gc.ca/publications/health-system-systeme-sante/report-healthcare-innovation-rapport-soins/alt/report-healthcare-innovation-rapport-soins-eng.pdf

5 Alberts, B., Kirschner, M.W., Tilghman, S., Varmus, H. Rescuing US Biomedical Research from its Systemic Flaws. *Proc Natl Acad Sci U S A*, 2014; 111(6): 5773-5777. doi: 10.1073/pnas.1404402111

6 Statistics Canada. Postsecondary enrolments, by registration status, Pan-Canadian Standard Classification of Education (PCSCE), Classification of Instructional Programs, Primary Grouping (CIP_PG), sex and student status (CANSIM table 477-0019). Ottawa: Statistics Canada; 2016.

7 Fang, F.C., Bowen, A., Casadevall, A. NIH Peer Review Percentile Scores are Poorly Predictive of Grant Productivity. *eLife*, 2016; 5: e13323. doi: 10.7554/eLife.13323. See also Berg, J. Well-Funded Investigators Should Receive Extra Scrutiny. *Nature*, 2012; 489: 203.

8 The Expert Panel on Women in University Research. Strengthening Canada's Research Capacity: The Gender Dimension. Ottawa: Council of Canadian Academies; 2012. Available from: http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/women_university_research/wur_fullreporten.pdf.pdf

9 See, for example, Lorsch, J.R. Maximizing the Return on Taxpayers' Investments in Fundamental Biomedical Research. *Mol Biol Cell*, 2015; 26: 1578-1582; Fortin, J.M., Currie, D.J. Big Science vs. Little Science: How Scientific Impact Scales with Funding. *PLoS ONE*, 2013; 8(6): e65263. doi:10.1371/journal.pone.0065263; Basson, J., Lorsch, J., Dorsey, T. Revisiting the Dependence of Scientific Productivity and Impact on Funding Level. NIGMS Feedback Loop Blog; 2016 July 8. Available from: https://loop.nigms.nih.gov/2016/07/revisiting-the-dependence-of-scientific-productivity-and-impact-on-funding-level/

10 International Peer Review Expert Panel [Internet]. Ottawa: Canadian Institutes of Health Research; 2016. Available from: http://www.cihr-irsc.gc.ca/e/49972.html

11 Collaboration between Federal Research Funding Organizations [Internet]. Ottawa: Government of Canada; 2016. Available from: http://science.gc.ca/eic/site/063.nsf/eng/h_A0A2F2CB.html

12 The Expert Panel on Science Performance and Research Funding. Informing Research Choices: Indicators and Judgment. Ottawa: Council of Canadian Academies; 2012. Available from: http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/science%20performance/scienceperformance_fullreport_en_web.pdf

13 Merit Review [Internet]. Ottawa: Social Sciences and Humanities Research Council; 2016. Available from: http://www.sshrc-crsh.gc.ca/funding-financement/merit_review-evaluation_du_merite/index-eng.aspx

14 2012 Global Summit on Merit Review. Global Research Council; 2012. Available from: http://www.globalresearchcouncil.org/meetings/2012-meeting

15 ORCID [Internet]. Available from: http://orcid.org/

16 *Employment Equity Act*, S.C. 1995, c. 44. Available from: http://laws-lois.justice.gc.ca/eng/acts/e-5.401/

17 Antecol, H., Bedard, K., Stearns, J. Equal but Inequitable: Who Benefits from Gender Neutral Tenure Clock Stopping Policies? Bonn: Institute for the Study of Labor (IZA); 2016. Available from: http://ftp.iza.org/dp9904.pdf

18 Dowdeswell, E., Fortier, S., Samarasekera, I. Report to the Minister of Industry of the Ad Hoc Panel on CERC Gender Issues. Ottawa: Industry Canada; 2010. Available from: https://www.ic.gc.ca/eic/site/icgc.nsf/eng/h_05589.html

19 Canadian Human Rights Tribunal Settlement Agreement. Tribunal File No. T11118/9905. Available from: http://www2.unb.ca/parl/Settlement-signed2.nov06pdf.pdf

20 Hannay, C. Court asked to enforce settlement on research award equity targets. *The Globe and Mail*; 2016 October 30. Available from: http://www.theglobeandmail.com/news/politics/court-asked-to-enforce-settlement-on-research-award-equity-targets/article32587991/

21 Canadian Association of University Teachers. The Changing Academy? A Portrait of Canada's University Teachers. *CAUT Education Review*; 2010, 12(1). Available from: https://www.caut.ca/docs/education-review/the-changing-academy-a-portrait-of-canada-rsquo-s-university-teachers-(jan-2010).pdf?sfvrsn=14

22 Hannay, C. Court asked to enforce settlement on research award equity targets. The Globe and Mail. 2016 October 30. Available from: http://www.theglobeandmail.com/news/politics/court-asked-to-enforce-settlement-on-research-award-equity-targets/article32587991/

23 See, for example, Lee, C.J., Sugimoto, C.R., Zhang, G., Cronin, B. Bias in Peer Review. *J Am Soc Inf Sci Technol.*, 2013; 64(1): 2-17.

24 Athena SWAN Charter [Internet]. London (England): Equity Challenge Unit; n.d. Available from: http://www.ecu.ac.uk/equality-charters/athena-swan/

25 Bias in Peer Review [Internet]. Ottawa: Canadian Institutes of Health Research; n.d. Available from: http://www.cihr-irsc.gc.ca/lms/e/bias/. Provided as part of CIHR's Learning Modules, available from: http://www.cihr-irsc.gc.ca/e/47021.html

26 An extensive demographic profile of postsecondary education researchers can be found in: Association of Universities and Colleges Canada. Trends in Higher Education, Vol. 2: Faculty. Ottawa: AUCC; 2007. Available from: http://www.eotb-cfeo.on.ca/download.php?id=47. Additional calculations by the secretariat with more recent Statistics Canada UCASS data show the same trends.

27 Canadian Institutes of Health Research Salary/Career Award Programs – Evaluation Report [Internet]. Ottawa: Canadian Institutes of Health Research; 2012. Available from: http://www.cihr-irsc.gc.ca/e/45365.html

28 Life Expectancy [Internet]. Ottawa: Statistics Canada; 2015. Available from: http://www.statcan.gc.ca/pub/89-645-x/2010001/life-expectancy-esperance-vie-eng.htm

29 TCPS 2 (2014) – the latest edition of Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans [Internet]. Ottawa: Panel on Research Ethics; 2015. Available from: http://www.pre.ethics.gc.ca/eng/policy-politique/initiatives/tcps2-eptc2/Default/

30 TCPS 2 – Chapter 9: Introduction [Internet]. Ottawa: Panel on Research Ethics; 2015. Available from: http://www.pre.ethics.gc.ca/eng/archives/tcps2-eptc2-2010/chapter9-chapitre9/#toc09-intro

31 CIHR Guidelines for Health Research Involving Aboriginal People (2007–2010) [Internet]. Ottawa: Canadian Institutes of Health Research; 2013. Available from: http://www.cihr-irsc.gc.ca/e/29134.html

32 Guidelines for the Merit Review of Aboriginal Research [Internet]. Ottawa: Social Sciences and Humanities Research Council; 2016. Available from: http://www.sshrc-crsh.gc.ca/funding-financement/merit_review-evaluation_du_merite/guidelines_research-lignes_directrices_recherche-eng.aspx

33 Truth and Reconciliation Commission of Canada: Calls to Action. Winnipeg: Truth and Reconciliation Commission of Canada; 2015. Available from: http://nctr.ca/assets/reports/Calls_to_Action_English2.pdf

34 Information from Genome Canada Submission to the Panel, September 30, 2016.

35 Mitacs releases Target 10,000: Talent, Ideas, Networks, a five-year strategic plan [Internet]. Vancouver: Mitacs; 2016. Available from: https://www.mitacs.ca/en/newsroom/news-release/mitacs-releases-target-10000-talent-ideas-networks-five-year-strategic-plan

36 State of the Nation 2014. Chapter 3: High Quality Knowledge. Ottawa: Science, Technology and Innovation Council Secretariat; 2015. Available from: http://www.stic-csti.ca/eic/site/stic-csti.nsf/vwapj/STIC_1500_SON_Report_e_proof4.pdf/$file/STIC_1500_SON_Report_e_proof4.pdf

37 Innovation is in our Nature: Annual Report 2015-16. Ottawa: Canada Foundation for Innovation; 2016. Available from: https://www.innovation.ca/sites/default/files/pdf/2016/final-cfi-ar-en.pdf

CHAPTER 6

FUNDING THE RESEARCH ECOSYSTEM: THREE KEY INGREDIENTS

With its cross-cutting themes, the preceding chapter raised many issues that need to be addressed by the four pillar agencies in concert. This chapter and Chapter 7 move even closer to the front lines and examine how well various federal research programs and funding agencies are working, both with respect to their individual mandates to support specific research activities and in their shared or coordinated efforts.

Readers will notice a contrast in the level of detail contained in these chapters as compared with Chapters 4 and 5 where we addressed broad issues of oversight, structures, governance, accountabilities, operating principles and processes, and values. Both Chapters 6 and 7 are at once more and less detailed. They are more detailed, obviously, in that specific programs and agencies are considered. They are less detailed because neither the histories nor the intricacies of the programs themselves are presented.

The rationale for this approach is straightforward. While we reiterate in general the previous chapters' call for programs to be more streamlined, harmonized, and coordinated, the Panel is not recommending any major program machinery changes. This should not be understood as a blanket endorsement, so much as an acknowledgment that programmatic shifts must be made by the agencies themselves in consultation with their research communities. Discussion of programmatic history and evolution is accordingly less important to understanding the Panel's conclusions in this context.

We also realize that many readers of our report will already be well informed about the programs covered here. For those who need more information, Appendix 1 provides program-by-program background, and the relevant agency websites are clear and helpful. At this stage, however, our goal is to focus on the arguments that support our identification of gaps and conclusions about remediation. Accordingly, the sections are brief, and move quickly to recommendations and elaborations.

While the granting councils are mandated by discipline, we have organized these two chapters around the kinds of resources that must be assembled to put a research project together:

- securing direct project funding;
- acquiring infrastructure;
- operating and maintaining that infrastructure;
- paying the people who do the work; and
- covering the full costs generated by the research project (i.e., facilities and administration charges).

Chapter 6 reviews the first three key ingredients. Chapter 7 covers the final two, and then sets out financial scenarios and trade-offs tied to the various recommendations.

Most research projects require adequate resources for all or most of these activities, secured from different programs, agencies, and institutions—not all of them from the federal government. The organization of the chapters therefore serves as a reminder of the cross-cutting nature of much of what is done by the granting councils and CFI. As such, it implicitly reinforces one of the main messages from the previous chapter: for research funding systems and researchers to reach their full potential, there must be more effective coordination among federal organizations and with organizations beyond the federal sphere.

The Panel recognizes that, for readers who are not participants in extramural research, this multi-government, multi-agency, and multi-program environment will be somewhat alien. Nonetheless, the broad elements of the Canadian system are not dramatically different from other systems around the world. The engines of every research funding system, as emphasized in Chapter 5, are peer review committees. Researchers are constantly judged on the quality of their proposals through a process of more or less open competition with adjudication by peers. This system provides continuous feedback and requires responsive adjustment. It steadily moves resources to areas of high potential and away from less promising areas through constant testing and assessment of results—a process not unlike the scientific method itself. Improvements can assuredly be made in the fairness and efficiency of peer review, not least in coordinating reviews around the multiple elements required for effective pursuit of a line of inquiry or research. Notwithstanding these and other limitations, these four agencies and smaller ones in the federal funding ecosystem have been integral to the success of Canadian scholars and scientists over the course of the last 40 to 50 years.

The following examination of these programs and agencies has been guided by the principles set out in Chapter 1, by very valuable input from researcher roundtables and submissions, and by the secretariat's analyses. We have paid particular attention to resources, given the concerns surfaced in Chapter 3, and identified a number of funding gaps. Recommendations have accordingly been made to address key shortfalls.

In addition to deliberating on the size of the funding envelopes available by activity, we do offer observations about many of the individual programs and make some recommendations for their improvement. These are, we repeat, competitive systems that allocate resources based on granular adjudication processes. There are no fixed, precise solutions. The best outcomes are achieved through a constant process of setting priorities, evaluating outcomes, and adjusting course where needed. This concern underpinned recommendations in Chapter 4 to do with improved oversight, priority setting, and evaluation; and recommendations in Chapter 5 that addressed the need for multi-agency planning, a lifecycle approach to personnel and operating support, and improved data collection. The recommendations here accordingly address the next several years in the evolution of the federal ecosystem with a working assumption that mechanisms will be in place to make longer-term course corrections as needed.

This chapter begins with granting council funding for the direct costs of research projects or programs. Such grants are the best known part of the research enterprise, and obtaining such grants is integral to the career development of most Canadian scholars and scientists.

6.1 Direct Project Funding

The granting councils had a combined budget of approximately $2.8 billion in 2015-16 to support research and research-related activities within Canada's postsecondary sector. This includes council-specific and tri-council support for student training and scholarships, postdoctoral fellowships, research chairs, research grants, networking, knowledge mobilization, and community engagement, and approximately $340 million[i] flowing to universities through the Research Support Fund (RSF) to partially offset facilities and administration (F&A) costs. These institutional costs of hosting research and researchers are sometimes called (inaccurately) indirect costs; the term "F&A costs" better captures the direct financial impact of these activities. Direct support for research through project and program grants comprises the largest funding

i For 2016-17 the Fund was raised to $369 million.

category at approximately $1.66 billion. While some of this, roughly $152 million in 2015-16, is delivered through tri-council competitions for large-scale research networks such as the NCE suite of programs discussed below, the bulk is awarded through other peer-reviewed competitions in which individuals or small teams of researchers submit proposals for grants to cover a variety of direct costs associated with research. Eligible research costs vary by granting council, but they generally include research material and small equipment, office supplies, travel, workshops or seminars, professional services, and stipends/salaries for the students, postdoctoral fellows, professionals, and technicians working on a project.

Research grants are delivered through a number of programs but, as observed earlier, can generally be grouped into two categories: (i) grants for investigator-led research, variously termed discovery-oriented, inquiry-driven, or simply "independent", a simple and inclusive description; and (ii) grants for priority-driven research, often carried out in partnership with government, business, and non-profit sectors. In the former category, decisions about what to study and how to conduct research rest largely with the researchers themselves. In the latter, these decisions involve a wider variety of stakeholders and include a greater number of considerations from outside the research environment.

Our analysis of support for direct research costs begins with an examination of whether the granting councils' current balance of funding between these two modes of research is optimal. These programs are the core support for research excellence in Canada and most other national systems. However, many world-leading research agencies devote resources to other elements as well: viz., building and sustaining critical mass, enabling international and multidisciplinary collaboration, promoting risky and potentially ground-breaking research, and supporting research that responds to rapidly emerging opportunities. The Panel makes specific recommendations in this and the following chapter on program changes that we believe would enhance global research excellence in Canada.

In 2015-16, programs supporting investigator-led research provided approximately $956 million in funding. These programs include council-specific programs such as NSERC's Discovery Grants, SSHRC's Insight and Insight Development Grants, and CIHR's Project and Foundation Grants. Programs supporting priority-driven research provided approximately $705 million in funding in 2015-16. This includes $553 million delivered through council-specific programs such as NSERC's Collaborative Research and Development Grants, Engage Grants, and Strategic Partnership Grants; SSHRC's Partnership and Partnership Development Grants; and CIHR's grants supporting Signature and Strategic Initiatives; as well as $152 million delivered through tri-council programs, such as the NCE program and CFREF. This latter number will rise by an additional $150 million once CFREF is fully ramped up.

Canada's postsecondary research ecosystem has grown considerably since 2000. Total research grant funding available grew from approximately $785 million to $1.66 billion.[ii] The value of this funding, however, has been eroded by inflation. The demands on it also have grown and the number of researchers has expanded significantly from approximately 33,000 to an estimated 65,000.[iii] This growth has paralleled the increasing recognition that research is a key activity in the innovative processes that bring a wide range of practical benefits to Canada and the world. A desire to increase these practical benefits led the previous federal government to target many of its new investments to priority-driven and partnered research.

Programs funding priority-driven research vary considerably in the types of support they provide, but they are similar in requiring applicants to design projects around specific practical objectives, often targeted to strategic government priorities and carried out with external stakeholders. Furthermore, many of these

ii This includes funding through the programs supporting both investigator-led and priority-driven research listed in this section.

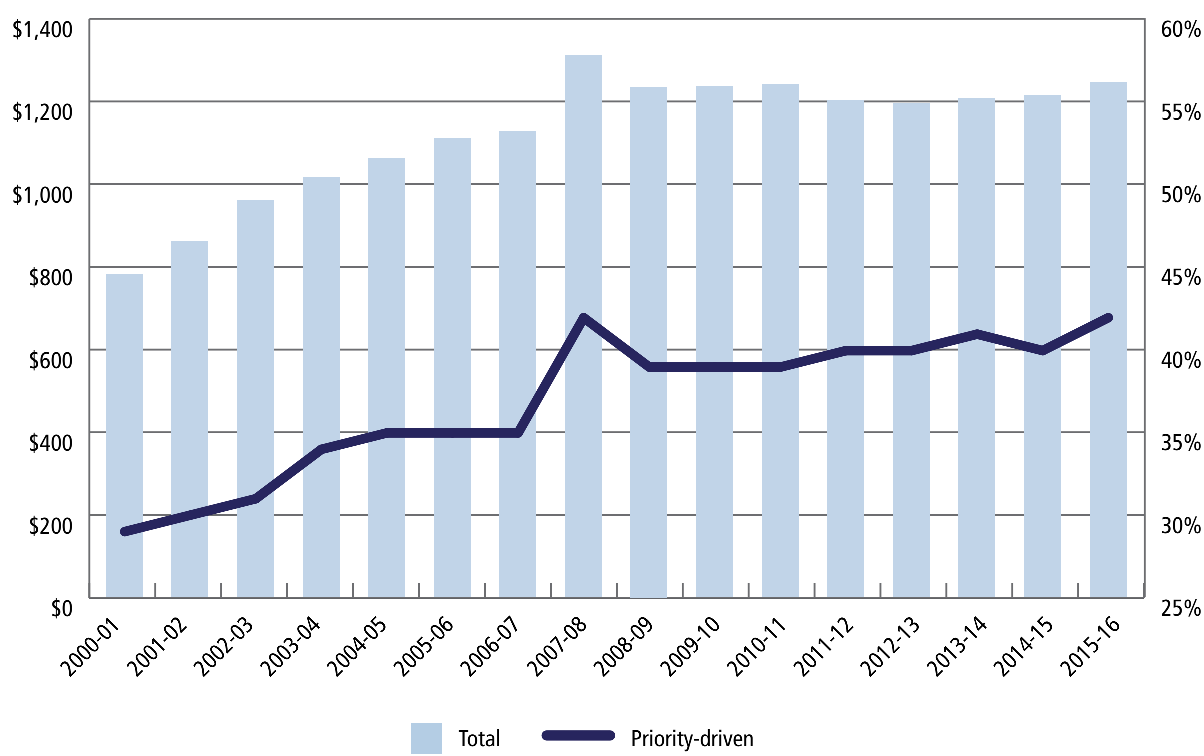
iii This number estimates the full-time equivalents of all personnel engaged in higher education research, including postdoctoral fellows and graduate students. Data from Statistics Canada: Personnel engaged in research and development, by performing sector, occupational category and type of science (CANSIM table 358-0159). The secretariat extrapolated the number of researchers for 2015-16 from 2013-14 data based on the recent average growth rate. The Panel and secretariat thank stakeholders who kindly lent us their data and expertise as we examined this issue.

programs require some form of matching support from non-academic partners. This requirement provides additional resources to the research ecosystem and is intended to ensure that those who apply the results are closely involved in designing and managing the project. Priority-driven research has long been part of the postsecondary research ecosystem and has resulted in a number of highly effective and productive partnerships between academic researchers and their business and government partners. Although priority-driven research is often focused on driving technological innovation and is therefore more prevalent in the natural and health sciences and engineering, research in the social sciences and humanities holds equal promise to help Canada address many of the challenges the nation faces.

The Panel welcomes the role taken by universities and academic researchers in addressing strategic priorities or supporting innovation in the public or private sphere; however, as noted in Chapter 2, these activities are only as strong as the foundation of investigator-led, discovery research on which they are built. Therefore, a careful balance must be maintained between the two types of research.

The changing balance between the two modes of research is clearly evident from Exhibits 6.1 and 6.2. In 2000, priority-driven research comprised approximately 30 per cent of total granting council research grants. Over the following 15 years, support for it grew substantially, focused particularly on research carried out in partnership with the private sector. By 2015-16, priority-driven research accounted for 42 per cent of spending in council-specific and tri-council research programs. While these new investments helped to grow the postsecondary research ecosystem and support an increase in the number of researchers, the failure to match these investments with adequate growth in investigator-led funding has resulted in rapidly declining success rates in investigator-led grant competitions, declining grant size, or both. The Panel was advised repeatedly that many young researchers have been left without a means to establish independent research careers and many senior researchers now spend substantially more time applying for multiple grants to sustain their life's work.

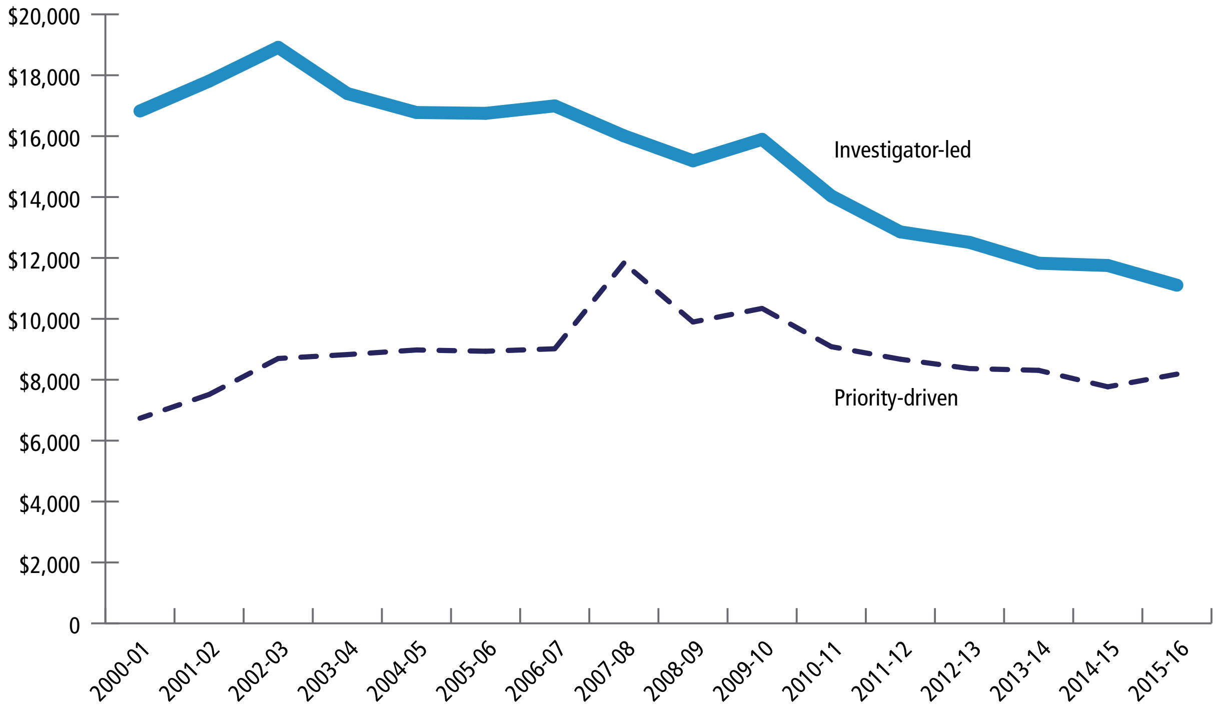
Exhibit 6.1: Overall Granting Council Research Funding, and Proportion for Priority-driven Research (Constant 2000 Dollars, $ Millions)



Note: Total research funding (left axis) is the sum of granting council expenditures on investigator-led and priority-driven research.

Source: Compilations from the secretariat based on data provided by the granting councils.

Exhibit 6.2: Granting Council Funding per Researcher for Investigator-led and Priority-driven Research (Constant 2000 Dollars)



Source: Compilations from the secretariat based on data provided by the granting councils. The number of researchers for 2014 to 2016 was extrapolated from prior year growth trends.

A mix of investigator-led and priority-driven research is part of every dynamic research ecosystem. Researchers at universities and university-affiliated hospitals clearly see value in both. They are actively extending the boundaries of knowledge and ensuring that the practical benefits of new knowledge are realized. While the optimum ratio of investigator-led to priority-driven research is open to debate, there is also wide agreement that priority-driven research cannot flourish without substantial investments in independent research. This holds true both because independent research, whether basic or applied, is a fertile training ground for the next generation of researchers and because many of the most innovative applications depend on knowledge that was created from independent research, especially basic research.

The Panel observes further that the application of knowledge to improve the health and the social, economic, and environmental well-being of Canadians is an activity that universities share with the private, non-profit, and government sectors. In contrast, the investigator-led pursuit of knowledge is one that the universities alone conduct, along with research hospitals and independent institutes. Shifting postsecondary research from discovery to application accordingly leaves a research gap that no other sector is equipped to fill. Similarly, the granting councils are Canada's primary instrument to support investigator-led research. Focusing council resources on priority-driven and partnered research leaves a funding gap for investigator-led research that no other organizations are able to fill.

Continuing the current imbalance between investigator-led and priority-driven research would leave Canada's research ecosystem increasingly dependent on discoveries and ideas generated by other countries, even as Canada's researchers became less integrated with the global research enterprise. As noted in Chapter 2, the Panel's view is that there is a virtuous circle here: Strong linkages between Canadian researchers and their counterparts around the world help Canada to identify and apply ground-breaking discoveries and insights that arise from outside our borders. These linkages depend in turn on Canada making a major contribution to the global trove of new knowledge. The training of successive generations of Canadian researchers capable of identifying and applying ground-breaking discoveries is of further importance in ensuring a vital investigator-led research community in Canada.

We documented in Chapter 3 the rapid growth of the postsecondary research ecosystem since 2000. This growth has helped to raise the international profile of Canadian researchers and created stronger research linkages across Canada's various sectors. However, that growth was built on underpinnings that now appear to be steadily eroding. Declining funding per postsecondary researcher, particularly for investigator-led research, is very evident in Exhibit 6.2. This phenomenon has clearly contributed to decreasing success rates for grant competitions. The Panel heard that low success rates have resulted in fewer mid-career researchers applying for council funding, and made it difficult for many ECRs to establish productive research careers. We have also been advised that low success rates and declining grant sizes have impeded the participation of Canadian researchers in large-scale international research projects.

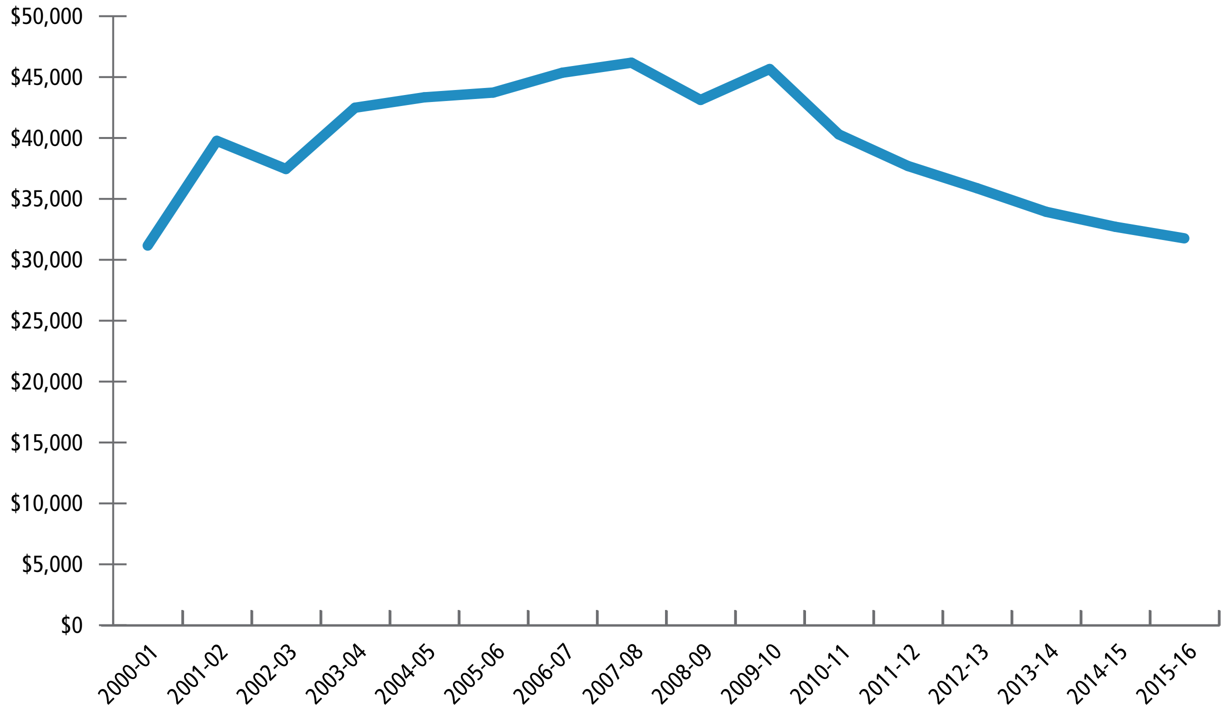
Of course, a balance could be restored between investigator-led and priority-driven research through reallocation of resources between those activities. The Panel considered and rejected this option. Our concern is not with the government's support of priority-driven and innovation-accelerating work. We believe such support is useful—all the more reason why, as we recommended in Chapter 1, the programs and their performance should be reviewed in depth. Our issue is with the overall funding level and related balance needed to keep the independent research enterprise healthy and productive.

Another and similar line of argument is that the boundaries between priority-driven and investigator-led research can be blurred. CFREF awards are advanced as an example: clearly priority-driven, but leaving considerable latitude for individual scientists to pursue their research within a pre-specified domain. The Panel acknowledges this dual nature of the CFREF program, but believes its character remains substantially different than that of, say, the Discovery Grants program, not least as regards concentration of resources and predetermination of boundaries for their deployment.

In any case, both lines of argument—whether about rebalancing or reclassifying within a fixed budget—are refuted by a very simple analysis of the total resources available per active researcher. For Exhibit 6.3, we include all granting council and tri-council funding for the postsecondary sector. The exhibit shows that following the austerity of the late 1990s, the reinvestment in extramural science steadily pushed up the total resources available per researcher, peaking in 2007-08 when the Harper government made a double-digit commitment to the three councils (albeit with a substantial proportion of funds tightly earmarked—as can be seen in Exhibit 6.2). Since then, funding has been relatively steady while the number of researchers has grown and inflation has slowly whittled away the value of the dollars provided. The result is that in 2015-16 the real resources available per researcher were down by 31 per cent from the peak. This does not argue for reallocation within the envelope but simply for a major reinvestment in the research enterprise.

The Panel also has substantial collective experience with excellent colleagues who move happily back and forth between investigator-led and priority-driven research, and would do so more readily if they had a secure funding base for their independent research agenda. A major new injection of funding into investigator-led research would rebalance the extramural research ecosystem, restore the foundations for the postsecondary research enterprise upon which Canada relies so heavily, and help to ensure that new knowledge is both discovered and applied to the benefit of Canada and the world.

Exhibit 6.3: Total Granting Council Funding per Researcher (Constant 2000 Dollars)



Source: Compilations from the secretariat based on data provided by the granting councils. The number of researchers for 2014 to 2016 was extrapolated from prior year growth trends.

Recommendation 6.1

The Government of Canada should rapidly increase its investment in independent investigator-led research to redress the imbalance caused by differential investments favouring priority-driven research over the past decade.

Restoring investigator-led funding to 70 per cent of total granting council research grants (i.e., the level it was at in 2000) would require new annual investments of approximately $575 million in investigator-led research starting from a 2016-17 baseline.[iv] This increased funding would dramatically improve the health of the ecosystem, enabling new researchers to establish their careers and more seasoned researchers to continue their pursuit of excellence. It would also allow the granting councils to better support currently underfunded aspects of research discussed below, such as international engagement, multidisciplinary collaboration, and risky but potentially ground-breaking projects.

As we have noted, the ideal ratio between investigator-led and priority-driven research is open to debate. Returning to the previous 70:30 relationship may no longer be optimal given the evolution in the postsecondary research enterprise and the changing needs of Canadian society. As such, this is but one indicator that we have used to develop our fiscal proposal for direct project funding in Chapter 7.

iv If funding for priority-driven research remains at the current rate of approximately $705 million per year, investigator-led research would need to reach 7/3 × $705 million, or $1.64 billion, to equal 70 per cent of total research funding (investigator-led plus priority-driven). Subtracting the 2015-16 investigator-led funding of approximately $956 million per year leaves an incremental annual investment of $688 million in investigator-led research. Budget 2016's investment of $113 million per year reduces the amount needed further to $575 million per year.

Regardless of what the optimal ratio might be, a significant overstep has clearly occurred in recent years and some redress is necessary. This is especially true given the continuing roll-out of CFREF, which will add some $150 million per year to the priority-driven research base, further exacerbating the current imbalance.[v]

The question of how much funding is required to restore balance and reinforce research excellence in Canada leads logically to questions about where and how this new funding should be distributed. As to the "where", the Panel believes, as is argued above, that the largest need is for open competitions for investigator-led research. However, this is a broad category of research that has evolved considerably since the granting councils were first created. As mentioned above, from the Panel's consultations and a survey of other countries, a number of modern characteristics of vibrant research ecosystems are noteworthy:

- existence of critical mass, with sufficient project funds to carry out world-leading research and support for clusters and networks that can build and sustain a Canadian advantage;
- participation in international collaborations;
- support for multidisciplinary/transdisciplinary research;
- focused funding for high-risk research with the potential for high impact; and
- the ability to respond quickly to rapidly emerging research opportunities.

The Panel therefore asked: How are these objectives currently being met? If there are gaps, it is reasonable to assume that new funds should also be directed to close them. We consider each of these objectives in turn.

6.1.1 Building Excellence with Ambition and Scale

Whether we call it "critical mass" or "strategic density", the research environment is most productive when experts in a particular field or set of related fields interact comfortably with each other and are able to take on bigger, more challenging questions through their collaboration. This type of interaction can occur locally or at a distance as evidenced by constant international collaboration. What matters above all is the strength and synergy of the collaborations.

Such interactions not only enrich the research and training environment but are more likely to attract the attention and engagement of potential users of research results, be they commercial or from civil society. It is not surprising then that individual universities try to build areas of particular strengths as part of their strategic plans. However, a relatively small country like Canada must develop a few areas of critical mass, with multiple centres of excellence, if we hope to achieve global influence in the development of new knowledge or, where applicable, expand industrial subsectors that can become global leaders.

The Panel emphasizes that the goal of critical mass is not an absolute. In research one can never know where the next breakthrough will be made or which attempt at hybridization will produce the most robust offspring. As noted in Chapter 5, the available evidence suggests that a balance must be maintained between building critical mass in some fields versus sustaining a broad capacity for knowledge generation and training across a wide range of geographic and disciplinary areas.

A natural first question about this topic becomes: Are there areas in which Canada and individual institutions should seek critical mass? NACRI, as noted in Chapter 4, should be well positioned to provide broad guidance. However, the Panel believes that, for basic research, these priorities should be largely determined by adjudicating promise as it grows on a bottom-up basis, rather than dictating priorities by a top-down process. The latter approach may well be appropriate when economic development or innovation is the goal, but it has yielded uneven results in basic research.

v In the analyses that follow, we do not include provision for the planned growth in CFREF spending. It should be kept in mind, however, that if CFREF expands as planned the Panel's estimate of the funding required for investigator-led research to achieve a better balance is significantly understated—in the order of $235 million per year.

Critical mass is abetted if a number of institutions develop mutually reinforcing, in contrast to competing, strengths. As such, some degree of institutional specialization can be seen as a positive step in this direction, an observation that brings us quickly to CFREF. Towards the end of its time in office, the Harper government launched this novel tri-council program designed to foster institutional specialization. CFREF began in 2014 with an initial investment of $1.5 billion over 10 years. It will have a base budget of $200 million per year once fully ramped up in 2018-19. Its objective is to help a limited number of Canadian postsecondary institutions achieve global leadership in strategic research areas that create long-term economic advantages for Canada.

CFREF does this by providing large-scale, seven-year grants for strategic research programs that involve multiple researchers and are anchored at specific institutions. Projects must be in one of the federal science, technology, and innovation priority research areas. There have been two CFREF competitions: the first funded 5 initiatives for a total of $350 million over seven years, and the second funded 13 initiatives for a total of $900 million. Project funding ranged from $33 million to $113 million. A third competition is scheduled for 2021-22.

The positioning of the program has been criticized as closely aligned with the science ethos of the Harper government in multiple dimensions. However, the Panel observes that, insofar as it supports both basic and applied research under a broad funding umbrella, CFREF should not be misconstrued as primarily oriented to rapid application. The more difficult criticism to address is the extent of concentration of resources. At $200 million a year, the investment in CFREF corresponds to more than one-half of NSERC's current annual expenditure on all of its Discovery programs.

CFREF builds in part on the CERC program, another Harper-era program that focuses high levels of funding in elite research teams. Created in 2008, CERC awards provide universities with up to $10 million over seven years to support world-renowned researchers and their teams in establishing ambitious research programs at Canadian universities. Unlike CFREF, the CERCs have a record long enough to allow more detailed consideration; this will be done later when we review personnel awards. What matters for now is that both programs represent local or regional concentration of resources to foster specialization and critical mass.

This leads us back to the question of national networks. As we know well, Canada is a large country with a relatively small and dispersed population. But the Panel also was under the impression that Canadians are excellent networkers who effectively compensate for our geographic challenges. We were disappointed to learn, as reported in Chapter 3, that collaboration rates among Canadian researchers were not only very low but have been declining. This is especially concerning as the federal government has long made national networking a priority. The oldest of these programs is the NCEs, created in 1989. Although there is now a suite of NCE-branded programs, including Centres of Excellence for Commercialization and Research (CECR) and Business-led NCEs, the original or so-called "classic" NCEs are open to all researchers. However, they have a requirement for "KTEE", i.e., knowledge translation, exploitation, and exchange. While this does include policy-related research, it most often extends into some form of commercialization.

This classic stream currently has an annual budget of some $62 million, supporting 12 large-scale networks and 5 smaller ones with a knowledge translation focus. Because it is a tri-council program, research and researchers must cover the mandates of at least two of the three granting councils. Applicants compete for five-year grants, which can be renewed twice based on a favourable peer review. Applications must demonstrate complementarity with

> The NCE program is limited in that it has a very strict definition of 'interdisciplinarity'. The definition relates to only Inter-Council research issues. Many projects would not be eligible within this definition. Smaller projects of three or five people do not fit easily in the current structure.
>
> – University of Manitoba

related research across the country and show evidence of international linkages. Partner contributions and strong engagement of industry and/or other end-users are required. Following a maximum of 15 years of NCE funding, centres that wish to continue must find other sources of funding.

The NCE program is generally well regarded. However, the Panel is concerned that the design of NCEs is not conducive to support networks of independent researchers who wish to collaborate primarily to generate, rather than translate, apply, or commercialize, knowledge. Furthermore, although there is meaningful participation by SSH researchers, the current configuration is suboptimal for these disciplines. Revised designs could offer a mechanism to scale excellence in independent research across Canada, serving initially as something of a counterbalance to the CFREF awards, and, when CFREF support winds down, as a way to link Canadian centres of excellence together.

Recommendation 6.2

The Government of Canada should direct the Four Agency Coordinating Board to amend the terms of the NCE program so as to include the fostering of collaborative multi-centre strength in basic research in all disciplines.

To implement this recommendation for the NCE program, the Panel suggests the following:

- Evaluation criteria for KTEE should be lessened or dropped, for at least some classic NCEs, as they disadvantage basic research in most disciplines, not least SSH.
- NCEs with a basic research mission should be allowed to participate in open competitions for refunding beyond current program limits. The requirement that commercially focused networks should plan to transition out of government funding after a certain time makes less sense for basic research where few partners are likely to provide continuing funding.
- A portion of the new funding allocated to direct project financing should be used for the creation of new NCEs, some of which should be at a smaller scale. This would be of greater use for certain disciplines, e.g., SSH or mathematics.
- The requirement for a corporate structure to oversee the activities of an NCE makes good sense when commercial or other outside parties are involved, but it should not be a requirement for NCEs composed entirely of university researchers pursuing basic research.

Given the low levels of collaboration among Canadian researchers, current funding pressures, and the concentrated or single-centre nature of CFREF awards and CERCs, the Panel has mixed views about CFREF. Members of the Panel admire the ambition of this program. Some believe that it represents a welcome degree of specialization on the part of universities, and builds critical mass for Canada to compete globally. Others believe that it over-concentrates resources and is a less efficient and sustainable model than funding self-aggregating groups of frontline researchers. All agree that it is too early to tell, and an interim review is needed before launching the third wave of CFREF awards.

Recommendation 6.3

The Government of Canada should direct the granting councils to undertake an interim evaluation of the CFREF program before the third wave of awards is made. The CSA and NACRI should be engaged in the design of the review. The results would guide a decision on whether to launch or defer the program's third round, but not impede the fulfilment of existing commitments.

CFREF will unquestionably give an enormous boost to research in a limited number of fields at a limited number of Canadian centres. It has also been encouraging to observe a greater degree of inter-institutional and international collaboration in the second round of CFREF awards. Over time the program may well facilitate real national strength rather than, as some suggest, promoting the prestige and productivity of the winning institutions alone. If trade-offs across programs must be made, the Panel emphasizes that the highest priority for new funds at this time must be restoring funding to open competitions for individuals and teams undertaking independent research. However, from the narrower standpoint of options for large-scale priority-driven programs, the question to be considered is the relative impact of sustaining CFREF versus directing some of these funds to NCEs focused unabashedly on basic research across all disciplines. As stated above, the jury is out. However, with careful stewardship, the end result could be the balanced catalysis of excellence and national capacity in two ways: through concentration within one or a very small number of super-sites serving as hubs for development, and through networks of strong peers.

6.1.2 Support for International Research

Research is a global enterprise and, as noted above, the networks that drive individual researchers and teams span all borders. World-leading researchers collaborate with individual colleagues and like-minded groups around the world in addition to participating in large international research projects. These connections also link researchers and their local clusters to the latest breakthroughs, wherever they occur.

Exhibit 6.4 illustrates the growth and increasing diversity of research collaborations across countries. The size of the nodes for each country is proportional to the total number of indexed publications where any authors based at its institutions appeared with any international co-authors for the given years (i.e., 1998 and 2011). The thickness of the lines between any two nodes represents the number of documents including co-authors from that pair of countries. The distances between the country nodes are inversely proportional to the strength of collaboration, estimated by combining these measures. Countries are included if they exceeded a minimum of 10,000 co-authored documents in either 1998 or 2011.

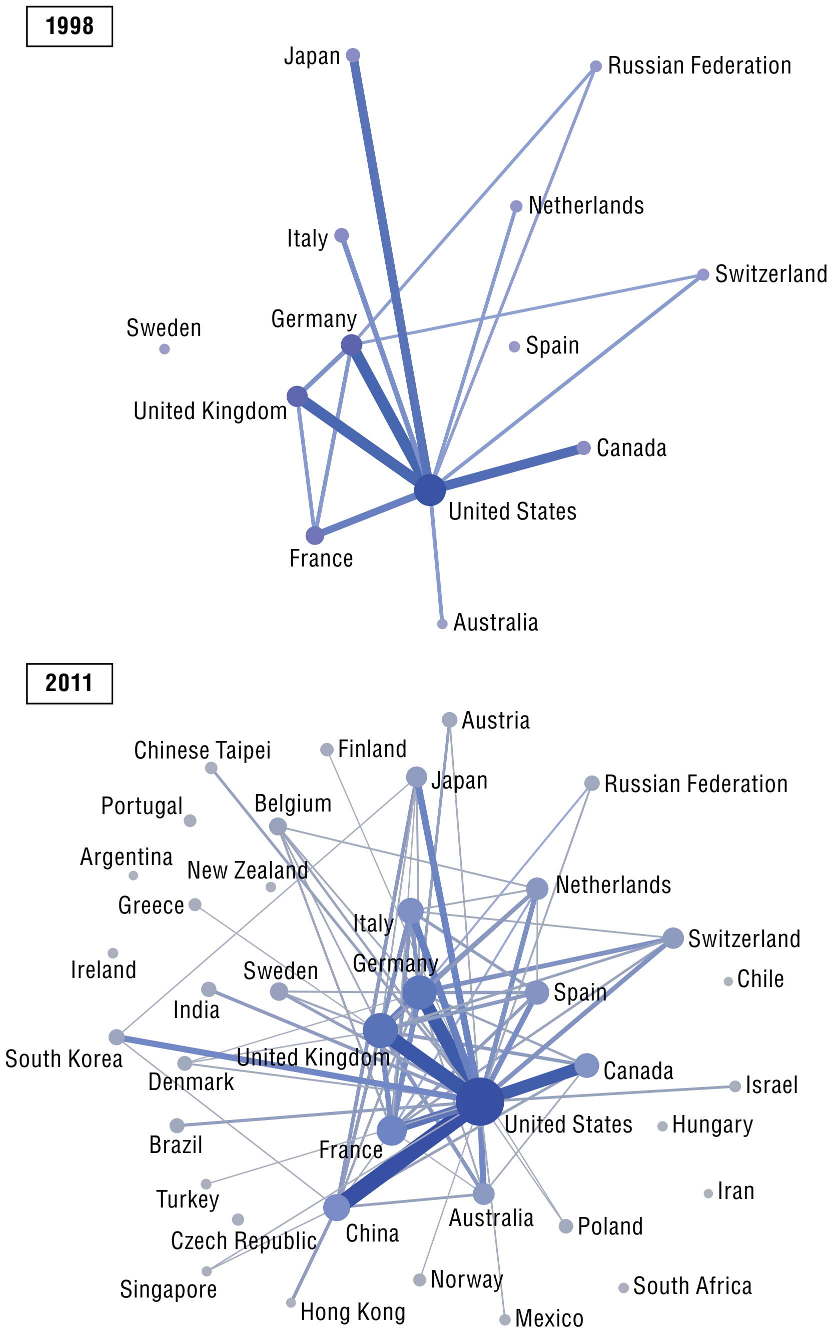
The message is clear: The number of countries important in science is growing rapidly as are the connections among researchers. Canada is clearly a significant participant in the internationalization of science. But the challenge will be to maintain our position and grow it further in the future.

The primary driver of most international collaborations appears to be the researchers themselves. They seek out the best people, institutions, and facilities to complement their research, wherever they may be. While such self-organizing networks have long characterized the global research landscape, new collaboration opportunities, which require a different and more focused and coordinated approach, are emerging at national and regional levels.

> Canada must play a greater role in the growing internationalization of public research if it wants its researchers to exercise leadership and reach wider audiences. The FRQ would like researchers to be better equipped to take advantage of funding opportunities on the international stage and position themselves as international leaders.
>
> – Fonds de recherche du Québec

Pockets of funding for international collaboration exist at the federal government level and within the granting councils. However, with many different departments and agencies pursuing their own objectives, there is little strategic coordination. Funding is often diluted, incorporated within other international governmental agreements for business and innovation, or discontinued. For example, Global Affairs Canada manages 13 science and technology agreements but any funding associated with them (through the Canadian International Innovation Program[1]) is for industrial R&D and limited to five countries. Similarly, its Going Global Innovation program[2] supports Canadian researchers who aim to commercialize technologies by pursuing collaborative international R&D opportunities. There is a clear gap, though, when it comes to providing funding for international collaborations with a focus on basic research.

Exhibit 6.4: International Collaboration Networks in Science, Whole Counts of Internationally Co-authored Documents, 1998 and 2011



Source: Organisation for Economic Co-operation and Development. OECD Science, Technology and Industry Scoreboard 2013: Innovation for Growth. Paris: OECD Publishing; 2013. Available from: http://www.oecd.org/sti/scoreboard-2013.pdf

Recommendation 6.4

The Government of Canada should mandate the Four Agency Coordinating Board to develop multi-agency strategies to support international research collaborations and modify existing funding programs so as to strengthen international partnerships.

In developing approaches to improve support for international research, the granting councils should consider:

- the need for dedicated funding for international research collaborations;
- improved mechanisms to collect and report data on international research activities; and
- proactive and coordinated efforts to engage with international funding partners to create opportunities for Canadian researchers.

The three granting councils have different levels of internationalization and generally fund internationally collaborative research out of existing grant structures. There does not appear to be an earmarked fund targeted to international research collaboration, or a harmonized approach. As a result, the councils vary in terms of participation in international networks and thematic initiatives. CIHR is the most active with over 50 agreements, while NSERC and SSHRC have a smaller number of initiatives. We understand that, on occasion, the councils have responded proactively to opportunities. For example, SSHRC played a leadership role in the Trans-Atlantic Platform, designed to develop international research cooperation in SSHRC disciplines, with 10 partners in the EU and the Americas. In general, however, the Panel saw little evidence of a coherent strategy.

Because there is no overarching federal strategy or reporting, we also had difficulty determining how much Canada spends overall, or should spend, on international collaborations. These data are not tracked because universities and researchers are not required to report these activities. Adding to the complexity of the landscape, the provinces have their own funding agreements and initiatives for international research. Quebec, for example, has a fund with three streams to support international science operation: bilateral projects, multilateral projects, and large-scale projects. It also has co-funding agreements with certain countries (e.g., China, France, Mexico, and the EU via ERA-Net) as does Ontario, which spends approximately $25 million a year on international collaborative opportunities.

Notwithstanding some good efforts by the councils to support individual collaborations, Canadian researchers lamented to the Panel the fact that Canada is not taking full advantage of the increasing number of opportunities to partner on a larger scale. Thus, while program flexibility that supports bottom-up collaboration must be encouraged and expanded, the scope and scale of international collaboration have increased to the point that the granting councils must make focused and coordinated efforts, often working closely with their international counterparts.

> I would strongly encourage Canada to be full partners in EU-funded programs. Currently this appears to be a hit and miss affair. Some competitions Canadians can apply as full members and others it can't. For example, the EU Horizon 2020 program does not allow Canadians to receive funds, or lead programs.
>
> – Active researcher, McGill University

Countries such as China, India, and the Republic of Korea have rapidly growing scientific establishments that provide new opportunities for collaboration. Others such as the U.S., U.K., and Australia have dedicated programs to fund and/or catalyze international research collaboration. Horizon 2020 is the largest EU research and innovation program with nearly €80 billion of funding available over seven years. Researchers outside the EU can participate in Horizon 2020 through open or targeted calls, joint calls between funding organizations, multilateral thematic initiatives, or co-funding arrangements. To capitalize on these and other opportunities, a clear strategy, concerted action, and earmarked investments are all needed.

6.1.3 Multidisciplinary Research

> There is a need to ensure that there are opportunities for those scholars who address subject matter that transcends the traditional disciplinary boundaries. … Many of the issues facing Canada and the world involve inexorably interconnected natural and social phenomena and processes that require distinct kinds of science to understand, and that tend to 'fall between the cracks' in funding programs structured on disciplines. Of course, this is not to suggest that inter- or trans-disciplinarity should be required in any way. Rather, just that there are clearly defined opportunities for those with the skill and courage to attempt to undertake these kinds of science.
>
> – Eminent researchers roundtable

World-leading research often crosses traditional knowledge and disciplinary boundaries and is increasingly multidisciplinary[vi] in nature—both in its bridging of previously unconnected fields of knowledge and its development of entirely new disciplines. As noted in the previous chapter, this challenges traditional peer review models that are based upon assessment by disciplinary experts. Granting agencies are also required to take on a more proactive role in training reviewers and revising review criteria for multidisciplinary proposals.

The prevalence and impact of multidisciplinary research has been on the rise since the mid-1980s. The number of references in academic articles to research from other disciplines is increasing.[3] Publications based on multidisciplinary research have been found to have a greater impact in the long term (as measured by number of citations) than discipline-based publications.[4] Multidisciplinary research is prevalent in all research areas and is increasingly crossing traditional boundaries between the social, natural, and health sciences and even between the humanities and engineering—in other words, all the boundaries that currently demarcate Canada's federal granting councils. Canadian universities have created a variety of structures that cross traditional departmental and disciplinary lines to accommodate and, in many cases, encourage the growing presence of multidisciplinary academic degree programs and research. The same trend is apparent in the array of scholarly and scientific conferences on offer each month and the growing number of journals in new fields created by the convergence of old disciplines.

The granting councils have taken some commendable steps towards supporting and encouraging multidisciplinary research; for example, the epistemological architecture of CIHR's institutes speaks to a new ethos. However, at various roundtables, the Panel was apprised of continuing challenges facing researchers whose work either does not fit readily into the competitions and assessment criteria for grant applications, or is adjudicated in ways that show puzzling blind spots.

Evidence reviewed in Chapter 5 suggests that multidisciplinary proposals from individuals or small teams of researchers are more likely to be disadvantaged in adjudication when success rates are low and review committees become more conservative in rating grant proposals. Challenges also apparently arise due to narrow definitions of merit whereby relevant milestones, such as establishment of collaborative networks or data-sharing agreements, are undervalued. Even in the Australian system where a single agency manages all grants and where a "big tent" viewpoint might be expected, a formal analysis showed that the greater the degree of multidisciplinarity, the lower the probability of being funded.[5]

Recommendation 6.5

The Government of Canada should mandate the Four Agency Coordinating Board to develop strategies to encourage, facilitate, evaluate, and support multidisciplinary research.

vi The Panel recognizes that the terms "multidisciplinary", "interdisciplinary", and "transdisciplinary" have different connotations and there is a lack of consistency in their usage. For simplicity we use "multidisciplinary" in this report.

In this work, the Panel suggests consideration of the following elements:

- the need for strengthened systems within granting councils to adjudicate multidisciplinary research proposals;
- creation of programs to support multidisciplinary research that spans the boundaries of granting councils;
- loosening of restrictions on the use of grant funds to facilitate the pursuit of broader lines of inquiry;
- more collaborative approaches among granting councils to take joint responsibility for researchers at the edges of their respective mandates; and
- improved mechanisms to support large-scale multidisciplinary research.

From what the Panel has learned, multidisciplinary research proposals cutting across disciplinary boundaries within individual granting council domains are usually adjudicated by special review committees constructed to ensure a wide range of experience and expertise. Even then there are challenges in ensuring the necessary expertise and quality of peer review, as noted elsewhere in this report. Proposals that cut across granting council boundaries, however, face a more difficult challenge as the councils have different program structures and funding timelines and there are very few mechanisms for councils to jointly adjudicate applications. One positive exception is the Collaborative Health Research Projects program, a joint initiative between NSERC and CIHR to fund projects involving any field of the natural sciences or engineering and any field of the health sciences.

Another barrier to multidisciplinary research is that funding awarded from one granting council currently cannot be used to support research or researchers outside that council's mandate. This means that a multidisciplinary project crossing council mandates would need to separately obtain funding from more than one council. NSERC's Collaborative Research and Training Experience (CREATE) program is an exception to this rule. It allows up to 30 per cent of the value of a CREATE grant to fund researchers and research at the interdisciplinary frontier between the natural sciences and engineering and the areas covered under the umbrella of SSHRC and CIHR. If this model has been proven to function as proposed, it may be worthy of wider adoption.

We note, too, that certain areas of research (e.g., health law, medical anthropology, design) are distinct disciplines that have not found consistent support from any of the granting councils. Reports of researchers being told by SSHRC or NSERC to "go to CIHR" and then by CIHR to "go to SSHRC or NSERC" were plentiful. The challenge in these instances is not so much that that these topics require multidisciplinary adjudication; rather, they represent transdisciplines with communities of scholars who do not fit cleanly within the mandate of a single granting council. The simple solution is for the agencies to collaborate in building a welcoming home for these orphan disciplines, and to ensure that appropriate peer review mechanisms are structured for them.

Federal funding for large-scale multidisciplinary research is primarily provided through the NCE program. As noted above, proposals to that program must include research and researchers covering the mandates of at least two of the three granting councils. However, this program's focus on finding solutions to major social, economic, or health issues leaves investigator-led research without an adequate funding instrument for networked collaborations. Allocating funding to the NCE program for the creation of smaller-scale networks in areas of basic research will help better support multidisciplinary collaborations across Canada.

6.1.4 Support for High-risk Research with Potential for High Impact

Research that tests the findings of others or drives incremental increases in knowledge is vitally important and indeed forms the majority of research worldwide. However, world-leading research challenges the status quo and takes risks by identifying new questions or proposing startlingly new answers to questions that many thought settled. All three granting councils have a mix of programming that offers latitude for riskier research questions to be pursued. However, concerns were raised in our consultations that current financial pressures are leading Canadian peer review committees to favour proposals using proven techniques, in areas that have been productive in the past, and from more established researchers with proven track records. A 2008 International Blue Ribbon Panel reviewing SSHRC programs[6] noted that a number of challenges remain in ensuring funding for high-risk, high-reward (HR^2) research when budgets are constrained. NSERC does add supplements to Discovery Grants that appear to be in the HR^2 category, but a 2014 international review of NSERC's Discovery Grant program[7] found that funding levels were too low to support truly innovative research in some fields.

> You cannot innovate and be leaders in your field or as a country by proposing and supporting research mainly with established lines of inquiry (and too often preordained results). ... In the past 10 years, [some grants have] become 'reimbursement forms' for past research with the application jam packed with so many preliminary results to support the hypothesis that no doubt is left on the success of the proposed research because it has already been done! Where is the innovation when only 'safe' science is proposed? The overwhelming majority of the game changing discoveries were not made by following a pre-established line of enquires, but rather by being interested in unexpected observations.
>
> – Active researcher,
> Université de Sherbrooke

These observations further support the Panel's contention that there is a pressing need to increase the overall level of support to Canada's granting councils. Risk aversion not only limits the opportunities for Canadian researchers to operate at the frontier of research, but, as noted earlier, it constrains the ability of young researchers, often at the peak of their creativity and intellectual curiosity, to establish innovative research programs. Finally, even in better-funded research ecosystems, many agencies recognize that HR^2 grants may not fare well with conventional peer review processes, and special competitions for small HR^2 developmental grants have been created.

Recommendation 6.6

The Government of Canada should mandate the granting councils to encourage and better support high-risk research with the potential for high impact.

In reviewing their programs and policies, the granting councils should consider the following elements:

- making support for high-risk, high-reward research an explicit part of their missions;
- amending funding program criteria to ensure that a meaningful portion of grants goes to riskier projects; and
- providing training to peer reviewers to reduce potential bias against high-risk research.

As noted, various countries and regions have programs of this nature, sometimes segregated by career stages. Most include a combination of specific funding and alternative forms of evaluations. Some also offer HR^2 grants that are shorter term and allow researchers to bypass full traditional peer review with a low-cost feasibility study.

In the U.S., this concept was endorsed in 2007 by the National Academies in their landmark report, *Rising Above the Gathering Storm*.[8] The authors recommended setting firm targets for high-risk research, suggesting that 8 per cent of total R&D budgets should be set aside for this purpose. At the agency level, the National Science Foundation (NSF) promotes what it calls transformative research (TR) across its programs. In 2012 it also modified its merit review criteria to include TR; established an agency-wide working group on the topic; added a number of funding mechanisms (e.g., EAGER—roughly 0.9 per cent of all NSF-funded research, or US$64 million in 2013) to support TR; and introduced training for program officers on the importance of TR. NSF continues to experiment with innovative approaches to promote and identify potentially transformative research. Indeed, its mission statement is clear in this regard: "In addition to funding research in the traditional academic areas, the agency also supports 'high-risk, high pay-off' ideas, novel collaborations and numerous projects that may seem like science fiction today, but which the public will take for granted tomorrow."[9] The U.S. NIH's High-Risk, High-Reward Research Program supports "exceptionally creative scientists pursuing unusually innovative research with broad potential impacts" through four award programs targeted to researchers at different career levels.[10] Some proposals for these awards do not require data or detailed research plans; others have two-panel review processes that include generalists.

There is no reason why Canada should be a laggard in this regard. If anything, our comparatively small size argues that we should be risk-takers if our aspiration is to have a much larger impact on the global flow of discoveries and ideas in the decades ahead.

6.1.5 Support for Rapid Response Research

For research to be world-leading, relevant, and impactful, it must adapt to new opportunities and to a changing social, economic, and natural environment. This includes opportunities created by new fundamental discoveries and insights developed elsewhere, natural disasters with both immediate and longer-term consequences, or rapid social shifts.

The majority of granting council funding opportunities occur on a regular schedule with one or two annual competitions. The Panel observed that other international agencies, best exemplified by Germany's DFG, have more nimble and flexible approaches to organizing competitions, while still providing in-person peer review and timely adjudication. Extending this approach to Canada's granting councils would require a culture shift to ensure that peer review processes are more adaptable and responsive. It also requires financial flexibility to accommodate fast-emerging frontier fields.

The granting councils must also be able to adjudicate proposals rapidly in response to emerging threats or immediate crises. There are positive domestic precedents: CIHR responded within weeks to the global and Canadian SARS outbreak in 2003. The granting councils have also responded commendably in recent years, such as SSHRC's recent partnership with Immigration, Refugees and Citizenship Canada to support research on the arrival, settlement, and integration of Syrian refugees. As with international collaborations and partnerships, these responses, while commendable, have been somewhat ad hoc. The CSA could play a key role here in helping to coordinate activities.

The Panel noted the effectiveness of the NSF's RAPID program as a potential model for a rapid response funding mechanism. This program is used for urgent proposals, including quick response research on natural or anthropogenic disasters. Only internal merit review is required for RAPID funding, which is up to US$200,000 and of one-year duration. The NSF also supports collaborative projects with other countries through this initiative, but will only fund the U.S. portion. In May 2016 for example, the NSF funded nine rapid response grants, totalling US$1.7 million, to find new ways of halting the spread of Zika, which was quickly becoming a major public health threat. It also funded grants to study the El Niño phenomenon and the aftermath of the Nepal earthquake.

Many rapidly emerging issues are multidisciplinary in nature and have international dimensions. The Panel believes that the creation of a dedicated tri-council funding mechanism for rapid response research would be timely given the accelerating pace of social change as well as the importance of evidence-based public policy-making at this juncture in human history.

Because demands on this fund would be intermittent and unpredictable, it could easily be structured alongside the international, multidisciplinary, and/or HR^2 research funds on a contingent basis. We have examined international precedents and estimated that the relevant contingency fund for these four priorities would be no more than 5 per cent of the investigator-led budget. Drawing that amount away in the currently constrained environment will be challenging, and we address this gap in the costing of recommendations in Chapter 7.

Recommendation 6.7

The Government of Canada should mandate the granting councils to arrive at a joint mechanism to ensure that funds and rapid review mechanisms are available for response to fast-breaking issues.

6.2 Funding for Research Infrastructure and Equipment

> CFI is missing a predictable funding envelope. This leads to uncertainty in the research ecosystem and hampers long-term research planning. Canada needs to address this issue by providing a predictable, multi-year funding commitment to CFI.
>
> – University of Calgary

The Panel strongly believes that the recommendations above will fill some of the most obvious gaps in the current suite of direct supports for Canadian researchers, and help to build and sustain scholarly and scientific excellence in Canada. However, while research operating grants in varied configurations are at the core of the ecosystem, the ability to use a grant effectively depends on a range of other supports. We turn our attention now to federal investments in research infrastructure and equipment.

While some very small-scale equipment and supplies can be readily covered from research operating grants, larger infrastructure costs are generally beyond the scale of individual grants and direct project support, and many span multiple projects and very large teams of scientists and scholars. As a result, researchers through their host institutions must apply for infrastructure funding separately from direct project funding. The relevant federal agency for such infrastructure is CFI.[vii] We examine CFI first, and then look briefly at how the digital infrastructure needs of researchers are served because these are met through other systems.

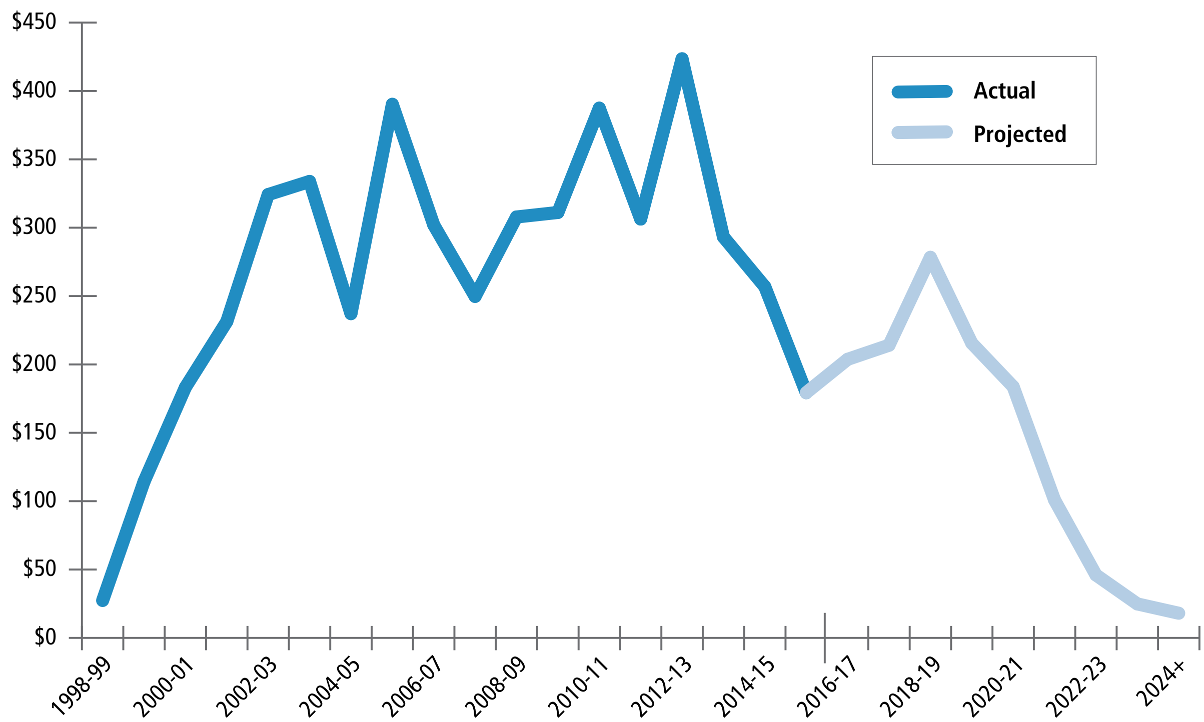
6.2.1 General Research Capital: CFI

We examined the governance of CFI in Chapter 4. Established in 1997, it is an arm's-length, non-profit corporation with the mandate to increase the capability of Canada's postsecondary institutions, research hospitals, and non-profit research organization by investing in research infrastructure. CFI was initially tasked with leveraging a federal investment of $800 million into $2 billion for research infrastructure, by providing 40 per cent of project costs with other partners providing the remaining 60 per cent. The provincial governments were the principal funding partners but universities, colleges, businesses, and charities also provided funds. The leveraging requirement allowed the federal and provincial governments to determine priorities jointly. CFI funding covered the full range of infrastructure from large-scale national projects to relatively small awards. All capital funds were allocated by peer-reviewed competition, with applications made by institutions rather than individual researchers.

vii We will not be examining the two major economic stimulus programs that governments have put in place to improve knowledge infrastructure, the Knowledge Infrastructure Program (launched in 2009 with $2 billion over two years) and the Post-Secondary Institutions Strategic Investment Fund (launched in 2016 with $2 billion over three years). Both of these are time-limited economic stimulus programs, although they might be viewed as having temporarily attenuated the need for an upward adjustment in the CFI capital budget. Another ongoing source of funding for the purchase or fabrication of smaller research equipment is NSERC's Research Tools and Instruments (RTI) program. The RTI budget fluctuates from year to year, but over the past decade it has provided an average of approximately $30 million per year.

Some 20 years later, CFI is still following essentially the same business model. It operates on a third-party contribution agreement and has received eight rounds of multi-year funding to date for a total of just over $6.8 billion. As Exhibit 6.5 shows, this intermittent flow leads to something of a saw-tooth pattern to annual outlays. This situation is hard to reconcile with the reality that CFI has effectively become the fourth pillar of federal support for postsecondary education research, and it has been treated as such throughout this report. Its program offerings have also been expanded over time to include the responsibility to provide some infrastructure operation funds and special funding for the operating costs of MSIs. These areas of activity, and their funding levels, are covered in the next section.

Exhibit 6.5: CFI Expenditures on Capital Programs ($ Millions)



Source: Compilations from the secretariat based on data provided by CFI.

Generally, the Panel has concluded that the CFI model is working well. No major changes in structure or programs are needed, other than the urgent necessity for the three granting councils and CFI to work more effectively together, as recommended in Chapter 4.

We believe that change is required in one area, however, which was brought repeatedly to our attention in the consultations. Although CFI is effectively a permanent part of the funding environment, its relationship with the federal government does not reflect this reality. CFI is funded on an ad hoc basis instead of having an ongoing budget, and it is mandated to create and manage specific funds for a set period of time. The result can be seen clearly in Exhibit 6.5: a high degree of variability in its year-to-year disbursements to capital projects.[viii] In consequence, it is often impossible for CFI and researchers to know from one year to the next what the timing or the size of the next competition will be. This greatly complicates coordination with the granting councils and hampers the ability of research institutions to

viii The apparent rapid decrease in projected funding in 2018-19 is due to future federal investments not having yet been made.

manage their capital plans efficiently. As discussed in Section 6.3, this is further complicated by the fact that a significant part of the CFI budget is now required for stable yearly operating support for previously granted infrastructure.

Recommendation 6.8

The Government of Canada should provide CFI with a stable annual budget scaled at minimum to its recent annual outlays.

Stability is only part of the solution. The level of the budget has to be set to create an effective balance across the research funding system. Over- or underinvesting in new infrastructure means that projects either cannot be done for lack of access to capital or infrastructure remains idle. Clearly CFI's investments in infrastructure should be linked to the granting councils' planned investments in research. We offer some views here on how a capital budget might be set, but freely admit that this is an art rather than a science. The needed level of investment in capital is dynamic and must be re-evaluated regularly as it varies with the kinds of research projects being funded, trends in capital costs, and several other factors.

As a starting point, however, we can look at the relationship between capital and project funding in other countries to provide some guidance. In 2014, ISED commissioned a report by Science-Metrix to look at this question.[11] It compares trends in Canada with those in Australia, Germany, the U.K., and the U.S. (NSF) over the 2008–2013 period. Although each country has a unique system for supporting research, their average spending on new capital fell by between 9 and 12 per cent of total research dollars. Exhibit 6.6 compares total granting council spending and CFI's capital outlays over the past 10 years. These expenditures have averaged 12 per cent of research funded over this period, varying from a high of 16 per cent to a low in 2015-16 of just 6.5 per cent.

Exhibit 6.6: Comparison of Total Granting Council Expenditures and CFI Capital Expenditures ($ Millions)

	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	Average
Granting Councils	$2,258	$2,554	$2,550	$2,593	$2,656	$2,658	$2,632	$2,633	$2,684	$2,735	$2,595
CFI	$302	$250	$308	$311	$387	$306	$424	$293	$257	$179	$302
Ratio of CFI to Granting Councils	13.4%	9.8%	12.1%	12.0%	14.6%	11.5%	16.1%	11.1%	9.6%	6.5%	11.6%

Source: Compilations from the secretariat based on data provided by the granting councils and CFI.

The Science-Metrix report also surveyed researchers about their experiences with research and infrastructure funding. While 51 per cent of researchers in other countries reported having adequate access to infrastructure and equipment, the corresponding figure for Canada was only 39 per cent. We believe that this response is at least partly related to the instability of the current system.

While the Panel does not claim to have found the optimal formula, we recommend that the government initially set CFI's capital budget at 12 per cent of overall federal research spending, which has been the average rate of investment over the past decade and is similar to other comparator countries. At the current rate of spending this corresponds to about $300 million per year in A-base funding.[ix] The adequacy of this level of investment should be monitored closely and adjusted with changes in the spending on research over time.

The level of spending on infrastructure operating is another area that requires further consideration and is addressed in both Section 6.3 and in Chapter 7's discussion of support of F&A costs through the RSF.

Finally, the Panel was made aware of a gap in the funding of infrastructure that should be addressed once CFI's budget is in place. While CFI provides the vast majority of infrastructure support at the federal level, there are gaps that are partially, but not completely, filled by the granting councils. In particular, the Panel heard on a number of occasions that small infrastructure needs are inconsistently handled. The Panel also was advised of the serious funding gaps at the lower end of CFI's program threshold. For these needs, researchers in the natural sciences and engineering are able to apply to NSERC's RTI program, an option not available to those in the health and social sciences or in the humanities. This situation warrants further examination by CFI and the granting councils to determine how best to provide streamlined funding and avoid gaps along the full infrastructure spectrum for all disciplines. This is the type of issue that must be on the agenda of the Four Agency Coordinating Board recommended in Chapter 4.

6.2.2 Digital Research Infrastructure

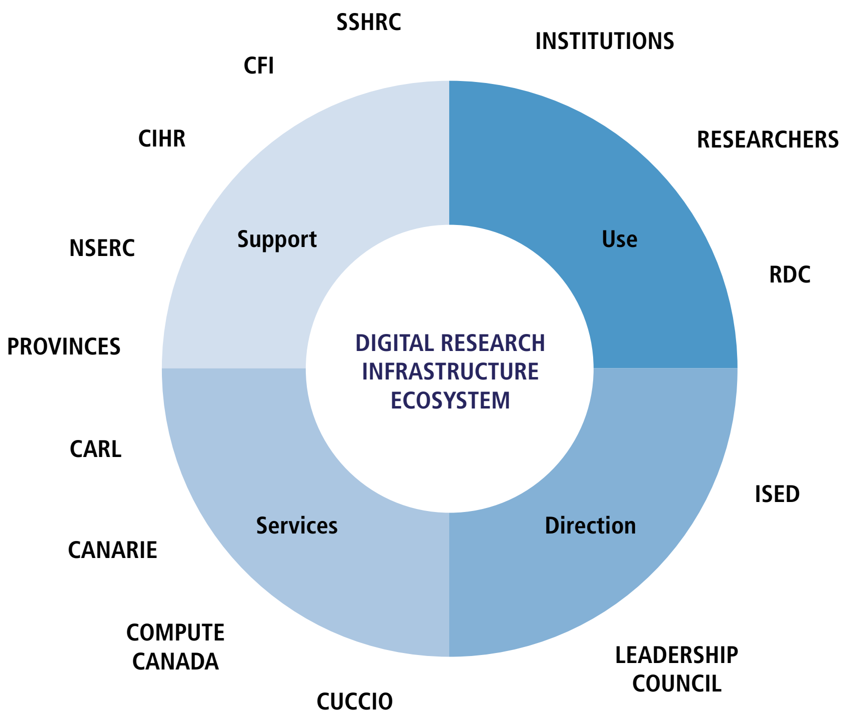
The Panel repeatedly heard that digital research infrastructure (DRI) requires focused attention. DRI consists of the advanced computing, networking, data storage, research software, and data management capabilities that provide researchers with the capacity to manipulate extremely large datasets and perform computationally complex research and analysis. A growing number of researchers across all disciplines are adapting to technological advances in computing and high-speed networking by working together in new ways to address research challenges. Exponential increases in the capacity to generate and process data are producing a "data deluge" that is intensifying pressure on the entire DRI system and, at the same time, opening new opportunities for discovery. The net result is that research, in Canada and globally, is becoming both more data-intensive and computationally-intensive. If Canada is to respond to rapidly growing needs, it must ensure that the increasingly complex DRI ecosystem is efficiently funded and effectively coordinated.

Canada's current DRI ecosystem is the result of the gradual development of a number of special purpose networks responding to particular research needs. As Exhibit 6.7 shows, many organizations support aspects of Canada's DRI. These include users (e.g., individual researchers, facilities, institutions, and Research Data Canada); funders (granting councils, CFI, and the provinces/territories); service providers (Compute Canada, CANARIE, Canadian Association of Research Libraries, and Canadian University Council of Chief Information Officers); and direction/leadership (CFI and ISED—and the Leadership Council for Digital Infrastructure or LCDI).

LCDI has worked patiently to coordinate these sometimes disparate interests, and convey the perspective of end-users with a view to creating an integrated and integrative approach that focuses on the needs of researchers across the public and private sectors. However, the current DRI ecosystem remains divided among uncoordinated and, at times, competing stakeholders.

ix This amount corresponds to recent annual spending by CFI. As such, the Panel does not consider that its recommendation to maintain this level represents an incremental investment. Thus, our proposal for CFI capital spending is not included in the financial roll-up in Chapter 7.

Exhibit 6.7: Actors in the Canadian Digital Research Infrastructure Ecosystem



Note: CARL, Canadian Association of Research Libraries; CUCCIO, Canadian University Council of Chief Information Officers; RDC, Research Data Canada.

Source: Canada Foundation for Innovation. Developing a digital research infrastructure strategy for Canada: The CFI perspective. Ottawa: CFI; November 2015. Available from: https://www.innovation.ca/sites/default/files/Funds/cyber/developing-dri-strategy-canada-en.pdf

The four pillar agencies provide some direct support to postsecondary researchers for a range of research-related expenditures, including those for software, computing hardware, and research data management. However, the two primary organizations delivering DRI infrastructure and services at the federal level are CANARIE and Compute Canada. CANARIE supports research software development and manages the high-speed national research and education network, connecting Canadian researchers nationwide and internationally. Compute Canada is a national, distributed platform offering high performance computing resources and support personnel to the research community, independent of the location of the equipment or the researcher.

> Researchers in all disciplines are using increasingly large data sets and advanced data-processing techniques, and [Humanities and Social Sciences] researchers are no exception. For instance, the digital humanities are an exciting, rapidly developing field of research in Canada. 'Digital humanities' describes scholarly activities involving computing and the disciplines of the humanities.
>
> – Federation for the Humanities and Social Sciences

While both of these organizations receive federal funding through five-year contribution agreements, they do so on different cycles and in very different ways. CANARIE is funded through federal budget decisions that are administered by ISED (per Exhibit 6.7). Compute Canada is funded through two CFI programs: capital through the Cyber-infrastructure Fund and operating and maintenance through the MSI Fund, both of which are allocated by competition. As noted above, the fluctuation with the size and timing of CFI competitions introduces a high degree of uncertainty into this process.

The Panel observes that Canada's DRI ecosystem is growing rapidly, but not quickly enough to keep up with increasing needs. A gap between demand and the availability of bandwidth, computing, and storage capacity (supply) is developing. Compute Canada was only able to meet 54 per cent of reviewed and validated compute requests from researchers in 2016. This is down from 85 per cent in 2012.[12] In 2015 the annual traffic carried by the CANARIE network was 172,000 terabytes, up from 29,000 terabytes in 2010. Network traffic has been growing at the rate of 50 per cent over the past several years.[13]

These shortfalls are emerging at a time when interconnections are becoming more important. The Panel heard clearly that there is an urgent need for stable funding, greater coordination, and streamlined accountability to realize the full potential of the investments being made by all parties. The federal government should be the leader in this effort but the current organization lacks critical mass and precludes the exercise of effective leadership. The need to reorganize this realm has been recognized since the first Digital Infrastructure Summit in 2012. That summit led to the creation of LCDI to develop a national vision for DRI. We look forward to a report from LCDI expected in 2017. This overview report should bring greater clarity to the magnitude of the shortfalls, the critical gaps, changes that might improve the situation, and the levels of funding needed to ensure Canada is at the forefront in digital infrastructure.

That said, LCDI does not have a governance role. Moreover, its membership includes the two organizations whose missions are increasingly convergent but whose boards and executive teams have not joined forces. As it stands now, Compute Canada and CANARIE are funded separately, operate independently, and report to separate boards of directors. In the Panel's view, this is inefficient and has become an impediment to progress.

Recommendation 6.9

The Government of Canada should consolidate the organizations that provide digital research infrastructure, starting with a merger of Compute Canada and CANARIE. It should provide the new organization with long-term funding and a mandate to lead in developing a national DRI strategy.

Funding for the new organization should be channelled through CFI to coordinate DRI funding with other infrastructure investments.[x] Given the complexity of the current funding of both organizations, and taking into account the pending LCDI report, the Panel does not believe it is appropriate to advise the Government of Canada on the initial budget. This will need to be established after LCDI has reported, and after a thorough review of the business models of the two largest organizations and any smaller entities that might be merged with them.

> In the big data era, data experts are invaluable. This is perhaps the biggest aspect of the research data management challenge we face. Better coordinating and integrating DRI in Canada will help address the need to support the highly qualified personnel who optimize the productivity of the system. The human resource dimension of DRI is as important as the infrastructure itself.
>
> – CFI

In sum, the need for a national strategy for DRI has long been recognized. We believe that a federal commitment to lead with early definitive action would be welcomed by many, and can facilitate the achievement of the vision that will be put forward by LCDI in 2017.

x As the government's infrastructure specialist, CFI may be best placed to take this on. However, the use of the 60:40 sharing ratio and the requirement for competition for operating funds are not appropriate for this role.

6.3 Infrastructure Operating Costs

Infrastructure operating costs encompass activities such as salaries of specialized personnel who run and maintain equipment; costs of maintenance and repairs; replacement parts; upgrades; services like power, security, and cleaning; and supplies and consumables needed for operation. Historically, federal capital investments in research infrastructure have been made on the understanding that ongoing operating costs will be borne by other partners. CFI's capital investments have instead included a one-time component for operating and maintenance (O&M), funded through the Infrastructure Operating Fund (IOF), equal to 30 per cent of the CFI capital contribution. Some of these costs are eligible under other federal programs, notably the RSF (discussed in Chapter 7) and small programs like NSERC's RTI program. Nevertheless, the total federal contribution for infrastructure operating costs is but a small proportion of expenditures actually incurred by institutions. This contrasts with other countries that provide continuing support for these O&M costs as incurred — an issue explored in more detail in the next chapter's treatment of the reimbursement of F&A costs.

While the Panel heard concerns about the general level of support provided for the operation of infrastructure, we are not making a recommendation to change the current IOF parameters. The Panel has recommended that CFI's capital budget be set at $300 million per year. Thus, maintaining the IOF at 30 per cent of the CFI contribution would entail ongoing expenditures of $90 million per year. As this amount is consistent with recent spending, the Panel does not consider it to be incremental and it is therefore not included in the financial roll-up of new spending in Chapter 7.

Building on the previous section's discussion of CFI's support of capital costs, we focus on two gaps that require immediate attention at two ends of the spectrum: (i) operating support for large, national-scale Big Science facilities through CFI's MSI Fund, and (ii) support for individual researchers to run and maintain their small-scale equipment.

> TRIUMF is a national resource with strategic value to the nation at large. As such, the expectation that federal funding be matched by provincial agencies is not consonant with TRIUMF's national role.
>
> – TRIUMF

Big Science facilities, such as MSIs, have had particular challenges in securing ongoing stable operating support. Such facilities often have national or international missions. We termed them "major research facilities" (MRFs)[xi] in Chapter 4, and proposed an improved oversight mechanism that would provide lifecycle stewardship of these national science resources, starting with the decision to build them in the first instance. The scope of MRFs means that funding partners, such as the provinces, gain economic benefits and research advantages from hosting these prestigious facilities. However, what is often unclear is whether the broader economic benefits offset the operating costs incurred by provinces, not least insofar as the facilities provide significant benefits for researchers from outside their boundaries. There is sometimes scope for cost recovery related to the direct costs of the operations of these facilities, but little head-room for the recovery of general operating costs. Prior to 2012 the federal government made no contribution to MSI operating costs beyond the small amount provided through CFI's IOF. As a result, a number of the MSIs that had been created with CFI funding have faced chronic difficulties and several have faced potential closure.

xi As noted in Chapter 1, the Panel adopts the term "major science initiatives" (MSI) from CFI, which defines these as major research facilities serving "communities of researchers from across the country and internationally". Here we distinguish between MSIs that meet CFI's basic criteria and those that, by virtue of scale and complexity and/or cost, track more closely to CFI's definition of a "national research facility", i.e., one that "requires resource commitments well beyond the capacity of any one institution" and "is specifically identified or recognized as serving pan-Canadian needs and its governance and management structures reflect this mandate." We call these "major research facilities" to make it clear that facilities proposed for inclusion are based on the Panel's initial assessment.

In 2012 the federal government mandated and funded CFI to create the MSI Fund, with $275 million available over five years on the same 40:60 ratio that it had provided for capital costs more generally. The amount of funding available by facility was determined by the actual operating costs incurred rather than by the extent of CFI's capital investment. This was a significant improvement over the previous situation. Subsequently, the MSI Fund has been expanded and extended. It now has a budget of $80 million per year through 2021-22. However, because the program kept the 40:60 matching formula, additional funds were used to expand the number of facilities eligible for support from 4 to 17, rather than to provide additional support to those facilities facing the greatest difficulties.

The Panel heard in its consultations that a number of MSIs continue to expend inordinate time and energy in assembling operating funds from other sources, but are on occasion still not able to use the full CFI award because of an inability to meet the matching requirements. This struck the Panel as a very inefficient use of resources and an impediment to the development of a national research enterprise that must include elements of Big Science to be internationally competitive.

The Panel acknowledges the merits of the matching principle used by CFI. Its intent of involving provincial governments in the funding of university- and college-based research infrastructure is an effective leveraging mechanism for research equipment and single-institution research facilities. It takes the same position on mid-sized MSIs where there is a close tie to the research and economic interests of a region and its institutions. We support the continuation of the 40:60 ratio for the overwhelming majority of infrastructure funded by CFI.

However, we have concluded that the 40:60 ratio may not be appropriate for MSIs that have a clearly national or international mandate and offer benefits far beyond the regions or institutions where they are located. That being the case, our view is that the federal government should consider a larger stake in ongoing support. Recommendations from stakeholders ranged from full federal support to a 50:50 split. Full support ignores the reality of local and regional benefits. We are also wary of an unreasonably large shift of scarce resources to MSIs after years in which support for the front lines of research has been constrained. Accordingly, we recommend shifting from 40:60 sharing to 60:40 for MRFs, the largest MSIs. This will relieve the pressure they face when attempting to securing matching funds, but also satisfy the need for creating strong partnerships with provinces and institutions.

Recommendation 6.10

The Government of Canada should mandate and fund CFI to increase its share of the matching ratio for national-scale major research facilities from 40 to 60 per cent.

Careful thought must be given to:

- which infrastructures should qualify for this new proposed arrangement;
- how the operating costs of new facilities would be covered over their life cycles; and
- the specific needs of small-scale specialized research equipment.

We recommend that only a subset of CFI MSI-funded projects be eligible for this matching formula. A logical group for consideration would be those that are considered MRFs as defined in the preamble to Recommendation 4.7 and are truly national in their scope. Based on past support, scope, scale, and future needs, we suggest the following infrastructures be considered: Compute Canada,[xii] Canadian Light Source, Canada's National Design Network, Canadian Research Icebreaker Amundsen, International

xii In our earlier discussion of DRI, we recommended that the structure of Compute Canada and its funding model be changed.

Vaccine Centre, Ocean Networks Canada, Ocean Tracking Network, TRIUMF,[xiii] and SNOLAB. Total operating costs for these are roughly $175 million per year. Using the current 40:60 formula, this equates to $70 million maximum per year from CFI. Using our proposed 60:40 formula, the total would increase to $105 million per year from CFI, or an annual increase of $35 million.[xiv]

As discussed in Chapter 4, decisions about the creation of future MRFs need to be made in a significantly more coordinated manner. Any decision to fund the capital costs of a new facility must be accompanied by a clear agreement among all the partners on how the operating costs will be covered over the facility's life cycle. We have already recommended that a Standing Committee on MRFs be involved in this process, along with ongoing reviews of the effectiveness of extant national MRFs and clarification of NRC's role in connection with some of the facilities.

> The 'infrastructure operating funds' that accompany CFI support and link the funding for personnel to the infrastructure are vital and must be strengthened.
>
> – Partnership Group for Science and Engineering of the Royal Society of Canada

At the other end of the infrastructure spectrum, small capital awards have no special operating support available beyond what is provided by the IOF. This one-time payment is calculated as 30 per cent of the value of the CFI capital contribution, or 12 per cent of the total capital, rather than being based on the actual operating costs incurred, as is the case with MSIs. The funding is provided directly to institutions, which allocate it to areas of greatest need.

The Panel heard that there may be a gap in how these funds are distributed, particularly in support to individual researchers and their teams of co-investigators who are usually charged with maintaining small-scale equipment. The generally accepted rule-of-thumb for large facilities is that the annual cost of operations is about 10 per cent of the total construction cost. For small-scale equipment and tools, costs are higher, varying from 10 to 30 per cent annually of total initial cost. While individual researchers therefore face higher proportional costs, they may not be well positioned to secure that funding from their institutions, which sometimes make larger multi-user capital projects and facilities their priority. Not providing sufficient operating funds leads to the ineffective use of equipment and means that researchers spend inordinate amounts of time trying to secure funding. In simple terms, the lack of adequate operating support limits adequate return on the initial capital investment. We noted earlier that this is part of a broader issue of F&A support, which we address further in Chapter 7. However, the Panel believes that early attention to this gap in funding could help ensure continuity of valuable research work.

Recommendation 6.11

The Government of Canada should mandate and fund CFI to meet the special operating needs of individual researchers with small capital awards.

CFI's support for smaller-scale capital projects that are principally managed by a single researcher is the John R. Evans Leadership Fund (JELF), which in recent years has had an annual budget in the $70 million range, making roughly 340 awards per year.

Based on the IOF formula and the estimated operating costs for small equipment, we estimate that the fund currently provides for about 10 months of operating support. That is only the case if the researcher's institution flows through the relevant share of the IOF payment that it receives in aggregate. The system needs a flexible solution that recognizes the variability in O&M requirements for small-scale specialized research equipment, helps bridge funding gaps when project funding is slow to come, and ensures that support reaches individual researchers.

xiii While TRIUMF meets the criteria we propose for an MRF, it has its own long-established funding model.

xiv We recognize that a case can be made for a larger increase, but the Panel's position reflects opportunity costs and trade-offs: viz. $35 million would competitively fund about 1,000 doctoral students.

A major part of the solution will be found in a general increase to the RSF, which we recommend in the next chapter. However, we recognize that growth in the RSF would be phased given its size. For immediate remediation, we recommend that the target level of operating support for small infrastructure should cover the equivalent of two years of operating costs instead of the current average of 10 months, and that this should be earmarked for individual research applicants as needed. We estimate that this new fund would require approximately $30 million per year based on JELF activity of $70 million per year in capital awards.[xv] To facilitate rapid implementation of this recommendation, this amount should be offset against growth in the RSF to render it costless to the federal government.

The Panel repeats that this situation is a bellwether for a broader problem of poor coordination. Whether for individuals, small teams, or large networks of researchers, a coordinated process is needed that aligns support for personnel, research operating costs including consumables, provision of equipment, and O&M costs for that equipment.

ENDNOTES

1 Canadian International Innovation Program (CIIP) [Internet]. Ottawa: The Canadian Trade Commissioner Service; 2017. Available from: http://tradecommissioner.gc.ca/funding-financement/ciip-pcii/index.aspx?lang=eng

2 Going Global Innovation [Internet]. Ottawa: The Canadian Trade Commissioner Service; 2016. Available from: http://tradecommissioner.gc.ca/funding-financement/ggi-vmi/index.aspx?lang=eng

3 Van Noorden, R. Interdisciplinary research by the numbers. Nature, 2016; 525(7569): 306–307.

4 Wang, J., Thijs, B., Glänzel, W. Interdisciplinarity and Impact: Distinct Effects of Variety, Balance, and Disparity. PLoS ONE, 2015; 10(5), p.e0127298.

5 Bromham, L., Dinnage, R, Hua, X. Interdisciplinary research has consistently lower funding success. Nature, 2016; 534(7609): 684–687.

6 Promoting Excellence in Research: An International Blue Ribbon Panel Assessment of Peer Review Practices at the Social Sciences and Humanities Research Council of Canada. Ottawa: SSHRC; 2008. Available from: http://www.sshrc-crsh.gc.ca/about-au_sujet/publications/peer-pairs_e.pdf

7 Report of the International Review Committee on the Discovery Grants Program. Ottawa: NSERC; 2008. Available from: http://www.nserc-crsng.gc.ca/_doc/Reports-Rapports/Consultations/international_review_eng.pdf

8 Committee on Prospering in the Global Economy of the 21st Century and the Committee on Science, Engineering, and Public Policy. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, D.C.: The National Academies Press; 2007. Available from: https://www.nap.edu/catalog/11463/rising-above-the-gathering-storm-energizing-and-employing-america-for

9 What We Do [Internet]. Arlington (VA): National Science Foundation; n.d. Available from: https://www.nsf.gov/about/what.jsp

10 NIH Common Fund High-Risk, High-Reward Research Program [Internet]. Bethesda (MD): NIH; 2015. Available from: https://commonfund.nih.gov/sites/default/files/HRHR%20program%20flyer%20Sept%202015_508%20Compliant.pdf

11 Science-Metrix. Examining international approaches to research infrastructure support. Montreal: Science-Metrix Inc.; 2014.

12 Compute Canada Technology Briefing. Toronto: Compute Canada; 2016. Available from: https://www.computecanada.ca/wp-content/uploads/2016/04/161114-Tech_Brief_PROOF_2016_EN_02-1.pdf

13 CANARIE Facts [Internet]. Ottawa: CANARIE; 2017. Available from: https://www.canarie.ca/about-us/facts/

xv This would be in addition to the $20 million per year that the JELF activity already generates in regular IOF.

CHAPTER 7

FUNDING THE RESEARCH ECOSYSTEM: TWO MORE ELEMENTS AND COST ANALYSES

This chapter, as noted earlier, is a continuation of Chapter 6, focusing on the key elements of support for those undertaking research, learning, and teaching in the extramural ecosystem. Its final section presents a comprehensive costing of the Panel's recommendations along with funding options and some comparators.

7.1 Personnel Awards

Chapter 6 gave our imaginary scientist or scholar a research operating grant, the necessary infrastructure and equipment to carry out her or his line of research, and additional operating support to ensure that any specialized equipment is fully functional. As always, however, the most essential ingredient is the quality of the people carrying out the work. This leads us to our fourth key area of federal research funding: personnel awards and salary supports.

As documented in Chapter 3, the majority of salary support for professors and other research staff comes from their institutions (e.g., universities, colleges, research hospitals, research institutes). For universities and colleges, those salaries are heavily subsidized by provincial operating grants in support of their educational missions. A significant level of investment in student scholarships and other forms of financial aid is also made by institutions, provinces, and the not-for-profit and private sectors, with philanthropy playing a steadily expanding role. Nonetheless, strategic federal investments can advance the overall research enterprise by developing and/or attracting, and then supporting, the elite personnel needed to achieve excellence.

To this end, the Panel focuses on two broad types of personnel awards: training support for students and postdoctoral fellows, and the flagship federal programs for supporting independent researchers—the CRC and CERC programs. Recognizing the global nature of research and the benefits that top foreign-trained researchers can bring to Canada, the Panel also considered ways to best promote domestic and international recruitment and retention.

7.1.1 Training Support for Doctoral Students and Postdoctoral Trainees

Research training at the doctoral and postdoctoral levels is critical to the development of the HQP needed by Canada's knowledge economy. Students and postdoctoral trainees or fellows (hereafter PDFs) are also essential components of the research workforce as they are involved in the conduct of the majority of postsecondary research in Canada. The Panel estimates that as much as $655 million from the federal granting councils goes to fund students and trainees. The two largest sources of funding are (i) *direct* support to trainees through scholarships and fellowships; and (ii) *indirect* support through operating grants awarded to their supervisors, from which the trainees are often paid stipends. A smaller amount of funding is given through specific training grants to institutions to improve their training environments and support groups of trainees. (While our focus is on federal scholarships and fellowships, we acknowledge the value of granting council programs, e.g., NSERC's CREATE program, that support innovative team training initiatives. We encourage the government to monitor the outcomes of these programs and make new investments as warranted.)

The number of scholarships and fellowships awarded by the granting councils is dwarfed by the overall population of doctoral-stream graduate students and PDFs in Canada. Our recommendation of a substantial increase in support for investigator-led funding would provide a major source of enhanced support for graduate students and PDFs across the ecosystem. Nonetheless, the Panel found more than sufficient evidence to conclude that the personnel awards provided directly by the three granting councils encourage excellence among students and trainees. We believe that they should be not only sustained, but also, ideally, expanded.

On the other hand, the Panel is puzzled by the current mix of council-specific and tri-council programs where awards vary considerably by value, duration, and international portability. As we have observed more generally with the proliferation of programs under the granting council umbrellas, we find these arrangements unduly complex and arguably inefficient. They also provide only a limited number of opportunities to bring international students and fellows to Canada.

To better visualize the gaps and challenges that need to be addressed, we begin with a short review of the various current programs.

The main source of federal awards for graduate students is the Canada Graduate Scholarship (CGS) program. The CGS-M (master's) and CGS-D (doctoral) programs each support 2,500 scholarships in any given year, allocated across the three granting councils: 400 to CIHR, 800 to NSERC, and 1,300 to SSHRC. A CGS-M award provides support for one year. A CGS-D award runs three years so that 833 new awards are made each year. There appears to be only intermittent review and readjustment of these numbers in relation to the growing population of graduate students across Canada and their distribution by disciplines.

CGS-M awards are valued at $17,500 for up to 12 months, while CGS-D awards are worth $35,000 annually for up to three years. Both awards are restricted to Canadian citizens and permanent residents and must be held in Canada. A notable improvement to the CGS-M program was the recent harmonization across the granting councils that resulted in a single-window application portal for applicants, standardized eligibility and evaluation criteria, and greater flexibility and administrative efficiency. Unfortunately, despite similar efforts to harmonize delivery of the CGS-D program, each council continues to deliver and brand the program independently. In addition, each council offers its own doctoral program. These vary significantly in the number, value, and duration of awards as well as the rules on their tenure for doctoral scholarships, as summarized in Exhibit 7.1.

Exhibit 7.1: Comparison of Doctoral Scholarship Programs

Granting Council/ Program	Total # of Awards (per year)	Annual Value	Maximum Duration	Tenure
CGS-D	2,500 (833)	$35,000	3 years	Canada
CIHR	30 (10)	$35,000	3 years	Abroad
NSERC	~ 1,200 (400)	$21,000	3 years	Canada or Abroad
SSHRC	~ 2,000 (500)	$20,000	4 years	Canada or Abroad

Source: Compilations from the secretariat based on data provided by the granting councils.

An additional layer of doctoral support arrived in 2008 with the introduction of the Vanier CGS program. It was intended "to strengthen Canada's ability to attract and retain world-class doctoral students and establish Canada as a global centre of excellence in research and higher learning."[1] It is open to Canadians and foreign citizens and provides awards of $50,000 per year for three years for studies at an eligible Canadian institution. The program is administered jointly by the three councils, and the 500 awards (167 per year) are equally distributed among CIHR, NSERC, and SSHRC.

Program differentiation by granting council extends to the postdoctoral level as well. As summarized in Exhibit 7.2, each council offers its own awards with significant variation by program.

Exhibit 7.2: Comparison of Postdoctoral Fellowship Programs

Granting Council	Total # of Awards (per year)	Annual Value	Maximum Duration	Citizenship	Tenure
CIHR	~ 600 (170)	$45,000 to $60,000[a]	3 to 5 years[a]	Canadians or foreigners	Canada or Abroad
NSERC	~ 360 (180)	$45,000	2 years	Canadian only	Canada or Abroad
SSHRC	~ 360 (180)	$40,500	2 years	Canadian only	Canada or Abroad

[a] Value and duration of awards varies depending on applicant's degree (PhD or health professionals) and tenure in Canada or abroad.
Source: Compilations from the secretariat based on data provided by the granting councils.

Finally, the federal government launched the tri-council Banting Postdoctoral Fellowships program in 2010 as part of a broader strategy to increase Canadian capacity for research excellence by attracting top-level talent to Canada. This prestigious program is open to Canadians and foreign citizens and awards 70 fellowships annually (distributed equally among the three granting councils) valued at $70,000 per year for up to two years, for a total of up to 140 active awards at any time.

The Panel believes that federal support for scholarships and fellowships would be greatly improved if doctoral scholarships and postdoctoral fellowships were harmonized across the granting councils, as master's scholarships currently are. This would greatly reduce the complexity for applicants and simplify the communication and promotion of federal support by creating one brand for each level instead of three.

In addition to streamlining program delivery and branding, the Panel heard a number of concerns about the current number and value of these awards. The number of CGS-M and CGS-D awards has remained static since 2007 despite increasing enrolment in graduate programs. Between 2006-07 and 2013-14, the number of full-time doctoral students enrolled in Canadian universities increased by over 38 per cent, and master's students by 32 per cent.[2] In addition, the value of the awards has not changed since the program was created in 2003, resulting in a 25 per cent decline in value due to inflation. In fact, combined with declining funding for council-specific awards, total inflation-adjusted spending on master's scholarships has decreased significantly since 2006-07 while doctoral scholarships have remained unchanged despite the creation of the Vanier awards. The council-specific doctoral awards from NSERC and SSHRC are only 60 per cent of the value of a CGS-D award, and again have not increased for many years.

At the postdoctoral level, funding is slightly more generous. However, because fellowships are taxed, PDFs may actually receive a lower net amount than students with a CGS-D award (the latter are tax exempt, as are all student scholarships). Award values, too, have remained relatively static. Even with the addition of the Banting Postdoctoral Fellowships program in 2010, inflation-adjusted spending on fellowships across the three councils has decreased by roughly 20 per cent since 2006-07, driven mainly by decreases at NSERC and CIHR. At the same time, similar to what has occurred with graduate students in the doctoral stream,

> As the CS [computer science] field has matured, the role of postdoctoral fellows has become increasingly significant, and postdocs typically obtain better positions afterwards. Unfortunately the amount of money offered for NSERC Postdoctoral Fellowships is not enough to attract top applicants. The low acceptance rate for postdoctoral applications and the fact that research grants in Canada are small and cannot support competitive postdoc salaries further complicate the problem.
>
> – CS-Can/Info-Can

the population of PDFs has been increasing significantly. The Panel cannot overemphasize the role played by PDFs in top-flight research. The Panel repeatedly heard from researchers across Canada that support levels for PDFs must be internationally competitive to ensure recruitment of the best talent from abroad and to mitigate the potential "brain drain" of Canada's top young talent to other countries.

Yet another issue relates to the duration of support. There is currently a lifetime maximum of four years of federal support for graduate studies (master's and doctoral), based on one year of support from the CGS-M program and three years at the doctoral level. Times to completion vary by discipline, but most doctoral programs extend beyond the three-year limit. Similarly, the duration of postdoctoral fellowships has not kept pace with the changing role of fellows. While the postdoctoral position was historically envisioned as a brief transition between graduate school and a full-time faculty appointment, there has been a trend towards more years spent in these positions. Indeed, as noted by the CAPS 2016 Canadian National Postdoctoral Survey, this has resulted in an increase of the average age of PDFs to 34.[3]

While we do not want to encourage the out-migration of young talent, there is a strong case for ensuring that Canadian students and trainees have more opportunities for international exposure. International research experiences can immerse young Canadian scientists and scholars in world-leading research environments not available at home. The EU's Marie Curie international postdoctoral program is a strong case in point, providing trainees with a base institution while funding them to spend time in other institutions abroad. Similar strategies would strengthen the presence of Canada on the international scene, and when these students and trainees return home, they bring with them long-term research linkages that connect Canada and the world. Current differences in the international portability of doctoral awards have resulted in top-ranked Vanier or CGS-D awardees, who wish to study abroad, declining the awards because they can only be held in Canada, in favour of the council-specific awards that can be taken abroad. Conversely, the lower value of these council-specific awards penalizes trainees who wish to go abroad, leading some students to forego international training opportunities for financial reasons. The Panel strongly encourages the government to remove restrictions on the international portability of scholarships and fellowships in the new harmonized programs. The councils should track the impacts of this change to assess the balance of domestic and international opportunities pursued by awardees.

Just as sending Canadians abroad for training enriches both the Canadian and international research ecosystems, so does attracting the best and brightest talent from abroad to Canada. In terms of recruiting international talent, the primary tools currently available from the granting councils are the Vanier and Banting programs, as most other programs are restricted to Canadian citizens and permanent residents. Despite a key objective of these programs being to attract international talent to Canada, the level of international participation has been declining. In the 2015-16 competition only 30 per cent of the Vanier scholarships and 26 per cent of the Banting fellowships were offered to foreign applicants. The Panel heard in its consultations that application processes are less than ideal. Many colleagues felt that the value of these awards was excessive, and that it is difficult to justify the distinctions drawn among domestic trainees with such small numbers receiving these premium packages at an early stage in their training. The Panel accepts that the value of the Vanier and Banting awards is necessary to compete for top international talent and should be maintained. However, the awards would be most effective if they were used exclusively for international recruitment and exchange opportunities in a similar vein to the Fulbright and Rhodes Scholar programs, raising the international profile and impact of both programs.

Recommendation 7.1

The Government of Canada should direct the Four Agency Coordinating Board to oversee a tri-council process to reinvigorate and harmonize scholarship and fellowship programs, and rationalize and optimize the use of current awards to attract international talent.

Specific elements and considerations to achieve these goals include:

- creation of harmonized tri-council programs to award and administer all doctoral and PDF awards, similar to the harmonized program for master's scholarships;
- more harmonized levels of support (in both value and duration) for all doctoral and PDF awards;
- elimination of restrictions on international portability of doctoral and PDF awards to Canadians, with monitoring of the results; and
- refocusing of the Vanier and Banting programs as tools for international recruitment.

The Panel is well aware of the complexities of harmonizing the duration and value of the diverse graduate and postdoctoral supports. The attendant total costs will be significant under any scenario. For any given amount of new funding provided, trade-offs will also be necessary with regard to durations, annual values, and numbers of awards. It could be argued that growth in numbers of awards is less essential given that stipendiary support for both graduate students and PDFs will be enhanced by investments in the pool of investigator-led grants. However, as noted, the numbers of both graduate students and PDFs have expanded substantially without concomitant growth in tri-council awards—awards that are valued not just financially, but also because they carry the imprimatur of Canada's granting councils.

The Panel does not wish to prejudge the outcomes of the recommended harmonization process. We understand that the process must be planned in consultation with institutions and the research community. It also must be phased, given the potential unintended exacerbation of disparities that already exist within and between institutions and disciplines. However, to arrive at some approximation of potential costs from different measures, we have considered several different scenarios.

For example, the Panel was advised that the current maximum tenure for the CGS-M program of 12 months does not reflect the reality that many disciplines have two-year master's programs for students in research streams. Doubling the current support from one to two years would add $44 million per year to program costs. Given the availability of more funds from operating grants and growth in direct entry to doctoral programs, this might not be the best use of available funds. However, smoother transitions to doctoral programs are desirable, and some funding could be directed to that end.

On the other hand, it seems difficult to defend the differential value of awards to students and trainees across disciplines. One scenario could see full standardization upwards. For example, the value of the new harmonized doctoral award could be set at the current CGS-D level of $35,000 per year and the value of the new harmonized postdoctoral award at the current NSERC and CIHR level of $45,000 per year. As noted above, it is also timely to extend the tenure of doctoral scholarships to four years for all disciplines, and to raise the lifetime limit on federal support for graduate students (master's and doctoral) to five years from the current four. Given evidence on durations of postdoctoral

> Postdoctoral funding terms are not representative of the typical length of postdoc training in today's world. In order to be competitive for academic or industry jobs, most individuals will have had 4-6 years of postdoc training, but the funding is typically in 2 year stints. The disadvantage of this approach (2 year funding bouts) is that postdocs are using much of their time applying for funding to cover their own salary. If funding terms were longer (3 or 4 years) then more time could be devoted to research.
>
> – Postdoctoral researcher, University of Windsor

positions by discipline, postdoctoral fellowships could be extended to three years for SSHRC- and NSERC-related disciplines, and four years for CIHR-related disciplines. The costs of these changes would be approximately $112 million per year while maintaining the current number of 1,750 doctoral scholarships and 530 postdoctoral fellowships awarded each year.

The Panel emphasizes again that these are scenarios to be considered among others. The granting councils, after consultation and consideration, may place greater emphasis on increasing the number of awards. Our conclusion is simply that meaningful reinvestment is readily justified, but must be accompanied by a thorough re-examination, with greater harmonization and coordination, and more effective planning to ensure effective use of new funds.

Dropping restrictions on international portability for all scholarships and fellowships and focusing the Vanier and Banting programs exclusively on attracting international talent would send two clear messages to the world—namely, that Canada is confident in its ability to compete on the international research stage and that we recognize the overall benefits to the Canadian research ecosystem of stronger international linkages. Especially if renewed investments are made in the Canadian research ecosystem, the Panel sees no reason why top Canadian talent would not return home, or why talented international students and trainees would not remain and help advance research excellence in Canada.

The Panel recognizes that there are currently roughly 350 domestic students who hold Vanier awards and 100 who hold Banting awards. Obviously, those in place would retain their support. To mitigate the impact of redirecting these awards exclusively to international recruitment, we encourage the government to increase the number of domestic doctoral scholarships and postdoctoral fellowships accordingly. This would require an additional 117 doctoral scholarships and 50 postdoctoral fellowships to be awarded each year, which given usual multi-year terms, would in steady-state replace the Vanier and Banting awards. The incremental cost would be approximately $23 million per year.

Finally, the Panel encourages the government to review the current level of support for PDFs in Canada. Their role in the research ecosystem is increasing across all sectors. However, there is a lack of adequate data on both the number of PDFs working in Canada and the level and duration of compensation they are receiving. Canada cannot compete globally unless we offer PDFs a level of support consistent with their advanced skills and stage of life. In their joint review the granting councils should consider whether the current fellowship rate is adequate and whether institutions should be mandated to guarantee a certain level of support for PDFs supported through federal funding (whether directly through fellowships or indirectly from research grants). Here we note simply that the NIH in the U.S. recently announced an increase to fellowship stipend levels with a base salary of US$47,484 growing in annual increments.[4]

7.1.2 Research Chairs for Excellent Scholars and Scientists

The major sources of federal funding for researcher salary support are the CRC and CERC programs. While some salary support is provided through council-specific programs, these investments have been declining over time. The Panel supports program simplification but, as noted in Chapter 5, we are concerned about the gaps created by the elimination of these personnel awards. While we focus here on the CRC and CERC programs because of their size, profile, and impact, our recommendations will reflect these concerns.

The CRC program was launched in 2000 and remains the Government of Canada's flagship initiative to keep Canada among the world's leading countries in higher education R&D. The program has created 2,000 research professorships across Canada with the stated aim "to attract and retain some of the world's most accomplished and promising minds"[5] as part of an effort to curtail the potential academic brain drain to the U.S. and elsewhere. The program is a tri-council initiative with most Chairs allocated to eligible institutions based on the national proportion of total research grant funding they receive from the three granting councils. The vast majority of Chairs are distributed based on area of research, of which 45 per cent align with NSERC, 35 per cent with CIHR, and 20 per cent with SSHRC; an additional special allocation of 120 Chairs can be used in the area of research chosen by the universities receiving the Chairs. There are two types of Chairs: Tier 1 Chairs are intended for outstanding researchers who are recognized as world leaders in their fields and are renewable; Tier 2 Chairs are targeted at exceptional emerging researchers with the potential to become leaders in their field and can be renewed once. Awards are paid directly to the universities and are valued at $200,000 annually for seven years (Tier 1) or $100,000 annually for five years (Tier 2). The program notes that Tier 2 Chairs are not meant to be a feeder group for Tier 1 Chairs; rather, universities are expected to develop a succession plan for their Tier 2 Chairs.

The CERC program was established in 2008 with the expressed aim of "support[ing] Canadian universities in their efforts to build on Canada's growing reputation as a global leader in research and innovation."[6] The program aims to award world-renowned researchers and their teams with up to $10 million over seven years to establish ambitious research programs at Canadian universities, making these awards among the most prestigious and generous available internationally. There are currently 27 CERCs with funding available to support up to 30 Chairs, which are awarded in the priority areas established by the federal government. The awards, which are not renewable, require 1:1 matching funds from the host institution, and all degree-granting institutions that receive tri-council funding are eligible to compete. Both the CERC and CRC programs are open to Canadians and foreign citizens. However, until the most recent round, the CERCs have been constrained to the government's STEM-related priorities; this has limited their availability to scholars and scientists from SSHRC-related disciplines. As well, even though Canadian-based researchers are eligible for CERC awards, the practice has clearly been to use them for international recruitment with every award to date going to researchers from abroad.

> The CRC program is flexible, allowing researchers and scholars to be recruited nimbly, as research areas expand and contract; they can be used to recruit exceptional scholars; they can be used for retention; and they can be used to address equity issues.
>
> – Queen's University
>
> The Canada Research Chairs program is in need of rethinking, particularly given the gap in support for mid-career faculty, the challenge of recruiting truly world-class Tier 1 researchers, and the lack of flex moves available to institutions that could enable them to build more early career researcher capacity.
>
> – Concordia University

Similar to research training support, the funding for salary support to researchers and scholars is a significant proportion of total federal research investments, but relatively small with respect to the research ecosystem as a whole. There are more than 45,000 professors and teaching staff at Canada's universities[7] and a very small fraction hold these awards. Nevertheless, the programs can support research excellence by repatriating top Canadian talent from abroad and by recruiting and retaining top international talent in Canada.

The programs can also lead by example in promoting equity and diversity in the research enterprise. Unfortunately, both the CRC and CERC programs suffer from serious challenges regarding equity and diversity, as described in Chapter 5. Both programs have been criticized in particular for under-recruitment of women.

While the CERC program has recruited exclusively from outside Canada, the CRC program has shown declining performance in that regard. A 2016 evaluation of the CRC program[8] observed that a rising number of chairholders were held by nominees who originated from within the host institution (57.5 per cent), and another 14.4 per cent had been recruited from other Canadian institutions. The Panel acknowledges that some of these awards may be important to retaining Canadian talent. However, we were also advised in our consultations that CRCs are being used with some frequency to offset salaries as part of regular faculty complement planning.

The evaluation further found that 28.1 per cent of current chairholders had been recruited from abroad, a decline from 32 per cent in the 2010 evaluation. That decline appears set to continue. The evaluation reported that "foreign nominees accounted, on average, for 13 per cent and 15 per cent respectively of new Tier 1 and Tier 2 nominees over the five-year period 2010 to 2014", terming it a "large decrease" from 2005 to 2009 when the averages respectively were 32 per cent and 31 per cent. As well, between 2010-11 and 2014-15, the attrition rate for chairholders recruited from abroad was 75 per cent higher than for Canadian chairholders, indicating that the program is also falling short in its ability to retain international talent.[9]

One important factor here appears to be the value of the CRC awards. While they were generous in 2000, their value has remained unchanged for some 17 years, making it increasingly difficult to offer the level of support that world-leading research professors require. The diminishing real value of the awards also means that Chair positions are becoming less distinguishable from regular faculty positions, threatening the program's relevance and effectiveness. To rejuvenate this program and make it relevant for recruitment and retention of top talent, it seems logical to take two steps:

- ask the granting councils and the Chairs Secretariat to work with universities in developing a plan to restore the effectiveness of these awards; and
- once that plan is approved, increase the award values by 35 per cent, thereby restoring the awards to their original value and making them internationally competitive once again.

In addition, the Panel observes that the original goal was for the program to fund 2,000 Chairs. Due to turnover and delays in filling Chair positions, approximately 10 to 15 per cent of them are unoccupied at any one time.[i] As a result, the program budget was reduced by $35 million in 2012. However, the occupancy rate has continued to decline since then, with an all-time low of only 1,612 Chair positions (80.6 per cent) filled as of December 2016. The Panel is dismayed by this inefficiency, especially at a time when Tier 2 Chairs remain one of the only external sources of salary support for ECRs—a group that represents the future of Canadian research and scholarship.

Recommendation 7.2

The Government of Canada should renew the CRC program on a strategic basis in three stages:

1. **Restore funding to 2012 levels, upon development of a plan by the granting councils and Chairs Secretariat to allocate the new Chairs asymmetrically in favour of Tier 2 Chairs, and increase the uptake of available funds through improved logistics in managing numbers and reduced delays in awarding Chairs;**
2. **Direct the granting councils to cap the number of renewals of Tier 1 Chairs and, in concert with universities and CFI, develop a plan to reinvigorate international recruitment and retention, for review by NACRI and approval by the government; and**
3. **On approval of that plan, adjust the value of the CRCs to account for their loss in value due to inflation since 2000.**

Among the considerations in formulating the above-noted plans should be:

- a major effort to increase the number of active Chairs at any one time to as close to 2,000 as possible;
- re-examination of the disciplinary distribution of CRC awards;
- detailed review of the relative cost-benefit of the CERC versus CRC programs to determine where the investments should be directed for the greatest impact;

i The Panel acknowledges that some of these delays may be strategic, e.g., keeping a Tier 1 CRC vacant to support a CERC that will be ending in the not-distant future. However, those numbers are very small.

- strategic evaluation to determine why the attrition rate for chairholders recruited from abroad has been significantly higher than Canadian chairholders;
- closer scrutiny of nominations from within a university to ensure that new internal awards reflect retention priorities; and
- setting of specific targets for international recruitment, as recommended by the recent CRC evaluation.

On these last two points, the Panel appreciates the need to maintain a balance between international and domestic recruitment given the rising quality of the Canadian research training system over the past number of years, the progression of excellent researchers through the ranks since the program's inception, and the risk that those individuals will be recruited away in mid-career. However, the Panel is concerned by the flagging ability of the CRC program to attract and retain top international talent, and believes that additional funding should depend on clearer plans and firmer accountabilities.

These changes would be staged; over the course of two to three years they would involve an additional base budget commitment of approximately $140 million—$35 million to augment the number of CRCs and restore the program budget to 2012 levels, and an additional $105 million to restore the value of the Chairs that has been eroded by inflation since 2000.

The Panel also heard concerns about the disciplinary distribution of CRCs. Only 20 per cent of CRCs are allocated to SSHRC disciplines. While this is roughly proportional to SSHRC's budget in relation to that of NSERC and CIHR, the Panel questioned whether this formula was appropriate. Recognizing that Canada's research ecosystem has changed since the CRC program was established, the distribution of chairholders should be re-evaluated to determine whether the current allocation is adequate and optimal to promote and support excellence in the present research environment. Such a review could be linked to the question of funding allocations across granting councils, raised at the beginning of Chapter 5.

The Panel further considered the role of the CRC program in supporting researchers across career stages, the importance of which is discussed elsewhere in this report. The CRC program is directed primarily at established researchers and ECRs through the Tier 1 and Tier 2 awards, respectively. The considerable gap between the two tiers has contributed to perceptions of a lack of support for mid-career researchers. The problem is compounded by the perpetual renewal of Tier 1 chairholders, resulting in a widening age gap between Tier 1 and Tier 2 chairholders and creating a risk that a growing number of researchers may fall into that gap. Currently a relatively equal division between Tier 1 and Tier 2 Chairs exists; however, this balance is no longer optimal due to the struggles faced by ECRs in Canada. We therefore conclude that it is timely to change the ratio of Tier 1 to Tier 2 Chairs, and to cap the number of times that a Tier 1 Chair can be renewed.

Finally, the Panel heard many concerns about the value of the CERC awards, and the uncertain sustainability of programs that focus such substantial resources around a single international recruit. Additionally, many questions were raised as to whether the impacts and benefits to Canada are proportional to the level of investment. CRCs, many with research records every bit as strong as CERCs, have quietly questioned the fairness of the program. On the other hand, the Panel recognizes the very high quality of researchers who currently hold CERC awards, and the need for high-value awards to attract the brightest and the best from around the world. We appreciate, too, that the CERC program may have particular value at a moment in history when events in

> There is currently a lot of emphasis on concentrating a lot of funding in a few individuals, such as through the CERC program, which focuses heavily on individuals who have already reached the pinnacle of their careers. I feel strongly that this money would be better spent by supporting an assortment of rising stars. If you divided the funds for one CERC chair among 10 early or mid-career researchers, you could certainly grow one or two new superstars and support 7 or 8 solid researchers. The overall impact of the funds would go much further.
>
> – Academic faculty member, University of Alberta

the U.K. and U.S. may have strengthened Canada's appeal to some excellent researchers currently based in those two leading jurisdictions. Such a window for recruitment, if indeed it has opened, is likely to be time-limited, and the government will need to decide how to respond.

However, the Panel believes that a thorough and critical policy and program review assessing the relative cost-benefit of the CERC versus CRC programs should be completed in 2017. If the CERC program does not have an impact commensurate with the higher value of its awards, its funding should be reallocated elsewhere, not least to the CRC program, where the investments may achieve a higher overall impact.

More generally, the Panel believes that special priority must be given to a longer-term, more widely applicable, and more sustainable strategy for international recruitment than the CERCs currently seem to provide. Our recommendations on renewal of the CRC program will help improve the situation. However, some intermediate strategy building on the CRCs, but less costly than the CERCs, may well be the most efficient and effective way to relocate a star scientist or scholar from abroad, and ensure that he/she is rapidly productive and remains in Canada.

7.2 The Full Costs of Research

Even after researchers and their institutions have arranged to cover all the project costs examined in this chapter, there is a final category to consider: the F&A requirements that the project generates (the institutional costs of hosting researchers and research on site). All postsecondary research depends upon maintaining common-use equipment; meeting regulatory standards; regularly upgrading institutional computer services; cleaning, lighting, and heating laboratories and research space; and administering grants and awards. On top of these costs are those related to the protection of IP and the commercialization of technologies arising from the research. These services are not top of mind for researchers, nor should they be, but their absence or inadequate delivery can hinder or even stop work.

Research grants provided by the federal government, however, do not permit expenditures on the F&A costs that they generate, with a few exceptions. CRCs and CFREF both allow up to 25 per cent of the award to be used for F&A costs, but there are impediments to claiming reimbursement: by design (in the case of CRCs, with their attachment to an individual researcher) and by administrative rules (in the case of CFREF).

There is accordingly a separate program for these costs: the RSF is delivered by SSHRC on behalf of the granting councils. Prior to 2003 the federal government did not reimburse postsecondary institutions for these costs. Since then, the RSF and predecessor programs have provided reimbursement in the 20 per cent range. An overview of the program's operations is provided in Appendix 1. The key elements are that the government determines a set budget (not linked in any way to the amount of research funded), and funds are allocated to universities and colleges based on how much research funding they received under a number of eligible funding programs.[ii] RSF funding is awarded to institutions rather than individual researchers. It is allocated on a reverse income tax model that sees smaller institutions paid first at rates of between 40 to 80 per cent, with the remainder of the funds distributed by equal proportion to institutions receiving more than $7 million a year in research funding. Accordingly, the reimbursement rate by institution falls with the more research done.

The RSF indicates that these grants may be used to:

- maintain modern labs and equipment;
- provide access to up-to-date knowledge resources;
- provide research management and administrative support;

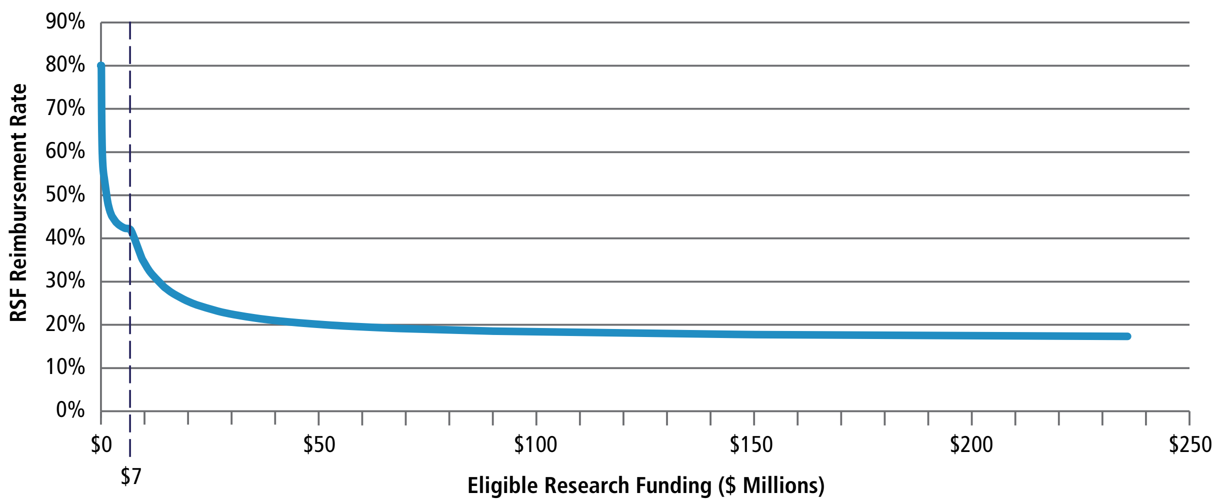
ii Programs such as CRC and CFREF that allow program funds to be spent on activities supported by the RSF are not included in the base.

- meet regulatory and ethical standards; or
- transfer knowledge from academia to the private, public, and not-for-profit sectors.

While most independent estimates find the indirect costs actually incurred to be in the range of 40 to 60 per cent of the cost of research,[10] the federal government currently reimburses at a much lower rate. On programs that are eligible for coverage, it currently stands at an overall average of 21.6 per cent. However, because of the way program funds are distributed, several large universities are compensated at rates in the 17 to 20 per cent range.[11]

The Panel has noted that there is widespread misunderstanding of the way the current formula works, a point that is highly germane to our recommendations. At exactly $7 million of eligible research funding, an institution receives a blended average of reimbursement of F&A costs totalling $2.93 million, just below 42 per cent. Every dollar thereafter, however, is reimbursed at a fixed rate set by the amount of funds in the remaining pool. Because every institution above $7 million starts with that higher reimbursement rate and fixed amount, none can ever fall to the "pooled" rate. The rate of decline, however, is fastest for smaller institutions in a growth phase between $7 million and $30 million. Exhibit 7.3 is based on recent RSF payment data.

Exhibit 7.3: RSF Reimbursement Rate by Total Amount of Eligible Research Funding



Source: 2016-17 Research Support Fund Control Sheet, provided to the secretariat by the RSF Secretariat.

It is very likely that implementing the Panel's recommended increases in support for investigator-led research would see about 15 to 20 institutions moving down the steep portion of the reimbursement curve and subject to the same cross-subsidy challenges faced by the largest institutions today. In effect, the RSF at the current level embodies a perverse incentive for the "gazelle" institutions that could grow fastest in a better environment. Shifting the threshold up from $7 million would be a stop-gap measure that would arbitrarily privilege some institutions, and further shift the RSF design away from its original purported goal of selective capacity building for small institutions.

As noted above, the current federal reimbursement rate for indirect costs paid through the RSF (average 21.6 per cent) is very low compared with other countries. For example, the U.S. has a complex and prescriptive system that aims to fully capture the actual indirect costs—now termed more accurately F&A costs—by having each university directly negotiate a reimbursement rate with a federal department. That

> Where we do fall short is providing more support for the indirect costs of research. … The current Research Support Fund (RSF) levels do not enable universities to provide robust, efficient research support services.
>
> – Canadian Association of Research Administrators
>
> The so-called indirect costs provided through our Canadian system are woefully inadequate to allow us to provide the support required for our scientists. We need to have support that matches the financial needs of the full cost of research. Without that the progress of our researchers is being substantially impeded. Providing funding for such costs, however, must be done in a coordinated way so as to not come at the expense of funding direct costs of doing research.
>
> – The Hospital for Sick Children Research Institute

rate (typically valid for three years before renegotiation) is then applied to all of that institution's federal research grants and contracts. Reimbursement rates under this system can range significantly, but normally fall in the 50 to 60 per cent range. The costs are closely audited. These are real costs borne by institutions, and there is no reason to believe that they are different in Canada. On that point, in a Canadian study, 12 institutions reported having measured their F&A costs in accordance with detailed U.S. guidelines and then successfully negotiating a reimbursement rate with U.S. funders. Of these, 11 agreed to divulge their negotiated rates, which ranged from 32 to 59 per cent with an average of 49.3 per cent and a median of 52 per cent.

While the U.K. does not measure F&A costs in terms of a percentage of direct costs, it has implemented a centralized model, the Transparent Approach to Costing (TRAC) system, which funds 80 per cent of the full economic costs of research, with institutions absorbing the remainder from their own resources.[12]

In Canada, at the provincial level, reimbursement for provincially funded research varies. The Government of Quebec is on the higher side of reimbursement. Through a combination of funding available through the indirect cost program of Fonds de recherche du Québec (Frais indirects de recherche) with funding through the Ministry of Economy, Science and Innovation (MESI), the Ministry of Higher Education and other departments, compensation rates can reach 60 per cent coverage for "heavy" or *lourde* research disciplines (e.g., medicine, engineering, chemistry) and 45 per cent for "light" or *légère* disciplines (e.g., history, psychology, communications).[13] The Government of Quebec makes no secret of its unhappiness at the federal government's low reimbursement rates. As we indicated in Chapters 3 and 4, this concern is shared by other provinces.

The failure to cover the full costs of research contributes meaningfully to the imbalances demonstrated in Chapter 3. There, we saw that Canada is anomalous internationally in the extent to which GERD is derived from universities and colleges. Focusing specifically on HERD, we saw this subsidy more clearly. To repeat: In 2015 the federal share represented only 23.3 per cent of all R&D funding for the higher education sector. The remaining 50 per cent comes from the higher education sector itself, amounting to $6.374 billion in 2015.

We appreciate that the extent of existing institutional subsidies for federally funded research is not widely understood. It is also unfortunate that this situation has gone unaddressed for years, despite repeated recommendations that a reimbursement rate of about 40 per cent would resolve it. Further costing is provided in the next section, but it is straightforward to estimate the current cumulative shortfall. The federal government currently pays about $369 million through the RSF on eligible grants totalling some $1.71 billion. To take the current rate to 30 per cent would add approximately $143 million to the tri-council base. The corresponding numbers for 35 per cent and 40 per cent are $229 million and $314 million.

The magnitude of this shortfall suggests two conclusions to the Panel. First, the Government of Canada should take immediate steps to reduce this liability. And second, given that new operating grants for independent research are urgently needed, a staged approach is needed to improve F&A reimbursement rates across existing and new RSF-eligible grants.

The magnitude of this liability also underscores why there are indeed consequences to the federal government's persistent underfunding of F&A costs. The Panel heard many complaints from researchers about the challenges in keeping equipment in top operating shape and the frustration of being forced to devote too much time to research grants administration due to the lack of central services. These problems have their roots in federal funders not providing for the full costs of the research supported. We were advised about the growing importance of DRI and the difficulties in keeping up with demand. Changes recommended in Chapter 6 to DRI support may help at the macro level, but much of the day-to-day burden for IT will still fall to institutions.

> The upstream development and creation of ever more complex partnerships require human resources … that the funding of the current Research Support Fund just does not take into account. Branding, marketing and technological entrepreneurship have become unavoidable and inextricable aspects of research support activities. … Without [such prospecting activities] research findings would only have a limited impact.
>
> – École Polytechnique de Montréal

While our focus is on the research mission, underfunding of F&A costs has other undesirable effects. This gap in the federal scheme more generally forces universities to cross-subsidize research from other sources of revenue, such as student tuition, leading to adverse effects on the delivery of other elements of the university mission—such as student support and teaching. Such adverse effects on the teaching and training mission of universities not only attenuate the broader value and impact of the nation's investment in extramural research, but also put undue strains on the teaching mission. One can reasonably argue that as a result of the underfunding of F&A costs, universities are using dollars designated for the *teaching* mission to underwrite the *research* mission. Finally, while innovation is not part of our mandate, we note that to be effective partners in innovation, universities need to engage in knowledge translation, manage their IP, and engage with business and other potential users of the insights, discoveries, and skills arising from postsecondary institutions. These activities are among those deemed eligible for reimbursement by the RSF. While few connect shortcomings on these fronts with the low levels of federal reimbursement of F&A costs, they are inextricably linked. It has been argued that unless Canadian universities receive appropriate levels of funding for F&A costs comparable to U.S. rates, they will never be able to successfully compete with the technology transfer record of U.S. universities.

Recommendation 7.3

The Government of Canada should gradually increase funding to the RSF until the reimbursement rate is 40 per cent for all institutions with more than $7 million per year of eligible funding. Current thresholds should be maintained to enable additional support for smaller institutions. As the size of the envelope of RSF-eligible operating grants grows, the funding of the RSF should be increased in lock-step to sustain the reimbursement rate of F&A costs on a trajectory towards this 40 per cent goal.

Cognizant that indirect costs are difficult to measure and attribute precisely, the Panel believes that targeting the lower end of what is generally acknowledged to be the true costs would be appropriate and ensure that institutions are not overcompensated. The Panel also found that the current program structure and coverage are basically sound; only the level of funding is a problem. However, as the program moves to more adequate levels of reimbursement, closer oversight and reporting will be required to ensure that all funding is going towards the provision of better quality services in support of researchers. In this respect our proposal is for phased increases in reimbursement rates. This approach not only reduces the immediate financial implications for the federal government, but also offers time for the granting councils, CFI, and

RSF Secretariat to consult with universities and research institutes on a mode of ensuring full transparency for use of these funds, and appropriate priority for their expenditure to improve the productivity and success of Canadian scientists and scholars.

We would add that while our recommendations are directed at research sponsored by the federal government, the Panel was informed that universities also have difficulty in getting funders such as businesses and charities to support full F&A costs.[iii] It seems likely that if the federal government takes leadership within its sphere, this would provide an impetus to other funders to follow suit. The hand of universities and research institutes in seeking appropriate cost coverage from research sponsors would be strengthened.

Exhibit 7.4 breaks down our recommended increase to the RSF. There are two variables at play: the reimbursement rate and the eligible program base. We recommend that the reimbursement rate rise over four years from the current 21.6 per cent to 40 per cent—starting at 25 per cent in year one and increasing by 5 per cent in each of years two, three, and four. The top section of Exhibit 7.4 shows the incremental cost of increases in the reimbursement rate on the current program base of $1,708 million a year. Increasing the rate from 21.6 per cent to 25 per cent in year one would carry an incremental cost of $58 million per year. For years two, three, and four, incremental costs associated with the recommended reimbursement rates are highlighted.

Exhibit 7.4: Proposed Increases to RSF Based on Current RSF Funding and on the Panel's Recommended Increase to Direct Project Funding ($ Millions)

	Year 1	Year 2	Year 3	Year 4
Current RSF-eligible Base of Direct Project Spending	1,708	1,708	1,708	1,708
Current RSF Funding	369	369	369	369
Increment to 25% Reimbursement	58	58	58	58
Increment to 30% Reimbursement	143	143	143	143
Increment to 35% Reimbursement	229	229	229	229
Increment to 40% Reimbursement	314	314	314	314
Panel's Recommended Direct Project Funding Increase	155	310	465	485
Increase to RSF at 21.6%[a]	33	37	70	75
Increase to RSF at 25%[a]	38	48	86	91
Increase to RSF at 30%[a]	47	63	110	116
Increase to RSF at 35%[a]	54	79	133	140
Increase to RSF at 40%[a]	62	94	156	164
Total Proposed RSF Increase	**96**	**206**	**362**	**478**

[a] Beginning in year 2, the amounts shown have been reduced by $30 million per year. This amount offsets the recommended increase in operating support for small capital awards delivered by CFI (see Recommendation 6.11).

iii While some provinces have adopted a 40 per cent rule (e.g., Ontario) or gone even higher (e.g., Quebec), few sponsors of research make adequate provision for F&A costs. In some cases, such as clinical trials, the F&A level may legitimately fall below the 40 per cent threshold. In others involving the life sciences, natural sciences, and engineering, it is likely to be well above that level.

Our recommended increases to direct project funding (first row of Exhibit 7.4, lower section) also result in additional RSF costs as again shown in highlighted cells, due to the higher overall eligible program base. Beginning in year two, we have reduced these amounts by $30 million to account for our recommendation of earmarked operating funds for small equipment grants by CFI (Recommendation 6.11).[iv] The final row shows the total proposed increase to the RSF based on the increased reimbursement rate and the increased level of direct project funding (i.e., the sum of the highlighted cells), beginning at $96 million per year in year one and rising to $478 million in year four.

We conclude that the current level of RSF funding is a major gap in the ecosystem. The strength of the research enterprise would be greatly enhanced if the federal government recognized the full costs of research in its programs. In this regard, one of the intriguing disconnects in our consultations was the frustration expressed by frontline researchers about services that should be funded by the RSF (such as maintenance and operation of equipment and facilities) and the relative paucity of discussion of the program itself. We appreciate, too, that the first priority in the current circumstance must be restoration of funding for investigator-led research. Doing so would have enormous benefits for Canadian research and scholarly inquiry, and also improve the opportunities for graduate students and PDFs across the country. However, reinvestment in investigator-led research would also mean that many more institutions will be faced with research-related financial pressures as they host and support those federally funded projects and people. The best time to ameliorate this long-standing RSF funding deficiency is concurrent with a transformative improvement in funding for investigator-led research.

7.3 Costing of Recommendations: A Four-year Plan to Renew Canadian Research

The Panel's recommendations are costed in this section with regard to the key envelopes at issue. The three granting councils provided approximately $2.7 billion to postsecondary institutions in 2015-16. When adjusted for inflation, this is 6 per cent lower than funding in 2007-08.[v] We estimate that Budget 2015 and Budget 2016 added $140 million per year to the granting councils during 2016-17, about 20 per cent to the RSF, and the rest (approximately $113 million) to investigator-led research. This sum is in addition to the ongoing roll-out of CFREF as a tri-council program. Accordingly, our estimate is that a meaningful amount of recent inflationary erosion has been ameliorated.

7.3.1 Direct Project Funding

This welcome improvement, however, has only partly redressed the impact of the redirection of funds away from investigator-led research and related diminution of funds available relative to the growth in the number of researchers—including university faculty, research institute scientists, PDFs, and doctoral students. To repeat: We have no evidence whatsoever to suggest that this growth is disproportionate relative to peer nations. On the contrary, Canada's doctoral outputs are below average for peers.

The Panel has calculated the appropriate scale for reinvestment in multiple ways. We have examined the impact of the shifting balance between priority-driven and investigator-led research; the drop in funding per researcher with starting dates of 2000, 2007, and 2008; and various international comparators. What we can say in brief is that despite their limitations, all the metrics that we examined suggest a substantial shortfall in federal support for investigator-led research.

iv We recognize that there is a certain level of overlap between the IOF and RSF in that the IOF provides one-time partial payments to help offset O&M for CFI-funded infrastructure. Our targeted rate of reimbursement takes this partial coverage into account, and there is no "double compensation" for the same costs in our recommendations. The increase of $30 million per year to the IOF for small capital in contrast is an earmarked increment addressing a priority concern. We offset it against the RSF to render it costless and facilitate rapid implementation of this recommendation.

v In contrast, from 2000-01 to 2006-07, inflation-adjusted granting council funding more than doubled.

We noted in Chapter 6 that, at a minimum, an additional $575 million in funding for investigator-led research would be required to address the imbalance that has resulted from a decade of preferential investments in priority-driven research. We have also estimated the investment required to restore the level of real resources for investigator-led research per researcher to that of the early 2000s (see Exhibit 6.2). Allowing for slowing growth in the number of researchers and continuing low inflation, this would still be in the $550 million a year range.

We recognize that neither of these measures is perfect. As already stated, a return to the 70:30 balance in favour of investigator-led research may no longer be optimal—and indeed may not be feasible, as it would require a doubling of investigator-led funding given the scale of investment in CFREF. We also understand that the composition of the number of active postsecondary researchers reported by Statistics Canada contains a growing number of graduate students and PDFs who make smaller demands on resources than faculty members. Given these considerations and the absence of a definitive methodology for determining the appropriate incremental investment needed, the Panel believes that it is responsible to make a recommendation at the low end of the range suggested by our calculations. **Accordingly, we propose an increase of $485 million on the current base of research funding ($1.66 billion), to be reached by year four of our plan**, equivalent to an average annual growth of 6.6 per cent per year. We believe an increase in this range to be eminently reasonable and affordable, especially given the social and economic returns reported for these kinds of investments in Chapter 2.

This recommendation is the Panel's highest priority for new funds.

As noted in Chapter 6, the Panel is concerned about the current funding for **international collaboration; multidisciplinary research; high-risk, high-reward projects; and research undertaken in requested response to fast-breaking issues or crises**. We found no firm benchmarks, but a combined allocation of 5 per cent of the final envelope for investigator-led research appeared conservative and reasonable, i.e., **approximately $80 million dollars**. We propose that these funds be earmarked from the general increase to operating grants outlined above. Again, this should be phased. The first priority should be international research collaboration to strengthen Canada's role in global science and inquiry.

7.3.2 Capital

CFI, as noted, has had variable outlays. We believe that the current average capital allotment of $300 million per year is meeting current needs, not least given the fact that the Government of Canada has undertaken a large-scale renewal of infrastructure with latitude for extramural research institutions to seek capital grants. We have recommended that CFI's average annual capital outlay of $300 million be regularized as A-base funding, and that the $90 million per year spent on O&M through the IOF be sustained. CFI's capital and infrastructure operating budget may have to be adjusted over time to maintain the balance between capital support and direct project funding. At present, however, these two allocations are fiscally neutral.

We have made **two further O&M recommendations**: $**35 million per year urgently to stabilize the operating funding of a number of Canada's MRFs through a new matching formula, and $30 million per year to ensure the successful initiation of operations and maintenance for small- and mid-scale equipment funded by CFI**. The latter recommendation reflects redress for a shortfall that would not have occurred if the RSF were scaled more appropriately. However, to close this gap, we are recommending an immediate investment, and believe that the $30 million should be set off against the final total for the RSF.

We also recognize that once the federal government has consolidated its organizations supporting DRI, new investments in capital and operating funds may be required. That amount cannot be estimated without a consolidated plan.

7.3.3 Personnel

Restoring the CRC program has been recommended for reasons already reviewed. The Panel puts a particularly high priority on improving the numbers and funding of Tier 2 Chairs given the challenges facing ECRs as they launch their careers and in making the critical transition to a productive mid-career period. To phase in spending, **we recommend starting with the $35 million per year required to restore the CRC envelope to its original $300 million per year level, with those funds targeting the creation of Tier 2 CRCs.** The phase-in period will also provide an opportunity for the granting councils to develop, in concert with universities and research institutes, a strategy to pursue global talent more aggressively. To accelerate international recruitment and retain top talent, we recommend that once a plan for renewal of the CRCs has been approved, **the full restoration of the value of both tiers of CRCs be undertaken, ideally in year two of the proposed renewal program, with a cost of $105 million per year**. This will rapidly remedy 17 years of erosion of the value of these flagship personnel awards.

Along with improving personnel supports for university and institute-based researchers through renewal of the CRC program, the Panel has recommended harmonization and upgrading of the suite of supports provided to graduate students and PDFs under the auspices of the granting councils and the tri-council CGS awards. We emphasize again the need for a detailed plan to achieve this goal, drawing on consultations with students, trainees, researchers, and institutions. We have done some indicative costings to provide a sense of the scale of reinvestment required. Given the need for planning and staging, and because some of the pressures on master's, doctoral, and PDF stipends and salaries will be eased by improvements in funding of investigator-led grants, **we recommend a $140 million per year increment phased over four years,** leaving to the granting councils the determination of the best mix of award levels, durations, numbers, and types.

7.3.4 Full Costs of Research

The last item on our list is essential to modernizing the federal research ecosystem. We have shown in Chapter 3 that, compared to peer nations, Canada depends heavily on extramural institutions, particularly universities, to conduct research in all disciplines. Our analyses also make clear that the Government of Canada has leaned heavily on those same institutions to cross-fund the research mission, with adverse results for both education and research. We have forewarned that this deficit is not only growing, but will begin to impinge on a wider number of institutions if our recommendations to restore investigator-led research are heeded. Panel members understand that this gap in the ecosystem is one that has the smallest constituency of advocates and is the least understood. However, absence of a fair reimbursement rate for F&A costs is particularly obvious given that we live and work next door to the country with the strongest research ecosystem on the planet and the most comprehensive and sophisticated system for reimbursing the full costs of research through federal granting agencies. Detailed projections of the required investments were provided in Section 7.2, and need not be repeated here. We shall instead simply emphasize that this gap is an "inconvenient truth" that exerts a large negative influence in the ecosystem and one that will have damaging consequences if allowed to grow.

The resulting four-year plan is set out in Exhibit 7.5. Against a current four agency envelope of approximately $3.23 billion, independent of additional outlays through contribution agreements, the plan entails growth by about 10 per cent per year. As structured, it is weighted towards the first three years. If elements were to be redistributed, the Panel's firm view is that funding for investigator-led grants should in no way be delayed. Other early priorities are growing the number of Tier 2 CRCs and making a serious start on harmonizing and upgrading funding for doctoral students and PDFs. We note further that some offsetting savings may be achieved downstream depending on the assessments of the yields and opportunity costs of the CERC and CFREF programs.

Exhibit 7.5: A Four-year Plan to Renew Canadian Research ($ Millions)

	Year 1	Year 2	Year 3	Year 4
Investigator-led Direct Project Funding[a]	135	270	405	405
Specialized Direct Project Funding[b]	20	40	60	80
Total Direct Project Funding	155	310	465	485
Operating Funds for Major Research Facilities[c]	35	35	35	35
Operating Funds for Small Capital Projects[d]	30	30	30	30
Scholarships and Fellowships[e]	35	70	105	140
Research Chairs for Excellent Scholars and Scientists[f]	35	140	140	140
Facilities and Administration Costs (Research Support Fund)[g]	96	206	362	478
Total	**386**	**791**	**1,137**	**1,308**

[a] Recommendation 6.1. The Panel recommends an increase of $485 million in investigator-led direct project funding phased in over four years.

[b] Recommendation 6.1 and recommendations 6.4, 6.5, 6.6, and 6.7. The Panel recommends that $80 million of the increase for investigator-led research be earmarked for international collaborations, multidisciplinary work, high risk, high reward projects, and research in response to fast breaking issues or crises, phased in over four years.

[c] Recommendation 6.10. The Panel recommends that $35 million a year in funding be provided for CFI to change the sharing ratio for operating costs for MRFs from the current 40:60 to 60:40.

[d] Recommendation 6.11. The Panel recommends that $30 million a year in funding be provided for CFI to increase the operating support available to the recipients of small capital awards.

[e] Recommendation 7.1. The Panel recommends that funding be provided to reinvigorate and harmonize scholarships and fellowship programs at a cost of $140 million per year, phased in over four years.

[f] Recommendation 7.2. The Panel recommends the CRC program be renewed at a cost of $140 million per year, phased in over two years.

[g] Recommendation 7.3. The Panel recommends that funding be provided to move the coverage of facilities and administration costs by the RSF on a trajectory from the current level of 21 per cent to 40 per cent, over four years. Exhibit 7.4 shows a full breakdown of RSF options and trajectories.

7.4 Balance and Scale

Over the last two chapters, we have completed our survey of key programs and gaps in the federal research ecosystem. Rather than retrace a rapid walk through a very complex landscape, the Panel will pause here to provide some sense of considerations of balance and scale that have broadly informed our recommendations for renewed investment.

First, it has been more than 40 years since a comprehensive review of the federal research ecosystem was undertaken. A burst of investments starting in the late 1990s renewed Canada's federal research supports, creating multi-year momentum that has begun to wane visibly. The challenges evident in recent years are not simply a function of flat-lining total research spending and reallocating funds away from independent science and inquiry. They also arise from a strategy of resource concentration, manifested in personnel supports (Vanier, Banting, CERC) and massive multi-year operating grants (CFREF). Panel members fully appreciate the importance of innovation to Canada's prosperity, and are sympathetic to elite programming that seeks to reward and amplify excellence. However, the strongest research ecosystems place a high priority on the basic natural and life sciences and on free-ranging inquiry in the humanities and social sciences. They rely on serious peer review to allocate resources, scale the intensity of peer review to the size of the allocations, and ensure at all times that the research ecosystem is diverse, balanced, and resilient—with a healthy mix of redwoods and mayflowers. The foregoing recommendations aim to restore the proportionality that characterizes a successful research ecosystem.

Second, from the standpoint of balance and scale, the investments above fall into four categories:

- new direct project funding to support independent research;
- personnel awards to graduate students and PDFs, and to scientists and scholars at different career stages;
- special purpose funds for unique types of research grants, and for gaps in coverage of O&M costs related to both ultra-large facilities and small-scale equipment funded by CFI; and
- reimbursement of existing and new shortfalls in institutional costs of research or F&A costs.

Direct funding of research grants is the largest item; coupled with the current reimbursement rate of F&A costs, it comprises 45 per cent of the total. Adding personnel awards brings the proportion to 67 per cent. The remainder is incremental coverage of operating, maintenance, and administration costs, bringing the ecosystem to a baseline for reimbursement that has been recommended repeatedly for some decades.

A third and final element relates to the financial scale of the recommendations. One straightforward comparison is to the totality of the annual federal budget. The Government of Canada Budget 2016 was $317 billion. The staged increases recommended in our four-year plan culminate in a new annual outlay equal to 0.4 per cent of federal spending in Budget 2016—a percentage that will be even smaller if, as is likely, total federal spending grows in the years ahead. We do not underestimate the many pressures on the Government of Canada. Conversely, we cannot overstate the urgency of need for reinvestment in independent research, the propitiousness of the timing given global trends, or the very positive impacts a wise allocative decision would have on the future of Canada.

ENDNOTES

1 Vanier CGS overview [Internet]. Ottawa: Vanier-Banting Secretariat; 2016. Available from: http://www.vanier.gc.ca/en/nomination_process-processus_de_mise_en_candidature_overview.html

2 Statistics Canada. Postsecondary enrolments, by registration status, Pan-Canadian Standard Classification of Education (PCSCE), Classification of Instructional Programs, Primary Grouping (CIP_PG), sex and student status (CANSIM table 477-0019). Ottawa: Statistics Canada; 2016.

3 Jadavji, N.M., Adi, M.N., Corkery, T.C., Inoue, J., Van Benthem, K. The 2016 Canadian National Postdoctoral Survey Report. Ottawa: Canadian Association of Postdoctoral Scholars-L'Association Canadienne de Stagiaires Post-doctoraux; 2016. Available from: http://www.caps-acsp.ca/wp-content/uploads/2016/11/2016_CAPS-ACSP-National_Postdoc_Survey_Report.pdf

4 Revised: Projected FY 2017 Stipend Levels for Postdoctoral Trainees and Fellows on Ruth L. Kirschstein National Research Service Awards (NRSA) [Internet]. Bethesda (MD): NIH; 2016. Available from: https://grants.nih.gov/grants/guide/notice-files/NOT-OD-16-134.html; see also Kuo, M. NIH Sets New Postdoc Stipend Levels [Internet]. Science (AAAS); 2016. Available from: http://www.sciencemag.org/careers/2016/08/nih-sets-new-postdoc-stipend-levels

5 About Us [Internet]. Ottawa: Canada Research Chairs; 2015. Available from: http://www.chairs-chaires.gc.ca/about_us-a_notre_sujet/index-eng.aspx

6 About Us [Internet]. Ottawa: Canada Excellence Research Chairs; 2016. Available from: http://www.cerc.gc.ca/about-au_sujet/index-eng.aspx

7 Statistics Canada. Number of full-time teaching staff at Canadian universities, by rank, sex, Canada and Provinces, annual (CANSIM table 477-0017). Ottawa: Statistics Canada; 2016. When this survey was ended in 2012 there were 45,000 professors of all ranks in Canada reported. The number has almost certainly grown since then.

8 Goss Gilroy Inc., Management Consultants. Evaluation of the Canada Research Chairs Program: Final Report. Ottawa: NSERC-SSHRC Evaluation Division; 2016. Available from: http://www.chairs-chaires.gc.ca/about_us-a_notre_sujet/publications/evaluations/Chairs_Evaluation_Report_E.pdf

9 Ibid.

10 CAUBO. Indirect Costs of Research: Results of a joint survey administered by CAUBO/CAURA. Ottawa: CAUBO; 2013. Available from: https://www.caubo.ca/knowledge-centre/surveysreports/indirect-costs-research-report/ or https://www.caubo.ca/wp-content/uploads/2016/03/Indirect_Costs_of_Research-CAUBO_2013.pdf

11 Data from 2016-17 Research Support Fund Control Sheet, provided to the secretariat by the RSF Secretariat.

12 History of TRAC [Internet]. Higher Education Funding Council for England; 2015. Available from: http://www.hefce.ac.uk/funding/finsustain/trac/history/

13 Gouvernement du Québec. Règles budgétaires et calcul des subventions de fonctionnement aux universités du Québec : Année universitaire 2015-2016. Québec: Ministère de l'Éducation, de l'Enseignement supérieur et de la Recherche; 2015. Available from: http://www.education.gouv.qc.ca/fileadmin/contenu/documents_soutien/Ens_Sup/Universite/Calculs_subventions/Regles_budgetaires_universites_2015-2016.pdf

CHAPTER 8

MINISTER'S OPENING QUESTIONS & PANEL'S CLOSING REFLECTIONS

Throughout this report the Panel has been steadily addressing all the questions put to us by the Minister of Science. Here, as outlined in Chapter 1, we revisit the questions that framed our mandate and summarize our responses to each of them. We also briefly consider what outputs and outcomes might follow from bold action on our recommendations for improvements in structures, processes, and resources.

8.1 Ten Questions, Three Themes

Our mandate included 10 specific questions and an invitation to address additional issues raised by our consultations (see Exhibit 1.1). For ease of reference Exhibit 8.1 aligns our recommendations and relevant text in the report with each question. What follows is obviously a much abbreviated summary of that material; hence, as we cautioned with respect to both the Executive Summary and the accompanying list of top-line recommendations, detailed interpretation and, *a fortiori*, action on any recommendation should draw on the full text with all the relevant elaborations and qualifiers. Lengthier quotes from the body of the report are shown below in italics.

8.1.1 Theme 1: Funding of Fundamental Research

The Granting Councils

The first set of questions related to the effectiveness and impact of the granting councils in supporting excellence in fundamental research: "Are granting councils optimally structured and aligned to meet the needs of the current research community in Canada? Are the current programs the most effective means of delivering the objectives of these organizations? And are they keeping pace internationally?"

In response, we identified a major gap in the Canadian research ecosystem, namely the need for improved coordination and oversight of the activities of the four key federal agencies. Chapter 4 is entirely devoted to considering both oversight and advice at the federal system-wide level (touching briefly on FPT coordination) as well as matters of structure and governance specific to the granting councils. *In the Panel's view, the limited mandate of STIC as an external advisory body and the lack of an NSA have put Canada in an unusual and weakened position compared with many nations in the OECD. The need for a high-level overview and coordination of research efforts seems particularly urgent given the global trends, our weakening competitive position as outlined in Chapter 3, and the critical challenges cited in Chapters 1 and 2.*

We accordingly **recommended (R4.1)** that *the Government of Canada, by an Act of Parliament, should create a new National Advisory Council on Research and Innovation (NACRI) to provide broad oversight of the federal research and innovation ecosystems.*

Exhibit 8.1: Alignment of Panel Recommendations with Mandate Questions

Questions	Relevant Recommendations and Report References
Theme 1: Funding of Fundamental Research	
Are granting councils optimally structured and aligned to meet the needs of the current research community in Canada? Are the current programs the most effective means of delivering the objectives of these organizations? And are they keeping pace internationally? The review should take into account the several reviews and evaluations that were performed in recent years on the councils and on science and scholarly inquiry in Canada.	Structure, Function, and Role of a National Advisory Council on Research and Innovation: • R4.1 – 4.4, R4.6, pp. 56–66 Privy Council Office Review of Machinery: • R4.5, p. 65 Federal-Provincial-Territorial Cooperation and Coordination: • R4.8, R4.9, pp. 67–69 Creation of a Four Agency Coordinating Board: • R4.10, pp. 69–73 Review of Agency-specific Governance and Legislation: • R4.11, pp. 73–77, 80–81 Review of Funding Allocation Across Agencies: • R5.1, pp. 81–86
Are students, trainees and emerging researchers, including those from diverse backgrounds, facing unique barriers within the current system and, if so, what can be done to address those barriers?	Review of Agency Funding Strategies: • R5.2, pp. 86–90 Equity and Diversity, Early Career Researchers, and Indigenous Research: • R5.4 – R5.7, pp. 92–101 Review of Scholarship and Fellowship Programs and Support for Research Chairs: • R7.1, R7.2, pp. 137–146
Is there an appropriate balance between funding elements across the research system, i.e. between elements involving people and other direct research costs, operating costs, infrastructure and indirect costs? What are best practices for assessing and adjusting balances over time?	Direct Project Funding for Investigator-led Research: • R6.1 – R6.7, pp. 110–126 • R6.11, pp. 134–135 Support for the Full Costs of Research: • R7.3, pp. 146–151
Are existing review processes rigorous, fair and effective in supporting excellence across all disciplines? Are they rigorous, fair and effective in supporting riskier research and proposals in novel or emerging research areas or multidisciplinary/multinational areas?	Oversight and Improvement of Peer Review Practices: • R5.3, pp. 90–92
Are granting council programs and structures sufficiently flexible to reflect and accommodate the growing internationalization of research? Are granting council programs and structures accommodating the full range of research areas; multidisciplinary research; and new approaches ranging from traditional knowledge, including indigenous research, to more open, collaborative forms of research? If not, what steps could be taken?	Support for Indigenous Research: • R5.7, pp. 98–101 Direct Project Funding for Investigator-led Research: • R6.1 – R6.7, pp. 110–126

Exhibit 8.1: Alignment of Panel Recommendations with Mandate Questions (continued)

Questions	Relevant Recommendations and Report References
Theme 2: Funding of Facilities/Equipment	
Is the Canada Foundation for Innovation optimally structured to meet the needs of the current research community in Canada? What are the strengths and weaknesses of the current model in delivering the objectives of this organization, including its ability to work complementarily with the granting councils? What is the appropriate federal role in supporting infrastructure operating costs and how effective are current mechanisms in fulfilling that role?	Review of Agency-specific Governance and Legislation: • R4.11, pp. 73–77, 80–81 Funding for Research Infrastructure and Equipment through CFI: • R6.8, pp. 126–129 Funding for Infrastructure Operating Costs: • R6.10, R6.11, pp. 132–135
What are best practices (internationally/domestically) for supporting big science (including, inter alia, international facilities and international collaboration)?	Coordination and Oversight of Major Research Facilities: • R4.7, pp. 66–67
Many requests for government support for research are not tied to the cycles of the four major research agencies, but they have economic or competitive relevance nationally or regionally, or major non-governmental financial support, or implications for Canada's international standing as an active participant in big science projects or major multi-institutional projects. How can we ensure that the Government has access to the best advice about funding these types of projects in the future?	Coordination and Oversight of Major Research Facilities: • R4.7, pp. 66–67
Theme 3: Funding of Platform Technologies	
What types of criteria and considerations should inform decisions regarding whether the Government should create a separate funding mechanism for emerging platform technologies and research areas of broad strategic interest and societal application? Are there any technologies that would appear to meet such criteria in the immediate term? When there is a rationale for separate funding, how to ensure alignment of funding approaches?	Coordination and Oversight of Major Research Facilities: • R4.7, pp. 66–67 Role of Third-party Delivery Organizations and Matching Funding Programs: • R5.8, R5.9, pp. 102–105 Funding for Digital Research Infrastructure: • R6.9, pp. 129–131
Today's emerging platform technology may rapidly become a standard tool used tomorrow by a wide variety of researchers. If such technologies are initially given stand-alone support via a dedicated program or agency, what factors should inform decisions on when it would be appropriate to "mainstream" such funding back into the granting councils?	

The key responsibilities that we envision for NACRI are as follows:

- *advice to the Prime Minister and Cabinet on federal spending as well as broad goals and priorities for research and innovation;*
- *improving the coordination and strategic alignment of different elements of federal support for research and innovation;*
- *evaluation of the overall performance of the extramural research enterprise;*
- *public reporting and outreach on matters determined by the Council;*
- *confidential or public advice on other matters as requested by the Government of Canada;*
- *a foresight function for research and innovation;*

- *in concert with the CSA, ongoing advice on (i) the effectiveness of extramural research agencies and the intramural research groups, and (ii) the facilitation of collaboration among them and with the extramural research realm;*
- *advice on large-scale domestic and international research infrastructure projects, and on unusual requests for research support that fall outside the usual remit of the granting councils and CFI; and*
- *liaison with parallel bodies in provinces and territories and internationally as appropriate.*

We applaud the Government of Canada for its decision to create the role of CSA, and envision NACRI working in close conjunction with the new CSA in fulfilling their respective mandates. Several **recommendations (R4.2 to R4.6)** in Chapter 4 describe in more detail our views on the optimal structure and functioning of NACRI.

The work of the councils and especially of CFI is facilitated by strong FPT collaboration. We **recommended (R4.8)** that greater attention be paid to those research relationships, with more regular interchanges; we see the CSA and NACRI as likely to be helpful in that regard. To reset those interactions on a very positive note, and celebrate science and scholarly inquiry in Canada's sesquicentennial year, we also **recommended (R4.9)** a First Ministers' Conference on Research Excellence in 2017.

As to matters of structure and governance specific to the granting councils, we noted with concern the uneven coordination across SSHRC, NSERC, CIHR, and CFI. We observed that *NACRI, working in close conjunction with the new CSA, can maintain a watching brief on the overall research funding system and report on problems and progress, or lack thereof, to relevant ministers and deputies as well as to the PMO as required.*

We considered a variety of international models to improve coordination, concluding *that there is no 'perfect' agency structure for disciplines in a funding ecosystem, and that putting a large number of divisions and operations under one umbrella does not necessarily ensure coordination.* Keenly aware of the potential for doing more harm than good with major structural changes, we *recommended a graded approach to making those shifts, strengthening agency-level governance, while also putting in place a formal coordinating body … chaired by Canada's new CSA.*

Thus, we see **Recommendation 4.10** as a starting point: *The Ministers of Science and Health should mandate the formation of a formal coordinating board for CFI, CIHR, SSHRC, and NSERC, chaired by the CSA. The membership of the new Four Agency Coordinating Board would include the four agency heads, departmental officials, and external experts. Reporting to the Ministers of Science and Health, the Coordinating Board would expeditiously determine and implement avenues for harmonization, collaboration, and coordination of programs, peer review procedures, and administration.*

In the event that this coordinating function proves ineffective, then the Coordinating Board could be reconstituted and given more authority to give binding strategic direction to the four agencies.

We also noted significant differences in the relevant legislation, governance, and accountability provisions for the four agencies. The three granting councils have all made efforts to address limits in their governance practices and mechanisms. We concluded, however, that *the major differences in legislation and ambiguities about accountabilities represent gaps that may only be remediated by legislative change.* We accordingly **recommended (R4.11)** that *the Government of Canada should undertake a comprehensive review to modernize and, where possible, harmonize the legislation for the four agencies that support extramural research. The review would clarify accountabilities and selection processes for agency governing bodies and presidents, promote good governance and exemplary peer review practices, and give priority to inter-agency collaboration and coordination.*

Among other changes, the review could also ensure that appointments to these governing bodies are made *with appropriate attention to the balance of expertise and need to reflect the diversity of Canada and the research community.*

The establishment of a coordinating board should precede any legislative review. This would prevent a focus on reforms to agency-specific governance from impeding progress on the more urgent issues of cross-agency collaboration and harmonization.

Efforts to align and optimize the function of the granting councils should include consideration of the allocation of funding across councils. We found that, other than the large increase to CIHR's budget in its early years following its creation in 2000, the proportions of funding allocated to the three granting councils have remained essentially unchanged since 1978-79 when NSERC and SSHRC were formed. However, the Canadian research landscape has changed considerably over the past four decades, as has the complexity and cost of social science research and extent of interweaving of SSHRC disciplines with the natural and health sciences. Given our recommendation of increased funding for the three granting councils, any shifts to current proportions can be made against the background of a rising tide for all. We therefore **recommended (R5.1)** that *NACRI should be asked to review the current allocation of funding across the granting councils. It should recommend changes that would allow the Government of Canada to maximize the ability of researchers across disciplines to carry out world-leading research. Particular attention should be paid to evidence that ongoing program changes have adversely affected the funding opportunities for scholars in the social sciences and humanities.*

Supporting the Next Generation

The second set of questions about the councils asked, "Are students, trainees and emerging researchers, including those from diverse backgrounds, facing unique barriers within the current system and, if so, what can be done to address those barriers?"

We found that significant gaps and challenges were indeed impeding the ability of Canada's researchers, particularly the next generation, to achieve their full potential. Declining success rates for grant applications, particularly at CIHR and to a lesser extent at SSHRC, have made it especially difficult for ECRs to enter the system and become established. The new generation is notably more diverse than its predecessors. Thus, these conditions are undermining not only the long-term growth and sustainability of research in Canada, but also the diversity of the research ecosystem.

At the same time, the system cannot undercut funding for established researchers who are at the top of their games. Our call for increased funding for independent research (described below) will greatly assist in addressing all these challenges. However, a more coordinated and strategic approach is still required, per **Recommendation 5.2**: *The Government of Canada should direct the new Four Agency Coordinating Board to develop and harmonize funding strategies across the agencies, using a lifecycle approach that balances the needs and prospects of researchers at different stages of their careers.* We also specifically **recommended (R5.6)** that *the four agencies should examine best practices in supporting early career researchers, augment their support of them consistently across disciplines, and track and report publicly on the outcomes.*

More generally, we believe that attention to equity and diversity concerns represents a very wise human resource strategy to maximize research excellence in a country like Canada with a small population. We accordingly **recommended (R5.4)** that *the Four Agency Coordinating Board should develop consistent and coordinated policies to achieve better equity and diversity outcomes in the allocation of research funding while sustaining excellence as the key decision-making criterion. This priority intersects efforts to improve peer review practices and requires a multipronged approach*—elements of which are covered in detail in Chapter 5. We emphasized that there must be careful evaluation and transparency for any and all changes—both to build trust with underrepresented groups as to steps taken and outcomes, and to assure the research community that merit remains the cornerstone of resource allocation.

Despite an improved awareness of equity issues, problems have persisted in specific programs, in particular the CRC and CERC. We are hopeful that these issues can be addressed through coordinated efforts by the granting councils, but as a fallback we added **Recommendation 5.5**: *The federal ministers responsible should* *consider hard equity targets and quotas where persistent and unacceptable disparities exist, and agencies and institutions are clearly not meeting reasonable objectives.*

The unique challenges and barriers faced by Indigenous researchers were also noted by the Panel. Despite some improvements, progress has been limited. To this end, we **recommended (R5.7)** that *the three granting councils should collaborate in developing a comprehensive strategic plan to promote and provide long-term support for Indigenous research, with the goal of enhancing research and training by and with Indigenous researchers and communities. The plan should be guided by the Truth and Reconciliation Commission's recommendations on research as a key resource.* We set out eight lines of action based on the Commission's recommendations, on our consultations, and on submissions we received.

We also reviewed the granting councils' personnel awards programs that provide direct salary support to researchers. A significant level of investment in student scholarships and other forms of financial aid is also made by institutions, provinces, and the not-for-profit and private sectors. For graduate students and PDFs in particular, even more federal support is derived from stipends associated with research operating grants held by their supervisors, than from specific salary awards. Our recommended enhancements to direct project funding would therefore have many benefits for graduate students and PDFs. *Nonetheless, the Panel found more than sufficient evidence to conclude that the personnel awards provided directly by the three granting councils encourage excellence among students and trainees. We believe that they should be not only sustained, but also, ideally, expanded.*

Upon reviewing those awards in Chapter 7, we found a *mix of council-specific and tri-council programs where awards vary considerably by value, duration, and international portability. … We find these arrangements unduly complex and arguably inefficient. They also provide only a limited number of opportunities to bring international students and fellows to Canada.*

We therefore **recommended (R7.1)** that *the Government of Canada should direct the Four Agency Coordinating Board to oversee a tri-council process to reinvigorate and harmonize scholarship and fellowship programs, and rationalize and optimize the use of current awards to attract international talent. Specific elements and considerations to achieve these goals include:*

- *creation of harmonized tri-council programs to award and administer all doctoral and PDF awards, similar to the harmonized program for master's scholarships;*
- *more harmonized levels of support (in both value and duration) for all doctoral and PDF awards;*
- *elimination of restrictions on international portability of doctoral and PDF awards to Canadians, with monitoring of the results; and*
- *refocusing of the Vanier and Banting programs as tools for international recruitment.*

Researcher salaries are largely provided by institutions (universities, research hospitals, and research institutes), with support from provinces, tuition, foundations, and a range of individual benefactors. The major sources of federal funding for researcher salary support are the CRC and CERC programs. *Similar to research training support, the funding for salary support to researchers and scholars is a significant proportion of total federal research investments, but relatively small with respect to the research ecosystem as a whole. ... Nevertheless, the programs can support research excellence by repatriating top Canadian talent from abroad and by recruiting and retaining top international talent in Canada.*

It is clear, however, that both the CRC and CERC programs have faced challenges as regards equity and diversity. The CRC program is also falling far short in recruiting and retaining international researchers, particularly when recent years are compared with its initial impact on the Canadian research ecosystem.

The Panel believes that the architecture of the CRC program is basically sound, but the program requires major adjustments to enable it to meet its original objectives. Thus, we **recommended (R7.2)** that *the Government of Canada should renew the CRC program on a strategic basis in three stages:*

1. *Restore funding to 2012 levels, upon development of a plan by the granting councils and Chairs Secretariat to allocate the new Chairs asymmetrically in favour of Tier 2 Chairs, and increase the uptake of available funds through improved logistics in managing numbers and reduced delays in awarding Chairs;*
2. *Direct the granting councils to cap the number of renewals of Tier 1 Chairs and, in concert with universities and CFI, develop a plan to reinvigorate international recruitment and retention, for review by NACRI and approval by the government; and*
3. *On approval of that plan, adjust the value of the CRCs to account for their loss in value due to inflation since 2000.*

We also recommended re-examination of the disciplinary distribution of CRC awards.

The Panel had more concerns about the CERC program, not least the sustainability of this degree of concentration of resources, and the wide gap between CERCs and Tier 1 CRCs in funding but not, so far as we could observe, in performance. We accordingly recommended a *detailed review of the relative cost-benefit of the CERC versus CRC programs to determine where the investments should be directed for the greatest impact.* In particular, if reinvestment and reinvigoration of the CRC program as recommended is not successful in accelerating international recruitment, then further adjustments to the CRCs may be required for that purpose.

Balance and Range

The third and fifth questions in this theme are related, in that an appropriate balance between funding elements (question 3) also allows the granting councils to accommodate the growing internationalization and full range of research areas (question 5). We also note that some of the issues raised later in the section about peer review pertain to balance and range and are covered here.

Total federal funding for both investigator-led and priority-driven research grants (distinct from innovation-directed programming) grew from approximately $785 million in 2000-01 to $1.66 billion in 2015-16. However, the value of this funding has been eroded by inflation, and a near doubling of the number of researchers in the same period. The result is that direct project funding per researcher has fallen by 35 per cent in real terms. Furthermore, as a proportion of total spending in council-specific and tri-council research programs, priority-driven and partnered research has risen from 30 per cent in 2000-01 to 42 per cent in 2015-16. This percentage will continue to shift towards priority-driven research as CFREF ramps up over the next three years. It is therefore unsurprising that we found serious gaps, concentrated overwhelmingly in support for investigator-led independent research.

The Panel strongly believes in the importance of priority-driven research, but noted that *shifting postsecondary research from discovery to application accordingly leaves a research gap that no other sector is equipped to fill. Similarly, the granting councils are Canada's primary instrument to support investigator-led research. Focusing council resources on priority-driven and partnered research leaves a funding gap for investigator-led research that no other organizations are able to fill.*

The current imbalance also renders Canada dependent on discoveries and ideas generated by other countries, and undermines the training of subsequent generations of Canadian researchers who will not only make ground-breaking discoveries but also become leading innovators in industry, government, and civil society.

To this end, we **recommended (R6.1)** that *the Government of Canada should rapidly increase its investment in independent investigator-led research to redress the imbalance caused by differential investments favouring priority-driven research over the past decade.* We recommended growing the overall envelope for operating grants by approximately 25 per cent over the course of four years, with the vast majority of that increase occurring over three years and directed to enhance open competitions.

The Panel also identified several areas of investigator-led research where gaps exist, and recommended specific program changes or early review in two cases, and earmarked funding in others.

First, we considered the issue of creating *critical mass, with sufficient project funds to carry out world-leading research and support for clusters and networks that can build and sustain a Canadian advantage.* Two programs operate in this field: NCE, which operates on a distributed model, and CFREF, which reinforces institutional specialization with major investments in single centres or a very small number of partners.

The NCE program in its original formulation was designed to support pan-Canadian networks of researchers and continues to be well regarded. *However, the Panel is concerned that the design of NCEs is not conducive to support networks of independent researchers who wish to collaborate primarily to generate, rather than translate, apply, or commercialize, knowledge. Furthermore, although there is meaningful participation by SSH researchers, the current configuration is suboptimal for these disciplines.*

Revised designs could offer a mechanism to scale excellence in independent research across Canada, serving initially as something of a counterbalance to the CFREF awards, and, when CFREF support winds down, as a way to link Canadian centres of excellence together. We therefore **recommended (R6.2)** that *the Government of Canada should direct the Four Agency Coordinating Board to amend the terms of the NCE program so as to include the fostering of collaborative multi-centre strength in basic research in all disciplines.*

We also recommended consideration of the following in revising those terms:

- *Evaluation criteria for KTEE should be lessened or dropped, for at least some classic NCEs…*
- *NCEs with a basic research mission should be allowed to participate in open competitions for refunding beyond current program limits…*
- *A portion of the new funding allocated to direct project financing should be used for the creation of new NCEs, some of which should be at a smaller scale. This would be of greater use for certain disciplines, e.g., SSH or mathematics.*
- *The requirement for a corporate structure to oversee the activities of an NCE ... should not be a requirement for NCEs composed entirely of university researchers pursuing basic research.*

The Panel noted that the CFREF program can help create critical mass through its support of both basic and applied research by fostering institutional specialization and helping *a limited number of Canadian postsecondary institutions achieve global leadership in strategic research areas that create long-term economic advantages for Canada.* However, concerns were raised about the ongoing concentration of resources through CFREF and whether this would represent the most efficient long-term use of limited federal funds. We therefore **recommended (R6.3)** that *the Government of Canada should direct the granting councils to undertake an interim evaluation of the CFREF program before the third wave of awards is made. The CSA and NACRI should be engaged in the design of the review. The results would guide a decision on whether to launch or defer the program's third round, but not impede the fulfilment of existing commitments.*

Four specific priorities for investigator-led research were identified for earmarked funding, to be drawn from the increases in the overall envelope recommended above.

1. Participation in international collaborations

We found various pockets of funding for international collaboration within the federal government, including in the granting councils, but little strategic coordination. In particular, we saw a clear gap in international collaborations focused on basic research. We therefore **recommended (R6.4)** that *the Government of Canada should mandate the Four Agency Coordinating Board to develop multi-agency strategies to support international research collaborations and modify existing funding programs so as to strengthen international partnerships.* Action points for the granting councils were delineated.

2. Support for multidisciplinary/transdisciplinary research

World-leading research often crosses traditional knowledge and disciplinary boundaries and is increasingly multidisciplinary in nature—both in its bridging of previously unconnected fields of knowledge and its development of entirely new disciplines. While the granting councils have taken some positive steps towards supporting and encouraging multidisciplinary research, the Panel was advised that, with one or two exceptions, funding awarded from one granting council currently cannot be used to support research or researchers outside that council's mandate. Moreover, *at various roundtables, the Panel was apprised of continuing challenges facing researchers whose work either does not fit readily into the competitions and assessment criteria for grant applications, or is adjudicated in ways that show puzzling blind spots.* This has implications for the organization of peer review, and again highlights the need for strong inter-council collaboration.

The Panel accordingly **recommended (R6.5)** that *the Government of Canada should mandate the Four Agency Coordinating Board to develop strategies to encourage, facilitate, evaluate, and support multidisciplinary research.* We also emphasized the need for councils to collaborate in definitively addressing the problem of transdisciplines (e.g., health law, medical anthropology, design) with communities of scholars who do not fall tidily within the mandate of a single granting council.

3. Focused funding for high-risk, high-reward (HR^2) research

In many cases, *world-leading research challenges the status quo and takes risks by identifying new questions or proposing startlingly new answers to questions that many thought settled. All three granting councils have a mix of programming that offers latitude for riskier research questions to be pursued. However, concerns were raised in our consultations that current financial pressures are leading Canadian peer review committees to favour proposals using proven techniques, in areas that have been productive in the past, and from more established researchers with proven track records.*

The Panel believes that the current climate of risk aversion is partly created by funding shortfalls that could be redressed over the next three or four years if federal investments were to be made as recommended. However, based on international precedents, this may well require the creation of special competitions and peer review mechanisms. We therefore **recommended (R6.6)** that *the Government of Canada should mandate the granting councils to encourage and better support high-risk research with the potential for high impact.*

A number of potential areas for action were noted, including *amending funding program criteria to ensure that a meaningful portion of grants goes to riskier projects; and providing training to peer reviewers to reduce potential bias against high-risk research.* The Panel also observed that several countries and regions have successful programs of this nature that could stand as valuable models for Canada's granting councils in filling this important gap.

4. The ability to respond quickly to rapidly emerging research needs

For research to be world-leading, relevant, and impactful, it must adapt to new opportunities and to a changing social, economic, and natural environment. Other jurisdictions seem to respond more nimbly than Canada to fast-emerging frontier fields.

A narrower issue in this same vein is adjudication of proposals rapidly in response to emerging threats or immediate crises. Canada's new CSA could play an important role in helping to delineate the need for, and terms of, such competitions. The Panel believes that the creation of a dedicated tri-council funding mechanism for rapid response research would be timely given the accelerating pace of social change as well as the importance of evidence-based public policy-making at this juncture in human history.

We therefore **recommended (R6.7)** that *the Government of Canada should mandate the granting councils to arrive at a joint mechanism to ensure that funds and rapid review mechanisms are available for response to fast-breaking issues.*

Because demands on this fund would be intermittent and unpredictable, it could easily be structured alongside the international, multidisciplinary, and/or HR^2 research funds on a contingent basis. We examined international precedents and estimated that the relevant contingency fund for these four priorities would be approximately 5 per cent of the final envelope for investigator-led research.

A final issue related to balance and range of funding is the F&A costs associated with hosting researchers and research projects on any given site. *All postsecondary research depends upon maintaining common-use equipment; meeting regulatory standards; regularly upgrading institutional computer services; cleaning, lighting, and heating laboratories and research space; and administering grants and awards. On top of these costs are those related to the protection of IP and the commercialization of technologies arising from the research. These services are not top of mind for researchers, nor should they be, but their absence or inadequate delivery can hinder or even stop work.*

Full coverage of these F&A costs has been recommended repeatedly by Canadian panels and studies since the 1970s. Since 2003, F&A costs have been partially reimbursed to institutions through the RSF, delivered by SSHRC on behalf of the granting councils. Reimbursement currently runs at 21.6 per cent, whereas most independent estimates find the indirect costs actually incurred to be more than double that amount. Quebec, for example, reimburses these costs at the 45 to 60 per cent level, depending on the nature of the research project. U.S. funders have enormous experience assessing and auditing these charges. Canadian institutions that have negotiated F&A costs in accordance with detailed U.S. guidelines are reimbursed at an average rate of 49 per cent and median of 52 per cent.

This gap represents a large and increasingly unsustainable charge against the teaching mission of Canadian universities. It also creates challenges for institutions in funding equipment maintenance, technology transfer and partnership programs, and efficient administrative machinery to reduce the load on researchers. These challenges will only grow if, as we recommended, support for investigator-led research is increased. In particular, the Panel's analyses indicated that 15 to 20 institutions could move from the higher level of reimbursement currently provided to offset diseconomies of scale for smaller grant-holding institutions, to a much lower rate in line with those faced by the largest institutions today.

The federal government currently pays about $369 million through the RSF on eligible grants totalling some $1.71 billion. To take the current rate to 30 per cent would add approximately $143 million to the tri-council base. The corresponding numbers for 35 per cent and 40 per cent are $229 million and $314 million. These numbers are daunting, but the gap cannot be allowed to grow.

We accordingly **recommended (R7.3)** that *the Government of Canada should gradually increase funding to the RSF until the reimbursement rate is 40 per cent for all institutions with more than $7 million per year of eligible funding. Current thresholds should be maintained to enable additional support for smaller institutions. As the size of the envelope of RSF-eligible operating grants grows, the funding of the RSF should be increased in lock-step to sustain the reimbursement rate of F&A costs on a trajectory towards this 40 per cent goal.*

If and when *the program moves to more adequate levels of reimbursement, closer oversight and reporting will be required to ensure that all funding is going towards the provision of better quality services in support of researchers.* There must be *full transparency for use of these funds, and appropriate priority for their expenditure to improve the productivity and success of Canadian scientists and scholars.*

Peer Review

The remaining question in this theme area asked, "Are existing review processes rigorous, fair and effective in supporting excellence across all disciplines? Are they rigorous, fair and effective in supporting riskier research and proposals in novel or emerging research areas or multidisciplinary/multinational areas?" In regard to the latter point, we have commented above on the need to earmark a portion of investigator-led research funding for these priority areas and to shape peer review around them. Questions on Indigenous research were also raised here and were covered earlier. However, on the broad issue of peer review, the Panel believes that the quality of review processes in the four agencies has historically been very high. This is a testament to the commitment of thousands of researchers in Canada and abroad who have served as voluntary reviewers.

On the other hand, a number of concerns were raised in our consultations. Many centred predictably on the controversy over peer review reforms initiated by CIHR, but the Panel also heard concerns about the burden on reviewers, the difficulty of adjudicating fairly when success rates fall to low levels, and the frustrations felt when success rates vary inexplicably across competitions and agencies. In response, we **recommended (R5.3)** that *the new Four Agency Coordinating Board should create a mechanism for harmonization as well as continuous oversight and improvement of peer review practices across the three councils and CFI.*

Among the desired outcomes would be:

- *a common set of guiding principles or values for peer review;*
- *mechanisms for more effective adjudication of multidisciplinary research;*
- *a streamlined process for submitting grants, starting with rapid and major improvements to the ease of use and agency harmonization of the Canadian Common CV; and*
- *support for experimentation and evaluation to study new approaches to peer review, including use of iterative review processes.*

8.1.2 Theme 2: Facilities and Equipment

The second group of questions relates to the funding of facilities and equipment. We were specifically asked to consider the strengths and weaknesses of CFI and the appropriate federal role in supporting infrastructure operating costs.

We reviewed the governance of CFI in Chapter 4, along with the other granting councils, and found that *it has been a well-run agency that has largely depoliticized very large capital grants that sometimes become the subject of intense political jockeying in other jurisdictions.* That said, the fiscal rationale for CFI's governance structure no longer exists, and may be untenable *if and when that agency receives standard A-base funding rather than intermittent allocations of one-time funding,* as we recommend below. We therefore included CFI in the comprehensive legislative review that we proposed in **Recommendation 4.11** to modernize and, where possible, harmonize the legislation for the four agencies.

As to budgeting, we made the following observations. *Although CFI is effectively a permanent part of the funding environment, its relationship with the federal government does not reflect this reality. CFI is funded on an ad hoc basis instead of having an ongoing budget, and it is mandated to create and manage specific funds for a set period of time. … In consequence, it is often impossible for CFI and researchers to know from one year to the next what the timing or the size of the next competition will be. This greatly complicates coordination with the granting councils and hampers the ability of research institutions to manage their capital plans efficiently.*

We therefore **recommended (R6.8)** that *the Government of Canada should provide CFI with a stable annual budget scaled at minimum to its recent annual outlays.*

Our analysis benchmarked CFI's budget to current overall research spending and comparator countries. We *recommended that CFI's average annual capital outlay of $300 million be regularized as A-base funding, and that the $90 million per year spent on O&M through the IOF be sustained.* This shift would regularize and stabilize the outlay rather than create new obligations on the Government of Canada. We also noted that *CFI's capital and infrastructure operating budget may have to be adjusted over time to maintain the balance between capital support and direct project funding.*

We did note two gaps related to infrastructure operating costs at *two ends of the spectrum: (i) operating support for large, national-scale Big Science facilities through CFI's MSI Fund, and (ii) support for individual researchers to run and maintain their small-scale equipment.*

Regarding Big Science, we observed that the creation of CFI's MSI Fund in 2012 was an important step towards helping cover the operating costs of these facilities. However, for many years there have been challenges related to administering and funding MSIs, particularly very large-scale facilities serving a broad national constituency. The Panel found that some of these major facilities had faced financial crises, while others were struggling to assemble operating funds given CFI's 40:60 matching formula. We supported *the continuation of the 40:60 ratio for the overwhelming majority of infrastructure funded by CFI,* but concluded that it *may not be appropriate for MSIs that have a clearly national or international mandate and offer benefits far beyond the regions or institutions where they are located.*

We accordingly **recommended (R6.10)** that *the Government of Canada should mandate and fund CFI to increase its share of the matching ratio for national-scale major research facilities from 40 to 60 per cent.* More generally, much closer attention to MSI planning and funding is needed in future, with clear-eyed decisions as to the financial implications of building, maintaining, and operating such facilities. The new advisory structures recommended by the Panel, in concert with the CSA, should close this gap (see below).

At the other end of the infrastructure spectrum, the Panel was concerned to learn that operational gaps were emerging because individual researchers and their teams struggled at times to initiate and maintain efficient operations with CFI-funded small-scale equipment. This occurs because the current level of CFI's IOF is insufficient to cover more than a small fraction of the ongoing costs of research infrastructure at a wide range of institutions, and funds may be consumed by a range of larger-scale operating costs. This leads to ineffective use of smaller-scale equipment and means that researchers sometimes spend inordinate amounts of time trying to secure funding.

A major part of the solution will be found in a general increase to the RSF (recommended above). *However, we recognize that growth in the RSF would be phased given its size. For immediate remediation, we* **recommended (R6.11)** that *the Government of Canada should mandate and fund CFI to meet the special operating needs of individual researchers with small capital awards.* Our analyses suggest that the cost would be approximately \$30 million per year. *To facilitate rapid implementation of this recommendation, this amount should be offset against growth in the RSF to render it costless to the federal government.*

The other two questions in this theme asked about best practices for supporting Big Science, and mechanisms to ensure that the government has access to the best advice about funding these types of projects (and more generally, requests for direct government support for research outside that of the four agencies). Based on our review of international best practices, the most effective approach is to depoliticize these decisions as much as possible through delegation of the scientific assessments of such proposals to an expert arms-length group. In Chapter 4 we not only envisaged a role here for NACRI, but also recommended that the CSA have a major role in these assessments and advising on decisions. In particular, we **recommended (R4.7)** that *a Special Standing Committee on Major Research Facilities should be convened by the CSA and report regularly to NACRI. The committee would advise NACRI and the Government of Canada on coordination and oversight for the life cycle of federally supported MRFs.* The relevant section of the report offers suggestions on the composition of the committee, and on its lifecycle approach to MRFs as follows:

- *a peer-reviewed decision on beginning an investment;*
- *a funded plan for the construction and operation of the facility, with continuing oversight by a peer specialist/agency review group for the specific facility;*
- *a plan for decommissioning; and*
- *a regular review scheduled to consider whether the facility still serves current needs.*

We strongly encourage the federal government to avail itself of these expert mechanisms to help guide future decision-making in a dispassionate and evidence-informed manner.

8.1.3 Theme 3: Platform Technologies

The Panel was also asked two questions about funding of platform technologies: the first about criteria and considerations for creating separate funding mechanisms to support new platform technologies; and the second about when to wind down these funding mechanisms and "mainstream" the funding back into the granting councils.

While we considered specific examples of these kinds of funding arrangements (such as Genome Canada), *we had neither the specialized expertise nor the time to review each of these smaller entities, but fortunately, that was not the expectation. … Our concern instead was to arrive at a depoliticized mechanism for ongoing review not only of the existing entities, but also of any proposals for new contribution agreements.*

The Panel noted that, in general, third-party organizations for delivering research funding are particularly effective in leveraging funding from external partners. They fill important gaps in research funding and complement the work of the granting councils and CFI. At the same time, we questioned the overall efficiency of directing federal research funding through third-party organizations.

As with MSIs and Big Science generally, we concluded that these decisions require an objective and arms-length review that would be best accomplished by NACRI, and might include a referral to the Special Standing Committee on MRFs depending on the nature of the platform. Specifically, we noted in **Recommendation 5.8** that *NACRI should be mandated not only to review proposals to create new third-party delivery organizations, but also to assess ongoing activities of all existing third-party organizations that receive federal support. It should guide their formal periodic review processes and advise the Government of Canada on the continuation, modification, or termination of their contribution agreements.*

Matching funding arrangements are a common and effective feature of these third-party funding mechanisms. *In areas of shared jurisdiction, matching support is beneficial as it ensures strategic buy-in from other partners and contributes to system-wide coherence. It may also stretch or conserve limited program funds, allowing more projects to be supported and more support to be dedicated to particular efforts.*

The Panel also observed many challenges, not least disciplinary variation in access to matching funds from the private and non-profit sectors or benefactors, wide variation across provinces in the availability of public or philanthropic matching funds, and excessive burden on researchers in recruiting funding partners. We found these issues less acute for applied and partnered research, leading to **Recommendation 5.9**: *When the intent is to support independent research, requirements for matching funds should be used sparingly and in a coordinated and targeted manner. In general, matching requirements should be limited to those situations where the co-funder derives a tangible benefit.*

Last, we identified one platform technology, DRI, that would benefit from a restructured funding mechanism. We found that *research, in Canada and globally, is becoming both more data-intensive and computationally-intensive. If Canada is to respond to rapidly growing needs, it must ensure that the increasingly complex DRI ecosystem is efficiently funded and effectively coordinated.*

The four pillar agencies provide some direct support to postsecondary researchers for a range of research-related expenditures, including those for software, computing hardware, and research data management. However, the two primary organizations delivering DRI infrastructure and services at the federal level are CANARIE and Compute Canada. … The Panel heard clearly that there is an urgent need for stable funding, greater coordination, and streamlined accountability to realize the full potential of the investments being made by all parties.

Thus, we **recommended (R6.9)** that *the Government of Canada should consolidate the organizations that provide digital research infrastructure, starting with a merger of Compute Canada and CANARIE. It should provide the new organization with long-term funding and a mandate to lead in developing a national DRI strategy.* We added that *funding for the new organization should be channelled through CFI to coordinate DRI funding with other infrastructure investments.*

8.2 Investing in Canada's Future

Readers will recall from Chapter 1 that the Panel was given two general questions: "First, are there any overall program gaps in Canada's fundamental research funding ecosystem that need to be addressed? And second, are there elements or programming features in other countries that could provide a useful example for the Government of Canada in addressing these gaps?" In brief, we were constantly guided by insights from our consultations and by reviews of best practices used by leading jurisdictions. The timelines were short, but we are confident in our broad conclusions. Canada's external research funding ecosystem has many core strengths and positive attributes. However, there are indeed many gaps that should be addressed, as outlined throughout the report and in encapsulated form above. Many were identified as we sought to answer the Minister's questions. Some reflected her gracious invitation that we were welcome "to raise additional questions and offer additional advice to the Government."

In this latter regard, the Panel emphasizes that the most critical gaps in the current ecosystem are not in architecture or programming but in resources and aspirations. In Chapter 6, we reviewed the sharp quantitative and qualitative shifts in funding that have occurred over the last two decades. As we complete this review, the first such comprehensive review in over 40 years, Panel members are concerned that Canadian extramural research is at serious risk of losing ground relative to peer nations, with some evidence of early erosion of its foundations already apparent in recent assessments and from our own analyses.

Several of the gaps in programming that we have identified may well reflect these resource constraints. We have not hesitated, obviously, to advocate repeatedly in this report for improved coordination across agencies and streamlining of programming, for better decision-making about priorities, and for the creation of an arm's length oversight body. Our recommendations about administration, coordination, governance, and oversight are all designed to strengthen the federal research ecosystem, independent of the level of resources ultimately provided by the current government.

Moreover, on the matter of resources, we believe that the most important resource is talented and committed people. We were privileged during this review to meet and hear from large numbers of scientists and scholars at all career stages, and can say, with confidence: Canada has that essential human resource in great abundance. Because excellent research capacity already exists domestically and is clearly under-resourced, new investments should bear rapid fruit. Canada also has a remarkable window of opportunity to draw talent from around the world to a nation that is recognized for its stability, civility, high standard of living, social solidarity, and pluralism.

We come next to a second gap—one in aspirations. Many nations are now placing a very high priority on improving educational attainment and accelerating science and inquiry. In response, the Panel believes that Canada in its sesquicentennial year should set its sights unabashedly on becoming the world's smartest nation. One key step in achieving that goal is to ensure that we have a truly vibrant ecosystem for extramural research—one that constantly generates breakthroughs and insights of global importance, educates and inspires the next generation of researchers, and thereby ensures a better future for all Canadians.

The new fiscal resources required to achieve that aspiration depend on a gradual investment cumulating to less than one-half of 1 per cent of what the Government of Canada spends in each budgetary year. That assessment was based on countless hours of analyses and benchmarking. Even so, as good Canadians, the Panel members paused late in our deliberations to consider whether too much was being asked. An intense digital interchange ensued. The sentiments of all members rapidly converged, and were encapsulated in a brief interjection made by one panellist urging us to stay the course: "We need to ask for what we need to make the country proud and successful."

What, then, does success look like? The Panel cannot warrant any specific outcomes from a specific level of investment. However, if our recommendations are followed, resources are provided, and aspirations are appropriately raised, a number of positive results can be anticipated:

- Improved funding, streamlined programming, and higher success rates will certainly lift the morale of the next generation of scientists and scholars, augment their productivity, enhance their collaboration, and sharply accelerate the pace of discovery and inquiry in Canada.
- This generational change will be associated with the emergence of a cohort of researchers who are more representative of the diversity of Canadian society, more comfortable crossing disciplinary boundaries, and more entrepreneurial. In turn, they will be better supported to carry out multidisciplinary research, to respond as needed to national crises or social upheavals, and to break new ground with HR^2 projects.
- The governance of the granting councils and CFI will be strengthened, and mandates better aligned with budgets. Coordination will be much improved, and decision-making about Big Science and contribution agreements will rest on a more rigorous footing. With NACRI and a new CSA functioning synergistically, Canada will be better positioned to pursue evidence-based public policy.
- Canadian businesses, governments, and non-profit enterprises will benefit from a new energy and openness in the extramural research community. As more PhDs take up positions outside of academe, research partnerships will become stronger and more productive, based not on skewed incentives but on aligned interests.
- With more appropriate reimbursement of the institutional costs of research, Canadian universities and institutes will be able to provide better support to researchers and strengthen their technology transfer offices. Pressure to use tuition and other revenues in support of F&A costs for research will abate, and the teaching mission will also benefit.
- With growth in the numbers of made-in-Canada discoveries and breakthrough ideas, Canadians will win more international prizes and awards for science and scholarship, with a welcome concentration of recognition for early and mid-career researchers.
- Canadian researchers will be more active participants in international research initiatives, thereby contributing to the global research effort as well as benefitting from discoveries and innovative thinking beyond our borders.
- The best and brightest in diverse fields of research from around the world will be attracted in growing numbers to Canada. This will greatly strengthen both the research and innovation ecosystems, and help make Canada a better country.
- The major upswing in the rate of generation of new knowledge will also bear fruit in the economic realm. No one can predict the time scale, but over time there will be more new inventions and innovative services, and a meaningful boost to Canadian innovation indices, to industrial productivity, and to national prosperity.

All those expectations, we believe, can and should be translated into metrics of one kind or another. What is harder to track are the intangibles, such as the positive impact on the aspirations of young Canadians who grow up with justifiable pride in their nation's status as a global powerhouse in knowledge generation. In brief, we are firmly convinced that by strengthening the foundations of Canadian research, this Government can make an immediate and major difference to the prospects of future generations. We urge decisive and rapid action on the recommendations contained in our report.

APPENDIX 1

FEDERAL SUPPORT FOR RESEARCH AND SCHOLARSHIP

This appendix describes federal support for the university research and scholarship enterprise, funding that covers research, associated infrastructure and indirect costs, research talent, and collaborative networks. This funding support is provided to and through a myriad of organizations and instruments, including:

- three granting councils, each focused on a particular area of scholarship—the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Institutes of Health Research (CIHR), and the Social Sciences and Humanities Research Council (SSHRC);
- funding agreements with large foundations with a close relationship to government—the Canada Foundation for Innovation (CFI) and Genome Canada; and
- funding agreements with medium-sized and small arm's-length organizations, with moderate or little government involvement.

Each is described in turn.

A1.1 Granting Councils

The three federal granting councils were created by Acts of Parliament that define their individual mandates to assist research and scholarship in the specific areas reflected in their respective names. The councils each report to Parliament through a minister of the government—NSERC and SSHRC through the Minister of Innovation, Science and Economic Development (ISED) and CIHR through the Minister of Health. The councils receive direct and ongoing annual appropriations of funds from the government ("A-base funding") to deliver on their core mandates, but they function with greater autonomy than line departments.

Collectively, the granting councils had a combined budget of $2.87 billion in 2015-16. This represented more or less steady-state through the period 2007-08 to 2015-16, when total granting council expenditures declined at an annualized rate of 1.0 per cent (adjusted for inflation). This had followed a period of sustained growth from 1997-98 to 2007-08, during which total expenditures had increased at an annualized rate of 10.6 per cent (when adjusted for inflation). Budget 2015 committed another $46 million per year to the granting councils starting in 2016-17. Budget 2016 announced a further increase of $95 million per year—$30 million for each of NSERC and CIHR, $16 million for SSHRC, and $19 million to support the indirect costs of research.

While a small part of their annual budgets is devoted to administration costs (on average around 6 per cent), the bulk of granting council money is used to fund awards (grants, fellowships, scholarships) to postsecondary researchers, students, and institutions. Through this funding, the granting councils support research and associated training and partnerships, and they facilitate commercialization, knowledge translation, and mobilization—each in their respective area of focus.

The councils also co-manage a number of joint initiatives, including some of the government's largest direct R&D support programs (see section on tri-council cooperation below).

All three granting councils run open competitions for research funding, based on rules that apply equally to all researchers. Funding competitions for most programs are launched annually; exceptions to this are noted. Awards are made through international peer review—independent, merit-based, and competitive processes that involve the assessment of applications by experts in the specific field. While the principles and general approach of the peer review process are the same across the three granting councils, some specific elements differ. This is demonstrated in Exhibit A1.1, which compares the application and adjudication processes for the foundational research grants offered by each granting council.

Overall strategic direction for each granting council is provided by a governing council that directs high-level policies and reviews and evaluates the organization's performance. Each governing council consists of up to 18 members representing academia, industry, and government, appointed by the government through Order-in-Council. Day-to-day operations of each granting council are managed by a president, acting as a chief executive officer supervising and directing the work and staff.

The three sections that follow provide details on granting council expenditures, both by high-level activity/theme (e.g., "investigator-led research") and by major programs under those themes. Readers are advised that each granting council groups its expenditures according to slightly different criteria. The Panel has grouped spending here in a way to show greater comparability. Therefore, the totals for activities may not always correlate directly with reports from individual granting councils.

A1.2 Natural Sciences and Engineering Research Council

NSERC operates in the natural sciences and engineering (NSE) space, funding research conducted by postsecondary researchers ("Discovery"), supporting postsecondary students and postdoctoral fellows in their advanced studies ("People"), and fostering innovation by encouraging Canadian companies to participate and invest in postsecondary research and training ("Innovation"). NSERC's budget in 2015-16 was $1.12 billion, the largest of the three granting councils. Over the past decade, the number of NSERC-funded researchers has remained stable at slightly over 11,000 per year.

A1.2.1 Discovery Suite

Expenditures: $360.3 million (2015-16)

The Discovery suite of grants provides an underlying base of support for "discovery" research in NSE. The centrepiece is the Discovery Grants program, complemented by other related programs.

Discovery Grants

Expenditures: $318.1 million (2015-16)

The Discovery Grants program is NSERC's longest-standing and largest program, considered the flagship for foundational research in NSE disciplines. Discovery Grants—comparable to CIHR's Foundation Grants and SSHRC's Insight Grants—support individual investigators' ongoing programs of research with long-term goals. The grants are awarded to researchers at all career stages.

Discovery Grants are not meant to support the full costs of a research program; award holders typically obtain significant funding from other programs (including NSERC programs) to supplement their Discovery Grants. In this respect, the grants are considered "grants-in-aid" of research. Recipients of Discovery Grants are not restricted to the specific activities described in their applications, but may adjust the goals and conduct of their research in response to unanticipated results and opportunities.

Exhibit A1.1: Application and Adjudication Processes for Foundational Research Grants

	Discovery Grants (NSERC)	Insight Grants (SSHRC)	Foundation Grants (CIHR)
Competitions per Year	1	1	1
Success Rate	~60%	~23% (2015-16 competition)	~13% (2015-16 competition)
Time Between Application and Results	6-7 months	5-6 months	9-10 months
Application and Review Process	Notification of Intent (NOI) submitted prior to full application, which is reviewed in two steps: • External reviewers read applications and provide a written report. • Evaluation groups assess applications as a group, informed by the reports of external reviewers.	One application submitted and reviewed in two steps: • External assessors read applications and provide a written report. • Adjudication committees assess applications as a group, informed by the reports of external assessors.	Three stage process, with one application submitted in Stage 1 and another in Stage 2 for those successful in the previous stage: • Stage 1 application and review focus on the calibre of the applicant(s). Virtual expert review over the internet. Successful applicants invited to submit an application for the next stage. • Stage 2 application and review focus on the quality of the proposed research program. Virtual expert review over the internet. • Stage 3 review (final assessment stage) to integrate the results of Stage 2 reviews. Face-to-face review conducted by a multidisciplinary committee.
Review Criteria	Three equally weighted criteria: • Scientific or engineering excellence of the researcher • Merit of the proposal • Contributions to the training of highly-qualified personnel	Three criteria: • Challenge: the aim and importance of the endeavour (40%) • Feasibility: the plan to achieve excellence (20%) • Capability: the expertise to succeed (40%)	Two criteria for Stage 1: • Calibre of applicant (75%) • Vision and program direction (25%) Two criteria for Stage 2: • Quality of the program (50%) • Quality of the expertise, experience, and resources (50%)

Note: The information contained here does not align perfectly with that in Exhibit 4.5 as they cover different time periods.

Source: Compilations from the secretariat based on information provided by the granting councils.

Other programs in NSERC's Discovery suite include (but are not limited to):

- ***Discovery Accelerator Supplements:*** These provide additional resources to a limited number of Discovery Grant recipients with proposals deemed outstanding for high-risk, novel, or potentially transformative research. Each supplement has a value of $120,000, normally paid over three years. Selection is made in conjunction with the review of Discovery Grant applications each year.
- ***Discovery Development Grants:*** These provide resources to researchers from small universities (defined as receiving $4 million or less in NSERC funding on an annual basis) whose Discovery Grant applications were deemed meritorious but were not funded in the competition. Each award is valued at up to $20,000 over two years.
- ***Discovery Frontiers Grants:*** These support a limited number of large, international, discovery-oriented activities or projects that are broad-based, collaborative/integrative, and potentially transformative. There is no annual competition cycle; instead, calls for proposals are issued periodically. Application, review, and selection procedures are tailored to each competition. The third call for proposals was issued in 2015, in the area of New Materials for Clean Energy and Energy Efficiency.

Complementing the Discovery suite is the ***Research Tools and Instruments*** program. These grants support the purchase or fabrication of research equipment with a net cost of between $7,001 and $250,000, through one-year awards of up to $150,000 each. In 2015-16, 216 new grants were awarded, and program expenditures totalled $26.1 million.

A1.2.2 People Suite

Like the other two granting councils, NSERC's key scholarships and fellowships are delivered through the tri-council Canada Graduate Scholarships (CGS) program, Vanier CGS program, and Banting Postdoctoral Fellowships program (see section on tri-council programs below). In addition, NSERC offers the following council-specific training awards:

- ***Undergraduate Student Research Awards (USRA):*** These awards, valued at $4,500 for a 16-week period, support undergraduates (Canadians and permanent residents) to gain research experience in academic settings at Canadian institutions. The awards are paid directly to the host university, which is required to supplement the amount by at least 25 per cent.
- ***NSERC Postgraduate Scholarships–Doctoral Program (PGS D):*** Valued at $21,000 a year (for two or three years), these scholarships are provided to doctoral students (Canadians and permanent residents) ranked in the second tier of candidates in the CGS doctoral competition. These awards are tenable at both Canadian and foreign universities (the latter providing that the candidate has received a previous degree from a Canadian university).
- ***NSERC Postdoctoral Fellowships Program:*** These fellowships provide $45,000 per year for two years for Canadian and permanent resident researchers to pursue their work at universities and other research institutions and laboratories in Canada and abroad.
- ***Collaborative Research and Training Experience (CREATE) Program:*** This program funds groups of researchers to develop and offer new, defined research training programs for master's and doctoral students to enhance professional, communication, and collaboration skills relevant to academic, industrial, and government research environments. Awards are valued at up to $150,000 in the first year and up to $300,000 for each of five subsequent years, for a maximum of $1.65 million over six years (non-renewable). While a minimum of 70 per cent of an applicant group must be from NSE disciplines, researchers at the interdisciplinary frontier between NSERC and SSHRC and CIHR disciplines may be incorporated into proposals.

A1.2.3 Innovation Suite

Under its Strategy for Partnerships and Innovation, NSERC offers a suite of programs to support collaborative research between academia and industry, student research experiences in business, commercialization of academic inventions, industrial research chairs (including in design engineering), and applied research in colleges. The two largest programs under the Innovation theme are the Collaborative Research and Development (CRD) Grants and the Strategic Partnership Grants (SPG).[i]

Collaborative Research and Development Grants

Expenditures: $83.2 million (2015-16)

CRD Grants support collaborations between university researchers and private-sector partners on well-defined projects (at any point in the R&D spectrum) that either have specific short- to medium-term objectives or are discrete phases in longer-range research programs. Each project must be supported by at least one industrial partner, which must match the amount requested from NSERC (half in cash and the balance in-kind) and demonstrate the intention and capacity to exploit the research results within Canada.

This program is not run on an annual competitive cycle; instead, proposals can be submitted at any time. All proposals undergo peer review, including site visits for large or complex proposals requesting $200,000 or more per year from NSERC.

Strategic Partnership Grants

Expenditures: $48.8 million (2015-16)

To promote knowledge transfer, SPGs support research and training partnerships between academic researchers and industry or government organizations in targeted areas—advanced manufacturing, environment and agriculture, information and communication technologies, and natural resources and energy. Academic researchers outside the NSE may participate in SPG proposals as co-applicants, up to a maximum of 30 per cent of the project costs.

There are two streams within the SPG program:

- ***Strategic Partnership Grants for Projects (SPG-P)*** fund early-stage project research over one to three years. At least one academic researcher and one partner organization must collaborate in the project. In 2015-16, a total of 221 projects were supported, and the average award value was $163,000.
- ***Strategic Partnership Grants for Networks (SPG-N)*** fund large-scale, multidisciplinary research projects. A network must involve a minimum of five academic researchers from at least three separate departments, faculties, or institutions, and proposals are required to have an international engagement strategy. NSERC provides funding of between $500,000 and $1.125 million per year for five years, for a maximum request of $5.5 million. Those networks building upon research objectives previously funded (whether through NSERC or other federal or provincial network-scale granting programs) require leveraging from industry and government partners ($1 for every $3 from NSERC). The application process is more complex than for SPG-P grants, with preliminary applications required, followed by full proposals. In 2015-16, a total of 16 networks were supported, and the average award value was $803,000.

i Other programs under the Innovation theme include Engage, Idea to Innovation Grant, Industrial Research Chairs, Chairs in Design Engineering, and the College and Community Innovation Program.

A1.3 Canadian Institutes of Health Research

CIHR focuses on four areas of health research: biomedical (about 62 per cent of CIHR's research budget over the past five years), clinical, health systems and services, and population health. At $1.02 billion, CIHR's budget in 2015-16 was comparable to that of NSERC. A total of about 2,600 principal investigators are supported by CIHR in any given year.

CIHR is distinct from NSERC and SSHRC in its organization, integrating research through an interdisciplinary structure of 13 virtual institutes, each consisting of a network of researchers dedicated to a specific area of focus. Each virtual institute is led by a Scientific Director and supported by five pan-Institute Advisory Boards. Together, the Scientific Directors form CIHR's Science Council, chaired by the president, mandated to provide leadership on priorities and strategies.

CIHR's research funding can be divided into two primary categories: investigator-led research and priority-driven research. CIHR also supports training through scholarships and fellowships. (The categorization of investigator-led research here follows that used by CIHR in its public annual budget statement. However, in that document CIHR assigned to this category a large number of competitions that have specific constraints on topics for investigation and would be regarded as priority-driven under the rubric used consistently throughout our report. We note further that the secretariat met with CIHR staff to review how they would categorize their research operating funds given our definitions. They agreed that the numbers used throughout this report fairly represent the proportions of independent investigator-led research based on the more specific definition adopted by the Panel. A similar exercise was undertaken with the other two granting councils.)

A1.3.1 Investigator-led Research

Expenditures: $500.4 million (2015-16)

These grants support individual researchers or research teams in investigator-led health research. In 2013, CIHR began implementing the transformation of its investigator-led programs, consolidating multiple short-term grants into single long-term ones. The majority of investigator-led research awards were until recently provided through the Open Operating Grant Program; this program (along with other smaller programs) has been replaced with the Foundation Grant program and the Project Grant program.

Foundation Grant Program

Expenditures: $67.4 million (2015-16)

The first competition under the Foundation Grant program was launched in 2014. Foundation Grants support researchers in long-term, broad research programs, allowing flexibility to follow innovative research pathways. In this way they are similar to NSERC's Discovery Grants and SSHRC's Insight Grants. Research programs are expected to include integrated, thematically linked research, knowledge translation, and mentoring/training components. CIHR also encourages collaborative and partnership-based approaches.

Different funding streams are available for participation by new/early career investigators and mid-career and senior investigators:

- New/early career investigators: five-year grants, open to applicants who have held an independent academic position (such as a faculty appointment) fewer than 60 months. A minimum of 15 per cent of grants are reserved for new/early career investigators.
- Mid-career investigators: seven-year grants, open to applicants who have held an independent academic position 5 to 15 years.

- Senior investigators: seven-year grants, open to applicants who have held an independent academic position more than 15 years.

Project Grant Program

Expenditures: $428.6 million (2015-16)[ii]

In contrast to the Foundation Grant program, the Project Grant program, launched in 2016, supports projects with a specific purpose and a defined endpoint, aiming to capture the best ideas to advance and apply health research. Like the Foundation Grant program, different funding envelopes are allocated to support new/early career investigators versus mid-career and senior investigators.

The Project Grant competition is run twice per year, through a two-stage review process:

- Stage 1: Virtual review by expert reviewers over the internet, assessing the impact and significance of the proposed research (25 per cent) and its feasibility (75 per cent).
- Stage 2: Face-to-face review conducted by a panel of reviewers.

A1.3.2 Priority-driven Research

Expenditures: $240.6 million (2015-16)

The purpose of priority-driven research grants is to "fill in the gaps" in underdeveloped or newly emerging areas of research by engaging partners to leverage expertise. Priority-driven research is composed primarily of Signature Initiatives and Strategic Initiatives.

Signature Initiatives

Signature Initiatives are typically large-scale, multidisciplinary initiatives engaging multiple CIHR institutes and partners from various sectors, including policy-makers, medical patients, health care professionals, and the private sector. The goal is to catalyze progress in priority areas and promising new fields in the near term. Currently, CIHR supports 10 Signature Initiatives:

- Canadian Epigenetics, Environment and Health Research Consortium
- Strategy for Patient-Oriented Research
- Community-based Primary Health Care
- Evidence-informed Health Care Renewal
- Inflammation in Chronic Disease
- CIHR Dementia Research Strategy
- Pathways to Health Equity for Aboriginal Peoples
- Personalized Medicine
- Environments and Health
- Healthy and Productive Work

ii The Project Grant and Foundation Grant programs have replaced the Open Operating Grant Program. This figure refers to commitments in 2015-16 under the Open Operating Grant Program. As the Foundation Grant program continues to ramp up, the Project Grant expenditures for 2016-17 are estimated at $376.0 million.

Strategic Initiatives

Strategic Initiatives funding is designed to address specific, longer-term research agendas through collaboration between two or more CIHR institutes, federal, provincial, and territorial governments, health charities, and other non-governmental organizations. Currently, CIHR supports seven Strategic Initiatives:

- Canadian Longitudinal Study on Aging
- Canadian Research Data Centre Network
- Canadian Research Initiative in Substance Misuse
- Drug Safety and Effectiveness Network
- eHealth Innovations
- Healthy Life Trajectories Initiative
- HIV/AIDS Research Initiative

A1.3.3 Training

Like the other two granting councils, CIHR's key scholarships and fellowships are delivered through the tri-council CGS program, Vanier CGS program, and Banting Postdoctoral Fellowships program (see section on tri-council programs below). In addition, CIHR offers the following council-specific training awards:

- ***Doctoral Foreign Study Awards:*** These awards support Canadian students pursuing health-related doctoral degrees abroad. They are valued at $35,000 per year over three years, with about 10 awards funded per year.
- ***CIHR Fellowships:*** These awards provide up to $60,000 per year for up to five years for post-PhD or post-health professional degree candidates pursuing health research either in Canada or abroad. Both Canadian and international students studying in Canada are eligible.

A1.4 Social Sciences and Humanities Research Council

SSHRC focuses on social sciences and humanities (SSH) research and scholarship. Its budget has historically been much smaller than that of the other two granting councils, at $380.6 million in 2015-16. As of 2014-15, 13,500 SSH researchers were supported on an ongoing basis.

SSHRC's program architecture bundles funding opportunities into three key areas: Insight, Talent, and Connections. With the notable exception of Insight Grants, SSHRC allows foreign researchers access to grants as co-applicants (at the discretion of the Canada-based principal applicant and the Canadian administering organization).

A1.4.1 Insight Suite

Expenditures: $153.7 million (2015-16)

The Insight suite of grants is SSHRC's signature program to support research about people, communities, societies, and solutions to societal challenges. The Insight suite is designed for individual researchers and small teams of researchers working collaboratively. The awards are open to any research theme that the applicants propose. Applicants may concurrently apply to CFI to request associated infrastructure support (see CFI section below).

Insight Grants

Expenditures: $77.1 million (2015-16)

Insight Grants—comparable to NSERC's Discovery Grants and CIHR's Foundation Grants—support long-term, mature research initiatives in SSH. They are open to both emerging and established scholars.

Insight Development Grants

Expenditures: $16.8 million (2015-16)

Insight Development Grant (IDG) funding supports short-term research in its initial stages. Adjudication in this program gives less weight to a researcher's track record, and 50 per cent of IDG awards are reserved for emerging scholars.[iii] Between 2011 and 2016, approximately 65 per cent of awards went to emerging scholars. Projects may involve national and international research collaboration.

Partnership Grants

Expenditures: $32.8 million (2015-16)

Partnership Grants provide support for new and existing partnerships between postsecondary institutions and the public, private, and not-for-profit sectors to advance research, research training, and/or knowledge mobilization in SSH. A minimum of 35 per cent in cash or in-kind contributions is required from sources other than SSHRC.

Partnership Grants are, for the most part, open to any research theme that the applicants propose. Applicants may concurrently apply to CFI to request associated infrastructure support (see CFI section below).

Partnership Development Grants

Expenditures: $13.3 million (2015-16)

Partnership Development Grants are intended to foster new partnerships for research and related activities or to design and test new partnership approaches.

SSHRC Institutional Grants

Expenditures: $5.8 million (2015-16)

SSHRC Institutional Grants (SIG) are annual block grants to postsecondary institutions to help them fund faculty members' small-scale SSH research and research-related activities. SIG funds may be used to assist researchers with modest research funding requirements, support national and international knowledge mobilization within and/or beyond the research community, and support the development of students.

Knowledge Synthesis Grants

Budget: up to $375,000 per year

Knowledge Synthesis Grants are not designed to fund original research; instead, they support the synthesis of existing research knowledge and the identification of knowledge gaps, especially on the state of research knowledge emerging over the past 10 years.

iii SSHRC defines "emerging scholar" as someone who has not yet had the opportunity to establish an extensive record of research achievement, but is in the process of building one. The scholar must have completed their highest degree no more than six years before the competition deadline or have held a tenured or tenure-track postsecondary appointment for less than six years; or have held a postsecondary appointment, but never a tenure-track position; or have had their careers significantly interrupted or delayed for health or family reasons within the past six years.

A1.4.2 Talent Suite

Like NSERC and CIHR, SSHRC's key scholarships and fellowships are delivered through the tri-council CGS program, Vanier CGS program, and Banting Postdoctoral Fellowships program (see section on tri-council programs below). In addition, SSHRC offers the following council-specific training awards:

- ***SSHRC Doctoral Fellowships:*** These awards of $20,000 per year, for 12, 24, 36, or 48 months, are tenable at Canadian and foreign universities (the latter contingent on the award holder having completed at least one previous degree at a Canadian university). As with NSERC, these fellowships are awarded to doctoral students (Canadians and permanent residents) ranked in the second tier of candidates in the CGS doctoral competition.
- ***SSHRC Postdoctoral Fellowships:*** These awards of $40,500 per year for 12 to 24 months (non-renewable) are also tenable at Canadian or foreign universities and research institutions for Canadians and permanent residents. Fellowships are normally awarded to candidates affiliated with universities other than those that awarded their PhDs.

A1.4.3 Connection Suite

The Connection suite of programs supports activities and tools that facilitate the flow and exchange of research knowledge to maximize the impacts of SSH research.

Connection Grants

Expenditures: $7.1 million (2015-16)

Connection Grants support events and outreach activities (e.g., colloquia, conferences, workshops, forums, summer institutes) in Canada or abroad, geared towards short-term, targeted knowledge mobilization initiatives. There are Institutional Connection Grants (for institutions) and Individual Connection Grants (for individual researchers or teams of researchers).

Support for Journals

Expenditures: $3.3 million (2015-16)

Grants of up to $30,000 per year for three years are awarded to scholarly journals to help defray the costs of publishing scholarly articles, assist with distribution costs, and support journal organizations in transitioning to and maintaining digital formats.

A1.4.4 International Activities

On the international front, SSHRC has co-led the Trans-Atlantic Platform for the Social Sciences and Humanities (T-AP), a consortium of 18 SSH funding agencies (10 from Europe and 8 from the Americas). T-AP aims to build sustainable administrative arrangements for funding joint initiatives whenever two or more participating agencies decide to collaborate on a joint call for proposals.

In 2016, T-AP launched its first joint call for research proposals—as the fourth round of the Digging into Data Challenge. First offered in 2009, the Challenge explores how "big data" changes the research landscape for SSH—how new sources and computational and analytical techniques can be applied to address SSH questions in new ways.

SSHRC and CIHR are also partnering on an international initiative, More Years/Better Lives, to enhance coordination and collaboration between European and Canadian research programs related to demographic change. From 2016 to 2019, CIHR and SSHRC will each contribute up to $500,000, while participating European countries have tentatively committed up to €5.3 million (approximately $7.7 million).

A1.5 Tri-council Programs and Collaboration

Each granting council administers tri-council programs on behalf of all three. All tri-council programs are governed by a Steering Committee composed of the granting council presidents, the deputy ministers of ISED and Health Canada, and the President and CEO of CFI as an observer. Some of the tri-council programs include external selection boards that assess applications, in addition to the standard academic peer review process. The Steering Committee is responsible for final award decisions across all tri-council programs, with the exception of the CGS program.

A1.5.1 Canada First Research Excellence Fund (CFREF)

Budget: legacy investment of $1.5 billion over 10 years; annual budget growing to sustained level of $200 million per year by 2018-19

CFREF, which was first announced in Budget 2014, makes awards to institutions in support of ambitious research objectives. CFREF's aim is to help them build on international research strengths to become global leaders. Institutions awarded a CFREF grant are expected to invest their own resources and those of partners to support the proposed initiative. CFREF considers large, potentially multi-institutional initiatives as well as smaller single-institution proposals, in the areas of environment and agriculture, health and life sciences, natural resources and energy, information and communications technologies, and advanced manufacturing.

The inaugural "quick-start" competition, completed in 2015, awarded a total of $350 million over seven years, while the second competition, completed in 2016, awarded roughly $900 million over seven years. Of 29 full proposals submitted in the second competition (representing a total CFREF request of $2.38 billion), 13 were approved for funding. The third CFREF competition is expected to be launched in 2021-22.

The second competition involved a two-stage application process. Institutions were first invited to submit a Letter of Intent, which was adjudicated for scientific merit and demonstrated capacity to lead on an international scale, as well as for strategic relevance to Canada. Successful applicants were then invited to submit full proposals. Assessment at both stages was undertaken by individual external reviewers and interdisciplinary expert review panels, as well as a Selection Board of academic and private-sector leaders that focused on "strategic relevance" (potential to achieve globally leading research outcomes in areas of long-term economic advantage for Canada) and "quality of implementation plan". The final phase of Selection Board adjudication involved face-to-face interviews and a due diligence review of budget requests by a third-party firm.

A1.5.2 Chairs Programs

The Canada Research Chairs (CRC) and Canada Excellence Research Chairs (CERC) programs aim to help Canadian universities attract and retain top research/professorial talent.

Canada Research Chairs Program

Budget: $265 million annually to support up to 1,800 Chairs

The CRC program was established in 2000 as Canada's flagship initiative to help Canadian universities attract and retain world-class researchers. Chairs are distributed among institutions in proportions roughly mirroring each granting council's funding share at program inception: 45 per cent in NSERC disciplines, 35 per cent in CIHR disciplines, and 20 per cent in SSHRC disciplines.

Chairs are offered at two levels:

- Tier 1 Chairs ($200,000 per year), tenable for seven years and renewable, are for established researchers recognized by peers as leaders in their fields.
- Tier 2 Chairs ($100,000 per year), tenable for five years and renewable once, are for emerging researchers recognized by peers as having the potential to lead in their fields.

Chair positions are allocated to universities on the basis of the total granting council funding awarded to their researchers over the previous three-year period. The program also sets aside a special allocation of 120 Chairs for smaller universities that have received 1 per cent or less of total granting council funding over the period.

The program offers two nomination cycles annually. At the time of nominations, universities may concurrently apply to CFI to request infrastructure support for their Chairs (see CFI description below).

Canada Excellence Research Chairs Program

Budget: ramping up to $42.9 million annually by 2017-18

Launched in 2008, the CERC program aims to build critical masses of research expertise in fields of strength, opportunity, and relevance for Canada. The program emphasizes international recruitment to attract the world's most accomplished researchers to Canada.

CERC awards require matching contributions, totalling a minimum of $10 million, from universities and their partners, including the private and not-for-profit sectors, and provincial and territorial governments.

By September 2016, as a result of two competitions, 26 CERCs were active at 17 institutions, with one more to arrive by January 2017. Budget 2016 announced that a third competition would be launched for up to 20 new CERCs (to replace the inaugural cohort) plus 2 new Chairs in clean and sustainable technology (with temporary additional funding of $20 million over seven years).

CERCs are awarded through an in-depth, two-stage competitive process:

- In Phase 1, universities compete for the opportunity to establish Chairs based on their demonstrated excellence in a proposed field of research. Universities do not identify individual Chair nominees in this phase.
- The most outstanding Phase 1 proposals are invited to participate in Phase 2, during which invited universities nominate researchers to fill their allocated Chair positions.

Individual assessment of proposals is done by international research experts, followed by collective assessment by a Review Panel of international experts. Strategic review is undertaken by an arm's-length Selection Board of Canadian and international academics and business leaders.

Universities may also request infrastructure support from CFI when submitting Phase 2 nominations (see CFI description below).

A1.5.3 Scholarships and Fellowships

Canada Graduate Scholarships

Budget: $132 million annually
Award value: master's $17,500 for one year; doctoral $35,000 annually for three years
Awards supported: total of up to 2,500 master's and 2,500 doctoral awards in any given year

Created in 2003, the CGS program provides financial support to Canadian citizens and permanent residents for master's (CGS-M) and doctoral (CGS-D) programs with significant original research components at Canadian institutions.

The awards are divided among the three granting councils through a formula founded in an original calculation based on university enrolment statistics. Fifty-two per cent of the scholarships are awarded in SSHRC disciplines (Joseph-Armand Bombardier CGS), 32 per cent in NSERC disciplines (Alexander Graham Bell CGS), and 16 per cent in CIHR disciplines (Frederick Banting and Charles Best CGS).

While now considered a tri-council initiative, for most of the program's life it was delivered separately by NSERC, CIHR, and SSHRC. Universities received council-specific allocations of awards based on the average distribution of awards held at each institution over the preceding three years. Granting council-specific expert selection committees reviewed applications (with different eligibility criteria across councils), and each granting council vice-president responsible for grants and fellowships formally approved his or her council's awards.

In June 2013, the granting councils announced plans to harmonize delivery of the CGS program. Through this initiative, institutions manage the process and award the CGS-M scholarships; the granting councils no longer conduct national selection processes. Harmonization of the CGS-D program is expected in 2017-18.

Vanier Canada Graduate Scholarships

Budget: $25 million annually
Award value: $50,000 per year for up to three years
Awards supported: about 167 new awards per year; total of up to 500 in any given year

The Vanier CGS program was announced in Budget 2008 as a prestigious companion to the CGS-D program, designed to attract and retain the very top doctoral talent. Institutions receive annual nomination quotas based on the amount of funding they received in previous years through the CRC and doctoral programs. Applications are managed by research area as delineated by granting council mandates—NSE, health sciences, and SSH—with awards divided equally among the three granting councils and applications assessed by arm's-length Selection Committees for each council.

Banting Postdoctoral Fellowships

Budget: $10 million annually
Award value: $70,000 per year for two years
Awards supported: 70 new awards per year; total of 140 in any given year

The Banting Postdoctoral Fellowships program was announced in Budget 2010 as another prestigious tool to attract and retain world-class researchers. Like the Vanier CGS, applications are managed by granting council research area, with awards divided equally among the three councils and applications assessed by arm's-length Selection Committees for each council. Unlike the Vanier CGS, there is no nomination quota among institutions.

Up to one-quarter of Banting awards may be used by Canadians for fellowships at foreign universities, provided the fellow completed his or her PhD at a Canadian institution.

A1.5.4 Networks of Centres of Excellence Suite of Programs

The Networks of Centres of Excellence (NCE) suite of programs focuses on building research and commercialization networks. The total annual budget is $108.3 million, to decrease to $105.3 million as of 2017-18.

Recipient selection in the NCE suite of programs is based on a two-stage review process. An external body of experts across granting council domains (the Private Sector Advisory Board for the CECR and BL-NCE programs, and the Standing Selection Committee for the NCE Classic and KM programs) reviews letters of intent and makes recommendations to the NCE Management Committee on those that should be invited to submit full proposals. Full proposals are assessed first by expert panels (in the fields addressed by the given applications) and then by the Private Sector Advisory Board or the Standing Selection Committee.[iv]

NCE Classic

Budget: $62.1 million annually
Award value: varies by proposal

Created in 1989, the NCE program (sometimes referred to as NCE Classic) supports large-scale, collaborative research networks to mobilize researchers in the academic, private, and public sectors. Grant funds can be used for the direct costs of research and facility access, stipends for research trainees, and the direct costs of research dissemination and science promotion. Networks are given five-year grants with the possibility of two five-year renewals, for a maximum funding period of 15 years. There are currently 13 networks funded through the NCE Classic program.

Knowledge Mobilization

Budget: $1.2 million annually (from the NCE Classic budget)
Award value: up to $400,000 per year for four years (with the possibility of a three-year extension)

The Knowledge Mobilization (NCE-KM) program supports the costs of networking and collaboration among well-established research teams and receptor communities to further the application and mobilization of knowledge. Grant funds cannot be used for research. There are currently five KM networks funded through the program.

Centres of Excellence for Commercialization and Research

Budget: $30 million annually
Award value: varies by proposal; five years, with one renewal

Created in Budget 2007, the Centres of Excellence for Commercialization and Research (CECR) program supports the commercialization of university research by funding up to 75 per cent of the operating costs and 50 per cent of the commercialization costs of research and/or commercialization centres. Grants do not cover direct research costs, nor expenses related to the construction, purchase, or lease of a building or building space. There are currently 23 CECRs funded through the program.

Business-led Networks of Centres of Excellence

Budget: $12 million annually
Award value: varies by proposal; five years, with one renewal

Also created in Budget 2007, the Business-led Networks of Centres of Excellence (BL-NCE) program funds national research networks that perform research to support private-sector innovation. The program supports up to 75 per cent of networking, administration, and commercialization costs and up to 50 per cent of direct research costs. There are currently five business-led networks funded through this program.

iv For the KM program, full proposals are assessed directly by the NCE Classic Standing Selection Committee.

International Knowledge Translation Platforms Initiative

Budget: $1.2 million annually over the next four years

In 2016, the NCE program launched the International Knowledge Translation Platforms Initiative to support international collaborations between networks, centres, and consortia and their international partners. Objectives of the Initiative include expanding strategic international partnerships through multidisciplinary and multi-sectoral networks, accelerating the international exchange of research results, reducing barriers to international research activities, fostering knowledge mobilization internationally, identifying knowledge gaps, and providing training opportunities.

A1.5.5 Research Support Fund

Expenditures: $340.4 million (2015-16)

The Research Support Fund (RSF) supports a portion of institutions' central and departmental administrative costs related to federally funded research. The program was introduced in 2001 as the Indirect Costs Program with an initial budget of $200 million, and it was established as a permanent program in 2003. RSF covers costs such as administrative support for researchers and for patent applications and technology licensing; renovation, maintenance, and technical support for research facilities such as libraries and laboratories; operating costs such as utilities and custodial service; and improved information resources and systems.

Each institution's annual grant is notionally calculated based on the average funding over the previous three fiscal years that the institution's researchers received from the granting councils,[v] within the context of the coming fiscal year's RSF budget. The formula provides higher rates of funding for institutions that receive the least amount of granting council research funding: the first $100,000 of research funding is supported at 80 per cent, the next $900,000 at 50 per cent, and the next $6 million at 40 per cent. The remainder of the funds are distributed by equal proportion to institutions receiving more than $7 million a year in research funding. Accordingly the reimbursement rate by institution falls with the more research done.

A1.5.6 Other Joint Competitions

On a periodic basis, the granting councils cooperate with one another and/or with other federal partners to issue joint calls for research proposals in thematic or strategic areas. Funding amounts and application and review processes are geared to the specific initiative. Examples of these initiatives include:

- ***Healthy and Productive Work****:* Collaboration between SSHRC and CIHR, with a commitment over 2016 to 2023 of $6 million from SSHRC and up to $8.4 million from CIHR.
- ***Advancing Big Data Science in Genomics Research****:* Collaborative competition among Genome Canada, CFI, NSERC, and CIHR (2013).
- ***International Research Initiative on Adaptation to Climate Change****:* Collaboration among NSERC, SSHRC, CIHR, and the International Development Research Centre (2010).

v A number of granting council programs are excluded from this calculation of annual research funding. Notable exclusions include the CFREF, CERC, and CRC programs, as those awards already include funding to cover indirect costs, as well as scholarship and fellowship programs including the CGS, Vanier CGS, and Banting Postdoctoral Fellowship programs.

A1.5.7 Other Tri-council Collaboration

The three granting councils have also worked to harmonize some of their policies governing funding awards. These include:

- the ***Tri-Agency Financial Administration Guide***, which harmonizes elements of the granting councils' post-award policies and guidelines on grantees' use of funds (Agreement on the Administration of Agency Grants and Awards by Research Institutions);
- the ***Tri-Agency Policy on Open Access to Publications***, relating to new requirements of grant-holders with respect to retaining, archiving, and sharing the research data they produce with granting council funds;
- the ***Tri-Council Policy Statement on the Ethical Conduct for Research Involving Humans*** and the ***Tri-Agency Framework for the Responsible Conduct of Research***, both supported by a joint secretariat; and
- the ***Tri-Agency Statement of Principles on Digital Data Management***.

NSERC and SSHRC also collaborate on some backroom administrative functions. Through their Common Administrative Services Directorate, they share common services to support financial administration, human resources, technology infrastructure, and internal audit and evaluation. The two agencies are also working on a joint web-based portal for preparing and reviewing applications, and for administering awards.

A1.6 Funding Agreements

The federal government also provides funding to a number of arm's-length organizations that either award research funding or conduct research themselves. Typically, these organizations are independent, not-for-profit corporations with their own by-laws and boards of directors.

Federal funding decisions for these organizations are typically made on an ad hoc basis, expressed through the annual Budget process. A Budget decision identifies the amount of the funding award (typically multi-year funding, with a specified end date) and its general parameters and purpose. With subsequent Treasury Board approval of the details, the government signs a funding agreement with the organization, setting out the obligations and terms and conditions. Payments are made annually through grants and contributions ("B-base funding"), with the specific amounts based on projected cash-flow requirements.

The two most significant recipients of federal government funding under this model are CFI (which the Panel argues has effectively become a permanent part of the funding environment) and Genome Canada.

A1.6.1 Canada Foundation for Innovation

Federal funding to date: $6.82 billion since inception

CFI is a not-for-profit organization created in 1997 by the Government of Canada to fund research infrastructure at Canadian institutions (universities, colleges, research hospitals, and non-profit research institutions). Its funding support covers equipment, laboratories, databases, specimens, scientific collections, computer hardware and software, communications linkages, and buildings. It funds up to 40 per cent of a project's eligible infrastructure costs, with the remaining 60 per cent to come from other sources (typically 40 per cent from provincial governments). In addition to capital awards, CFI provides some operating support for the projects that it funds. The Infrastructure Operating Fund (IOF), for example, makes a one-time payment equal to 30 per cent of CFI's capital contribution for operations and maintenance.

CFI is wholly funded by the Government of Canada. The most recent funding injection was announced in Budget 2015—a commitment of $1.33 billion over six years, to start in 2017-18. CFI's annual outlays vary considerably as a result of its funding model. It typically takes up to two to three years for the funds announced in a Budget to reach successful research projects.

CFI awards funding to institutions (not individual researchers) through a merit-based peer review process that generally assesses the quality of the research and its need for infrastructure, the project's contribution to strengthening the capacity for innovation, and the potential benefits of the research to Canada. CFI also requires that each institution submit a strategic research plan against which its infrastructure proposals are assessed.

CFI is governed by a Board of Directors responsible for policy direction and final decisions on funding awards. The Board consists of 13 directors from academia, industry, and government, 6 of whom are appointed by the government through Order-in-Council. The remaining directors are appointed by the CFI Members, a higher governing body of 15 individuals similar to a company's shareholders, but representing the Canadian public. An ISED representative attends Board meetings as an observer.

CFI's core programs for university infrastructure include the following:

John R. Evans Leaders Fund

Budget: up to $258 million committed in Budget 2015 over three years, starting in 2017-18

Formerly the Leaders Opportunity Fund, the John R. Evans Leaders Fund (JELF) supports institutions' proposals for the acquisition of infrastructure required by individual researchers (current or proposed faculty members). Institutions receive predetermined allocations of funds; those with a minimum annual average of $300,000 in sponsored research income (excluding CFI awards) are eligible to receive a dedicated funding allocation.

The JELF has four streams: the unaffiliated stream (with three funding calls per year) and three partnership streams. The former is dedicated to institutions' proposals for researchers in pursuit of their individual projects/programs. Up to three candidate researchers may be listed on a proposal when there is a demonstrated need to share infrastructure. The three partnership streams focus on infrastructure needs associated with the CRC (two funding calls per year) and CERC programs, SSHRC's Insight and Partnership programs, and NSERC's Industrial Research Chairs program. Although interested institutions must submit a separate infrastructure proposal to CFI for these partnership initiatives, the review processes are administered by the responsible granting council, in accordance with CFI criteria. Final funding decisions for the research portion of a proposal are made by the granting councils, while those for the infrastructure portion are made by the CFI Board.

Innovation Fund

Budget: $552 million ($425 million plus 30 per cent for operating costs through the IOF) (2017-18)

Launched in February 2016 (formerly the Leading Edge and New Initiatives Funds), the Innovation Fund is intended for larger cutting-edge and transformative infrastructure projects (whether upgrades to existing CFI-funded infrastructure or new initiatives). Institutions are encouraged to build on established capabilities with real or potential global competitiveness and where new infrastructure funding could accelerate research and technology development. They are also encouraged to use their funding to develop multi-institutional projects.

The application and review processes for the Innovation Fund are more complex than those for JELF. Applicant institutions must first submit a notification of intent (NOI), followed by a full proposal. Proposals go through a three-stage review process of expert committees, multidisciplinary assessment committees, and a final Special Multidisciplinary Assessment Committee that makes funding recommendations to the CFI Board, which is responsible for final award decisions. CFI attempts to coordinate with provincial and territorial funding authorities throughout the review process, and encourages institutions to work with their respective provincial and territorial authorities throughout development of their proposals.

Major Science Initiatives Fund

Budget: $400 million over five years, starting in 2017-18
Awards supported: from the first competition in 2012 through 2016, a total of about $210 million awarded to 13 facilities

The Major Science Initiatives (MSI) Fund supports a portion of the operations and maintenance costs of national research facilities (whether single-sited, distributed, or virtual) to support their long-term viability. These facilities conduct leading-edge research and technology development and provide shared access to substantial and advanced specialized equipment, services, resources, and scientific and technical personnel. Typically, they are jointly owned by several institutions, and they require resource commitments that are well beyond the capacity of any single one. Examples include the Canadian Light Source, SNOLAB, and Canadian Research Icebreaker Amundsen.

Similar to the Innovation Fund, applicants must first submit an NOI, followed by a full proposal. Assessment generally includes two stages: expert committee review and multidisciplinary assessment review. Multidisciplinary assessment committees make funding recommendations to the CFI Board of Directors, which is responsible for final award decisions.

Cyberinfrastructure Initiative

Budget: $60 million + Budget 2015 allocation of $75 million for 2018-19

The Cyberinfrastructure Initiative supports the infrastructure needs of computationally- and data-intensive research. Challenge 1 supports investments in research data infrastructure projects to devise optimal ways of organizing and using research data resources. In 2016, CFI awarded about $10 million to seven proposals. Challenge 2 supports the upgrading and modernization of the computational and data storage capacities of the pan-Canadian advanced research computing platform managed by Compute Canada. $30 million was awarded in 2015 in the first stage; results of the second stage are expected to be publicly announced in 2017. Budget 2015 also allocated an additional $75 million in support of digital research infrastructure.

A1.6.2 Genome Canada

Total federal funding to date: $1.2 billion since inception. Budget 2016 committed an additional $237.2 million over four years, starting in 2016-17

Genome Canada is a not-for-profit organization independently incorporated in 2000 with a mandate to develop and implement a national strategy in genomics research. It invests in and manages large-scale genomics research projects in selected areas, provides access to leading-edge technologies, and supports the translation of genomics discoveries into practical applications. Between 2000 and 2015, its research support focused on genomics related to health (62 per cent), agriculture (13 per cent), environment (7 per cent), forestry (5 per cent), fisheries (4 per cent), and energy (2 per cent).

Genome Canada supports six independently incorporated regional Genome Centres, located in British Columbia, Alberta, the Prairies, Ontario, Quebec, and Atlantic Canada. "Head office" is responsible for developing strategies and national and international partnerships, and for launching national competitions and merit review processes for award selection. Regional Genome Centres are responsible for identifying regional strengths and opportunities, monitoring compliance and performance, and helping secure co-funding from partners.

Genome Canada is governed by a Board of Directors, with members from the academic, private, and public sectors. The relationship between Genome Canada and the federal government is more arm's-length; unlike the granting councils and CFI, the government has no formal role in Board appointments. Genome Canada's Board includes the presidents of the granting councils, CFI, and the National Research Council. As with CFI, an ISED representative attends Board meetings as an observer.

Genome Canada uses a merit-based peer review process to select award winners through key funding opportunities such as:

- ***Large-scale Research:*** National competitions to support genomics research projects (including ethical, environmental, economic, legal, and social aspects) on the scale of $5 to $10 million over a term of up to four years, co-funded by at least 50 per cent from other sources. The 2017 competition will focus on Genomics and Health; previous competitions have addressed Natural Resources and Environment (2015), Feeding the Future (2014), and Personalized Medicine (2012). Applicants apply through their regional Genome Centre, in a process comprising three steps: registration, pre-application, and full application.
- ***Strategic Initiatives:*** Support for addressing emerging issues facing Canada that require immediate action and for collaboration with the international community on global challenges that require collective expertise and resources. While there are no competitions currently underway or planned, previous initiatives have included, *inter alia*, the International Barcode of Life, the Structural Genomics Consortium, and the Cancer Stem Cell Consortium.
- ***Technology Support:*** Support for the operations of 10 technology platforms, which provide researchers with access to tools and expertise needed to analyze genomes in various ways, including laboratory services for DNA mapping and sequencing, genotyping, microarrays, bioinformatics, and statistical analysis. Funding supports operations of the platforms, as well as development of new and improved technologies.
- ***Translation:*** Launched in 2013 to support partnerships between academic researchers and users (industry, governments, not-for-profits) to translate genomics-based discoveries into applications and/or marketable products. The Genomic Applications Partnerships Program focuses on downstream R&D (e.g., proof-of-concept, validation, product/tool development), supporting small-scale projects (minimum of $100,000 for six or more months) through to large-scale projects (maximum of $2 million for up to three years). Genome Canada funds one-third of the project costs, with another third required from the user (cash or in-kind). It is devoting $30 million to this program.

A1.6.3 Other Science Contribution Agreements

The federal government is one of a number of funding partners that contributes to other organizations that conduct or support research. While terms and conditions of the government's contributions are articulated through funding agreements (typically tied to specific activities and results), the government has little or no involvement in these organizations. Exhibit A1.2 enumerates the federal government's support for these organizations.

Exhibit A1.2: Other Funding Agreements

Organization	Role	Federal Funding
Brain Canada	Registered charitable organization that funds multidisciplinary, collaborative, high-risk, high-reward brain research through an open, international peer review process. Founded as NeuroScience Canada in 1998.	2012: Commitment of $100 million over six years, to be matched by other donors. Budget 2016: Up to $20 million over three years, starting in 2016-17, for the Brain Research Fund. To be matched by other non-government partners. **Total: $120 million**
CANARIE	Non-profit corporation founded in 1993 that delivers digital research infrastructure in Canada.	1993–2015: $529.5 million total. Budget 2015: An additional $105 million over five years. **Total: $634.5 million**
Centre for Drug Research and Development (CDRD)	Not-for-profit corporation founded in 2007 that focuses on translating and commercializing early-stage health research from academic institutions and Canadian SMEs into marketable products.	2008–2016: $37.03 million total. Budget 2016: Up to $32 million over two years, starting in 2017-18. **Total: $69.03 million**
Canadian Institute for Advanced Research (CIFAR)	Not-for-profit organization founded in 1982 that funds Canadian and international researchers to study complex scientific, social and economic issues.	1987–2015: $109 million in federal funding. Budget 2015: $5 million over two years expiring March 2017. **Total: $119 million**
Institute for Quantum Computing (IQC)	Conducts experimental and theoretical research on quantum computing and performs scientific outreach. IQC was founded in 2002.	2009–2014: $68 million total. Budget 2014: Announced a further $15 million over three years expiring March 2017. **Total: $83 million**
Mitacs	Not-for-profit organization founded in 1999 that supports student research internships and postdoctoral fellowships in industry, and links foreign and Canadian students with research expertise, training, and networking opportunities.	1999–2016: $115.8 million total. 2016-17 to 2020-21: $166.3 million. **Total: $282.1 million**
National Optics Institute (INO)	Not-for-profit organization founded in 1985 that supports research and provides development assistance to firms in the field of optics and photonics.	2006–2015: Federal support averaged $9 million per year. Budget 2016: $50 million over five years, starting in 2016-17.
Perimeter Institute	Founded in 1999, independent non-profit theoretical physics research institute. Supports a large educational outreach program. Substantial international reputation.	2007–2016: $140 million total. Budget 2016: Starting in 2017-18, federal funding of $50 million over five years. Each dollar is to be matched with two dollars from the institute's other partners. **Total: $190 million**
Stem Cell Network	Funds stem cell and regenerative medicine research with a focus on translating research into commercial products. The Stem Cell Network was founded in 2001.	2001–2017: $83.3 million. Budget 2016: Up to $12 million over two years starting in 2016-17. **Total: $95.3 million**

APPENDIX 2

SUMMARY OF THE CONSULTATION PROCESS

This appendix summarizes how the Panel and secretariat consulted with Canadians. It provides a list of institutional and organizational submissions and roundtable participants. General information about the individuals making submissions is provided where permission to do so was granted. All individual submissions have been treated as private communications, and no individuals are identified by name in this report.

Through the **sciencereview.ca** website, we created an online portal that allowed direct communications with the Panel. We received more than 1,100 responses over two rounds of solicitation. We also encouraged organizations, institutions, associations, and provinces and territories to email their input directly to us and close to 150 did so. We were greatly impressed by the thoughtfulness and thoroughness of the information we received.

Roundtable discussions were also held on a wide variety of topics in five cities across Canada. In total, over 200 people participated in 12 of these events. The Panel conducted a number of in-person meetings with key stakeholders. Collectively, these discussions helped us to form our views and to test our ideas with knowledgeable interlocutors.

A2.1 Online/Digital Responses

Online responses were gathered in three ways: through an initial open submission, through targeted sets of questions, and directly by email (Exhibit A2.1). A list of the organizations and institutions that provided submissions can be found in Exhibit A2.7.

Exhibit A2.1: Summary of Online Submissions

Source	Submissions
Online (Open Submission Form) June 12 – August 12	374
Online (Community Responses) August 12 – September 30	753
By Email	148
Total	**1,275**

A2.1.1 Open Submissions

Immediately on launch of the Review, an online submission form was made available on our website. This provided respondents with an open forum for sharing information, views, and recommendations. By the time this forum closed on August 12, 2016, 374 responses had been received from researchers, administrators, and other interested Canadians. Input received was used to inform the next part of the online consultations where sets of targeted questions were developed for each community in the ecosystem.

A2.1.2 Community Questions

A Call for Evidence and Input, using the targeted questions, was initiated on August 12, 2016 and ran to September 30, 2016. The questions appear at the end of this appendix (Exhibit A2.8). The following communities were solicited for feedback:

Researchers:

- Current/former researchers in the academic, hospital, government, and private sector
- Organizations of researchers

Institutions and Administrators:

- Organizations of postsecondary institutions
- Individual postsecondary institutions
- Organizations of postsecondary administrators
- Current/former postsecondary administrators
- Research hospitals/hospital institutes

Students, Trainees, and Postdoctoral Fellows:

- Undergraduate and graduate students
- Postdoctoral researchers

Funders:

- Organizations that distribute funding to support investigator-led research

Facilities:

- Facilities, platforms, and other infrastructure that support investigator-led research

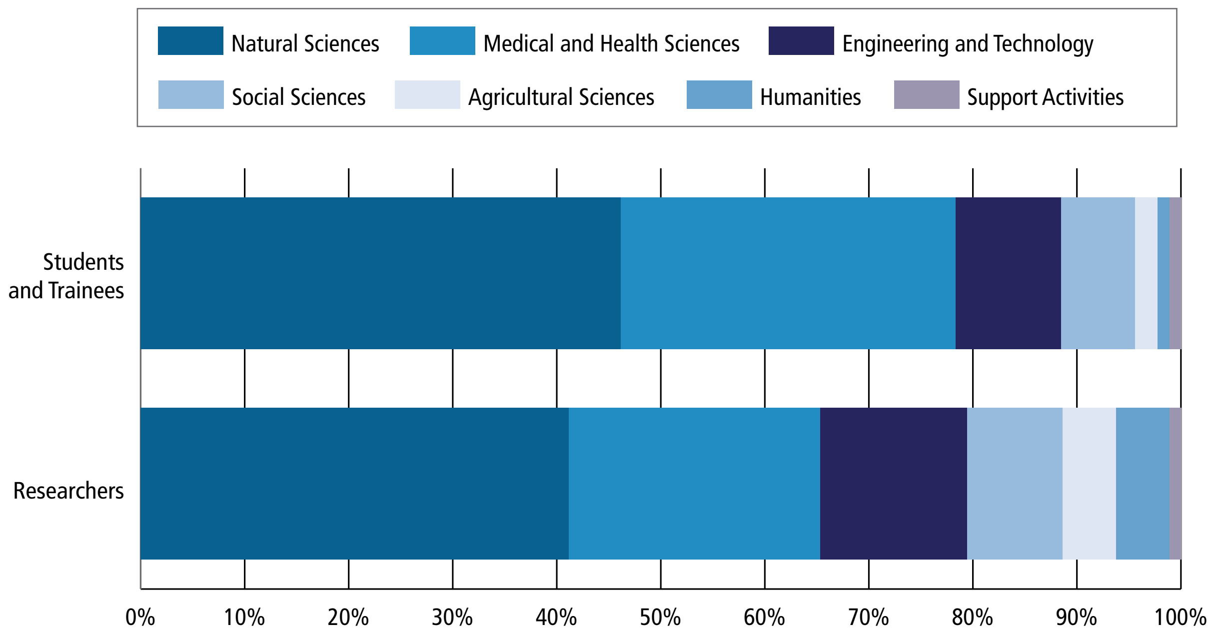
An online survey, created for researchers, administrators, students, trainees, and postdoctoral fellows, captured some demographic data and allowed respondents to answer any or all questions specific to their community. We received over 750 responses, summarized in Exhibit A2.2 (table) and Exhibit A2.3 (graphic format).

Exhibit A2.2: Summary of Online Community Responses

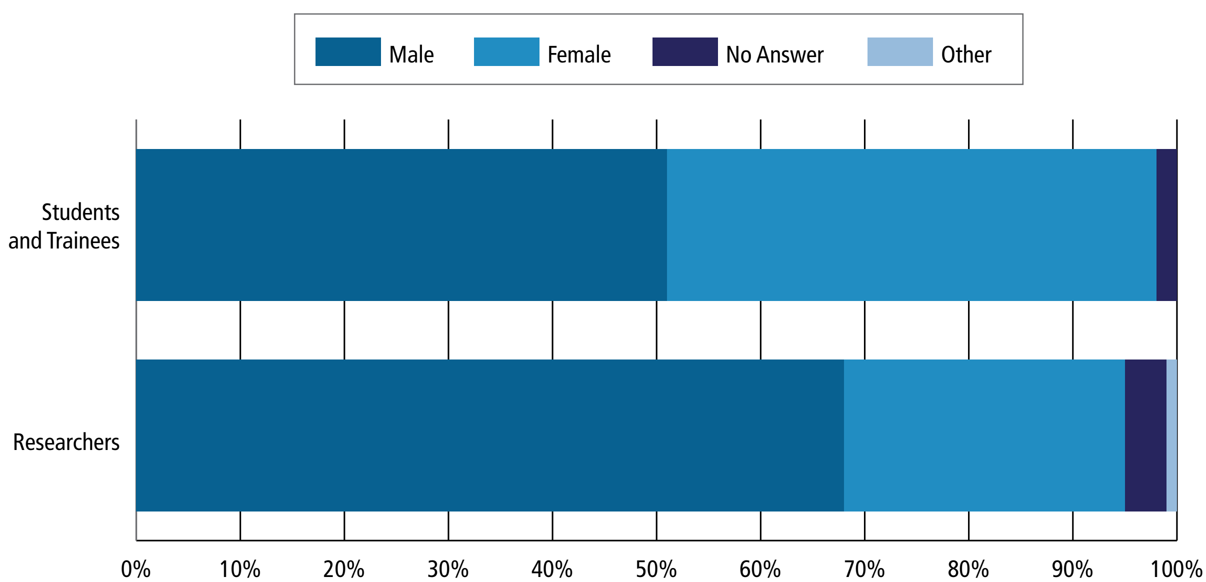
Community	Submissions	# of Questions in Survey	Average Proportion of Questions Answered
Researchers	523	22	63%
Students and Trainees	111	17	61%
Administrators	22	18	63%
Institutions	60	18	38%
Others	37	N/A	N/A

Exhibit A2.3: Profile of Respondents from the Community

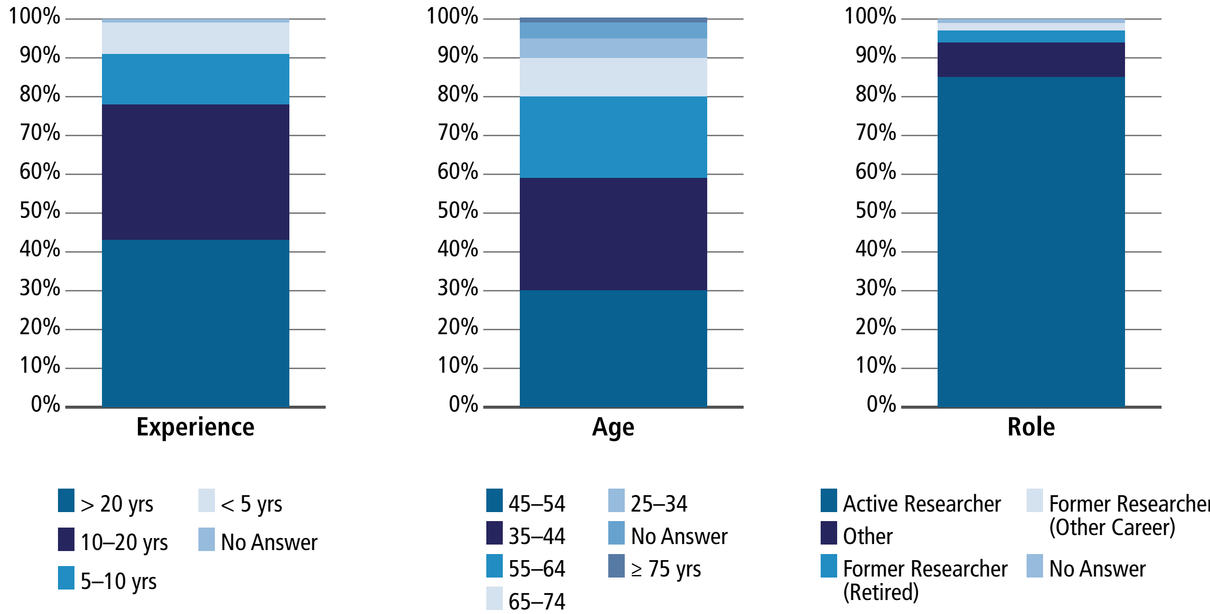
A. Community responses: by discipline



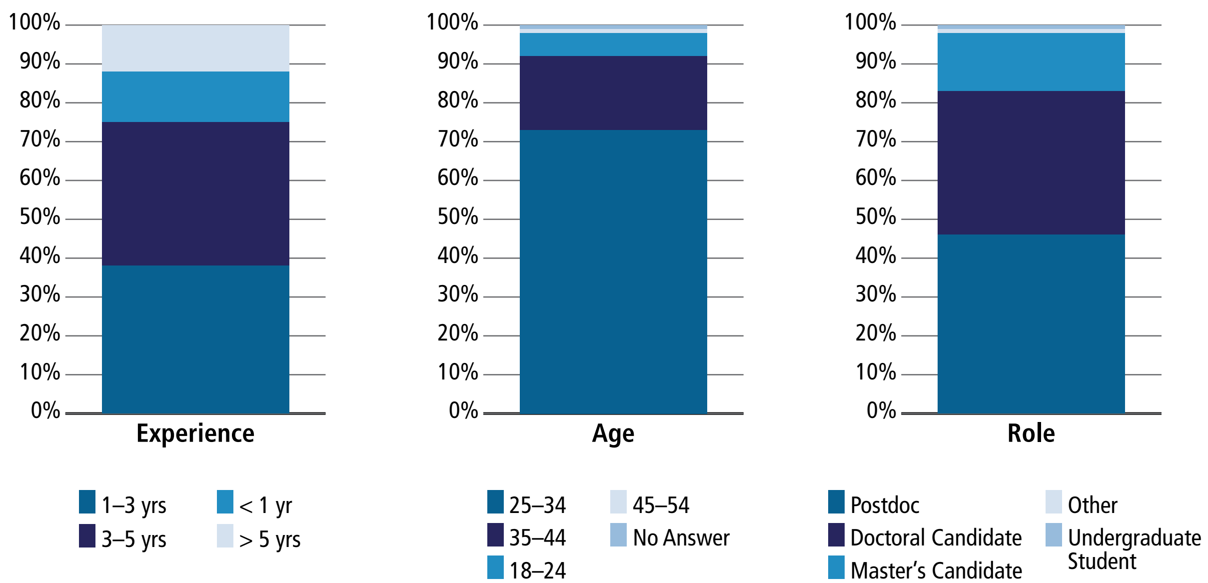
B. Community responses: by gender



C. Community responses: researchers



D. Community responses: students and trainees



A2.1.3 Responses to Email Solicitation

Directed emails were sent to a number of key stakeholders, including organizations, institutions, research facilities and infrastructures, associations, and provinces and territories. We received almost 150 responses. The constituencies or communities represented by these stakeholders are summarized in Exhibit A2.4.

Exhibit A2.4: Number of Responses by Community

Community Represented	Reponses
Administrators	4
Facilities	22
Funders	15
Institutions	52
Provinces and Territories	4
Researchers	35
Students and Trainees	4
Other	12

A2.2 Roundtables

A list of the roundtables is provided in Exhibit A2.5, along with the number of participants and a description of each topic. In total, over 200 people participated in 12 roundtables. A comprehensive list of attendees is given in Exhibit A2.6.

Exhibit A2.5: Roundtables

Date	Location	Roundtable Topic	No. of Attendees	Description
July 26	Toronto	Early Career Researchers and Trainees	13	Unique barriers faced by researchers early in their careers
Sept. 15	Ottawa	Researchers in Canada	21	General discussion about the funding of investigator-led research in Canada
Sept. 29	Calgary	Researchers in Canada	13	General discussion about the funding of investigator-led research in Canada
		Big Science – Infrastructure	20	Domestic funding of large science research facilities in Canada; Canadian participation in large international projects
		Big Science – Wicked Problems and Platform Technologies	13	Government funding in areas of broad strategic interest, societal application, or emerging technologies
Oct. 11	Montreal	Researchers in Canada	24	General discussion about the funding of investigator-led research in Canada
		International Research	26	The growing trend of international collaboration; flexibility of funding international collaboration (included large infrastructure) and Canada's voice on the international stage
		Social Sciences and Humanities	23	Unique barriers faced by the social sciences and humanities communities in terms of investigator-led research including collaborating with other disciplines
Oct. 17	Halifax	Researchers in Canada	16	General discussion about the funding of investigator-led research in Canada
		Multidisciplinary Research	17	The growing trend of multidisciplinary research. Is the Canadian funding system able to support research across disciplines (i.e., granting councils)?
		Diversity	22	Unique barriers faced by women, indigenous, and other underrepresented groups in obtaining support for investigator-led research
Oct. 24	Toronto	Eminent Researchers	15	General discussion on investigator-led research in Canada with a select group of distinguished participants

Exhibit A2.6: List of Roundtable Attendees

A. Toronto

Early Career Researchers (July)

Catherine Normandeau
Karisa Parkington
Eric Chapman
Sally Rutherford
Erin Stewart
Suzanna Prosser
Jean-Philippe Lambert
Daniel Schramek
Joseph S. Sparling
Kristin Connor
Kaitlin Patterson
Michael Hendricks
Sarah Burch

Eminent Researchers (October)

Alan Bernstein
Gilles Brassard
Richard Bond
Thomas Ming Swi Chang
Ford Doolittle
Sarah Diamond
Suzanne Fortier
Louis Fortier
John Charles Polanyi
Frank Plummer
Barry Smit
Janet Rossant
Sam Weiss
Kathy Siminovitch
Neil Turok

B. Ottawa

Researchers in Canada

Alexandre Blais
Jeremy J. Schmidt
Aicheng Chen
William R. Smith
John Fisher
Alison Sills
Paul Hébert
Alexandre Stewart
Wayne Hocking
George Townsend
Steven Kerfoot
Donald Welsh
James Knibb-Lamouche
Stephen I. Wright
Dawn Martin Hill
K. Peter Pauls
Margaret McKinnon
Isabel Pedersen
Freda Miller
Keren Rice
Dennis Murray

C. Calgary

Researchers in Canada

Kristine Alexander
Louise Barret
Joseph Casey
Petra Dolata
Erica Dyck
Liisa Galea
Garth Huber
Ubaka Ogbogu
Brenda Parlee
Lynne Postovit
Barbara Triggs-Raine
Justine Turner
C Kenneth Waters

Big Science – Wicked Problems and Platform Technologies

David Bailey
Mark Dietrich
Annemieke Farenhorst
Linc Kesler
Cecile Lacombe
David Mate
Jeffrey McDonnell
Maribeth Murray
Benoît Pirenne
Søren Rysgaard
Erik Snowberg
Pascal Spothelfer
Martin Truksa

Big Science – Infrastructure

Roberto Abraham
Benoît Pirenne
Jonathan Bagger
Andrew Potter
David Bryce
John Root
Jeffrey Cutler
Nigel Smith
Mark Dietrich
Randall Sobie
James Drummond
Mario Thomas
Jim Ghadbane
Kathryn McWilliams
Nassif Ghoussoub
Lise Phaneuf
Darren Grant
Megan Meridenth-Lobay
Garth Huber
David Mate

D. Montréal

Researchers in Canada

Isabelle Gandilhon
Stéphane Bouchard
Alan Cohen
Sylvie Perreault
Anne Whitelaw
Victoria Kaspi
Gustavo Turecki
Andrew Gonzalez
Maryse Lassonde
Bernard Robaire
Mohammad-Ali Jenabian
Catherine Laprise
Nathalie Grandvaux
Céline Audet
Normand Landry
Frederic Bouchard
Normand Voyer
Guillaume Raymond
Pierre Chastenay
Jill Baumgartner
René Laprise
Louise Poissant
Renaldo Battista
Nada Jabado

International

Éric Archambault
Yves Gingras
Renaldo Battista
My Ali El Khakani
Jacques Beauvais
Bartha Maria Knoppers
Sylvain Benoit
Maryse Lassonde
Diane Berthelette
Rod McInnes
Marie-Josée Blais
Catherine Montgomery
William Cheaib
Oussama Moutanabbir
Paul Dufour
Pierre Noreau
Fabien Durif
Barbara Papadopoulou
Pierrette Gaudreau
Louise Poissant
Alain G Gagnon
Vincent Poitout
Lucie Germain
Guy Sauvageau
Brigitte Vachon

Social Sciences

Anne-Marie Séguin
Annie Pilote
Bertrand Gervais
Benoît Dupont
David Graham
Carl Lacharité
Guylaine Beaudry
Cléo Paskal
Isabelle Cossette
François Duchesneau
Lyne Sauvageau
Graham Carr
Louise Poissant
Jason Edward Lewis
Margaret Lock
Jean Piché
Maryse Lassonde
Joseph Yvon Thériault
Renaldo Battista
Juan Luis Klein
Simon Harel
Nathalie de Marcellis-Warin
Shana Poplack

E. Halifax

Researchers in Canada

Amanda Slaunwhite
Darrell Varga
Erin Bertrand
Gavin Fridell
Heather Sparling
Jamie Baxter
Janice Keefe
Jerry White
Jon Grant
Julie LaRoche
Leslie Jane McMillan
Marcia Ostashewski
Megan Bailey
Rachel Chang
S. Karly Kehoe
Sara Iverson

Multidisciplinary Research

Cate Murray
Clive Baldwin
David Black
Fei-Fei Liu
Fred Whoriskey
Janice Graham
Jean Saint-Vil
Joanna Mills-Flemming
Krista Connell
Laurel J. Trainor
Mark D. Gibson
Mark Filiaggi
Michael A. Rudnicki
Nancy Reid
Raisa B. Deber
Rob Beiko
Robert Andersen

Diversity

Rod McCormick
Alexandre Baril
Alana Cattapan
Billy-Jo Hardy
Christine T. Chambers
Eddy Ng
Fred Wien
Holly Witteman
Imogen Coe
Janice Braun
Jeff Reading
Josée Lavoie
Kevin Hewitt
Margaret Robinson
Nur Zincir-Heywood
Pedram Sadeghian
Sheila Brown
Shiva Nourpanah
Shohini Ghose
Stephanie Kienast
Tamara Franz-Odendaal
Ingrid Waldron

Exhibit A2.7: List of Organizations that Made Submissions to the Panel

Advanced Laser Light Source
Alberta Prion Research Institute
Alliance of Canadian Comprehensive Research Universities
Alzheimer Society of Canada
ArcticNet
Association francophone pour le savoir
Association of Atlantic Universities
Association of Canadian Universities for Research in Astronomy
Association of Faculties of Medicine of Canada
Association of Faculties of Pharmacy of Canada
Athabasca University
Atlantic Association for Research in the Mathematical Sciences
Atmosphere-Related Research in Canadian Universities
Brain Canada
Canada's Mathematical Sciences Institutes
Canadian Academy of Health Sciences
Canadian Alliance of Student Associations
Canadian Association for Graduate Studies
Canadian Association for Neuroscience
Canadian Association of Physicists
Canadian Association of Postdoctoral Scholars
Canadian Association of Research Administrators
Canadian Association of Research Libraries
Canadian Association of Schools of Nursing
Canadian Association of University Research Parks
Canadian Association of University Teachers
Canadian Astronomy Data Centre
Canadian Blood Services
Canadian Botanical Association
Canadian Cancer Society
Canadian Consortium for Research
Canadian Council of Independent Laboratories
Canadian Cryospheric Information Network/Polar Data Catalogue
Canada Foundation for Innovation
Canada Foundation for Innovation – Board of Directors
Canadian Historical Association
Canadian Institute of Ecology and Evolution
Canadian Institute of Nuclear Physics
Canadian Institutes of Health Research
Canadian Meteorological and Oceanographic Society
Canadian Network of Northern Research Operators
Canadian Network of Scientific Platforms
Canadian Neutron Beam Centre
Canadian Nuclear Laboratories
Canadian Nutrition Society
Canadian Psychological Association
Canadian Research Knowledge Network
Canadian Science Publishing
Canadian Society for Digital Humanities
Canadian Society for Molecular Biosciences
Canadian Society for Pharmaceutical Sciences
Canadian Subatomic Physics Long Range Plan Committee
Canadian Water Network
CANARIE
Canola Council of Canada
CAP-NSERC Physics Liaison Committee
Carleton University
Centre d'études nordiques
CIFAR
Clinician Investigator Trainee Association of Canada
Coalition for Canadian Astronomy
Colleges and Institutes Canada
Compute Canada
Concordia University
Conestoga College Institute of Technology and Advanced Learning
Consortium Érudit
Dalhousie University

Directeurs de bibliothèques universitaires du Québec
Doctors Without Borders
École Polytechnique de Montréal
Evidence for Democracy
Fédération du personnel professionnel des universités et de la recherche
Federation for the Humanities and Social Sciences
Fonds de recherche du Québec
Genome Canada
George Brown College
Government of Alberta
Government of British Columbia
Government of Ontario
Government of Yukon
Health Charities Coalition of Canada
HealthCareCAN
Heart and Stroke Foundation
Holland Bloorview Kids Rehabilitation Hospital
Humber College Institute of Technology and Advanced Learning
Innovative Medicines Canada
Institute for Circumpolar Health Research
Institute of Gender and Health
Institute of Health Policy, Management and Evaluation
Institute of Particle Physics
Intellectual Property Institute of Canada
Joint submission – AFMC, BIOTECanada, CIC, HealthCareCAN, HCCC, IMC, MEDEC, RC
Joint submission – TRIUMF, SNOLAB and the Canadian Light Source
Joint submission – University of Lethbridge, University of Winnipeg, Lakehead University, Vancouver Island University
Lakehead University
Lawson Health Research Institute
Lunenfeld-Tanenbaum Research Institute
Maple League of Universities
McGill University
McMaster University
Memorial University
Michael Smith Foundation for Health Research
Mitacs
Mount Saint Vincent University
National Alliance of Provincial Health Research Organizations
National ME/FM Action Network
National Research Council – Research Officers and Research Council Officers
Natural Resources Canada's Polar Continental Shelf Program
Natural Sciences and Engineering Research Council of Canada
Neurological Health Charities Canada
New Brunswick Health Research Foundation
Nova Scotia Health Authority
Nova Scotia Health Research Foundation
NSERC-Chemistry Liaison Committee
OCAD University
Ocean Networks Canada
Ontario Institute for Cancer Research
Ontario Molecular Pathology Research Network
Partnership Group for Science and Engineering
Perimeter Institute for Theoretical Physics
Polar Knowledge Canada
Polytechnics Canada
Population Data BC
Queen's University
Red River College
Research Canada
Research Data Canada
Research Manitoba
Rotman Research Institute
Royal Canadian Institute for Science
Ryerson University
Saint Mary's University
Saskatchewan Polytechnic
Simon Fraser University
Social Sciences and Humanities Research Council of Canada
St. Michael's Hospital
Stem Cell Network
STEM Fellowship Journal
Structural Genomics Consortium
Sunnybrook Research Institute

Syndicat des professionnelles et professionnels de recherche de l'Université Laval
Télé-université (TÉLUQ)
The Hospital for Sick Children Research Institute
The King's University
Thompson Rivers University
U15 Group of Canadian Research Universities
Union étudiante du Québec
Université de Moncton
Université de Montréal
Université de Sherbrooke
Université du Québec
Université du Québec à Montréal
Université du Québec à Rimouski
Université du Québec à Trois-Rivières
Université du Québec en Abitibi-Témiscamingue
Université Laval
Universities Canada
University of Alberta
University of Alberta – Health Sciences Council
University of British Columbia
University of British Columbia – Biomedical Research Centre
University of Calgary
University of Guelph
University of Lethbridge
University of Manitoba
University of Northern British Columbia
University of Ontario Institute of Technology
University of Ottawa
University of Ottawa – Faculty of Medicine
University of Ottawa – Graduate Students
University of Ottawa Heart Institute
University of Regina
University of the Fraser Valley
University of Toronto
University of Toronto – Basic Science Chairs
University of Toronto – Collaborative Program in Engineering Education
University of Toronto – Department of Electrical and Computer Engineering
University of Toronto – Department of Physics
University of Toronto – Faculty of Arts & Science
University of Toronto – Faculty of Medicine
University of Toronto – School of Graduate Studies
University of Victoria
University of Waterloo
University of Winnipeg
VIDO-InterVac
Vineland Research and Innovation Centre
Western Grains Research Foundation
Women's College Hospital
Women's College Research Institute at Women's College Hospital
Working Group on Atmosphere-Related Research in Canadian Universities
York University
Yukon Research Centre, Yukon College

Exhibit A2.8: A Call for Evidence and Input – Community Questions

A. Funders

1. How does your organization identify the needs of the Canadian research community? How do you adapt to needs as they change?
2. How do you measure the effectiveness of your governance, operations, and approaches? What areas for improvement have you identified? What steps are you taking to make improvements?
3. How is funding coordinated between members of the federal science funding community (e.g. the granting councils, the CFI, and agencies or organizations that distribute funds supporting investigator-led research)? Are there areas where coordination and collaboration can be improved?
4. We are interested in how your organization flows funds to researchers:
   a) What is the history of the number of applicants in relation to your budget(s)?
   b) What is the average grant size of your various programs? Is there a difference between investigator-led and mandate-driven grants? How does your average grant size compare with other organizations in Canada and elsewhere?
   c) What is the balance between funding of teams and individuals? How has this changed over time?
   d) What is the balance between funding that goes to established versus emerging scientists? How do you ensure the balance is appropriate? How has it changed over time?
   e) What proportion of funding is allocated to projects with constraints on the topics of study versus project-initiated and led by scientists?
5. Comment on career-supporting funding versus project-based funding. What are the pros and cons of each structure? Should support structures be higher at the front end of careers and less so as they are established?
6. Is there a need for the federal government to improve the balance across funding elements (e.g. investments in principal researchers, funding of research staff and other direct costs of research, funding of infrastructure and equipment operations and maintenance, and reimbursement of indirect costs)? If so, how can this balance be achieved?
7. What should the balance be between funding risky, novel, or emerging research versus research with established lines of inquiry? How do your programs and review processes achieve the right balance?
8. What should the balance be between funding research to meet government priorities and having research priorities determined by the research community? How do your programs and review processes achieve this balance?
9. Could the application processes for funding be improved? If so, what would you suggest? Are there issues with the matching programs associated with various funding programs? If so, how could this be improved?
10. How do your programs accommodate the growing internationalization of research? What barriers do you face? Are there particular research fields or disciplines where more emphasis on international collaboration is needed? Are there particular geographic regions where Canadian researchers could enhance their collaborations?
11. How is multidisciplinary research supported by your organization? Does the funding ecosystem work collaboratively and effectively across disciplines or is there some duplication? Is there collaboration across granting councils to meet the needs of multidisciplinary researchers and their teams? If not, how can the situation be improved?

12. What are the elements of your peer review process that make it rigorous, fair and effective? What elements of your peer review process could be improved? What barriers has your organization identified to implementing these improvements? Do you request feedback from reviewers on the peer review process?
13. Are your programs effective in supporting major science initiatives or "Big Science" including large international collaborations and facilities? How can funding and oversight of existing and new initiatives be strengthened?
14. What is the best way to fund areas of strategic interest such as emerging, transformative or potentially disruptive technologies, and/or areas of broader societal interest? Are granting councils well placed to fund/support these areas or are separate mechanisms required?
15. Identify the unique barriers that the following groups face in obtaining support for investigator-led research. Do current programs address these barriers? What else could be done to address these barriers?
    a) students, trainees, and early career researchers
    b) women
    c) aboriginals and other underrepresented groups.
16. Are there international programs, structures, models, or best practices that Canada should consider adopting? If so, please provide specifics on why these are desirable.
17. What should the vision be for Canadian science? If we imagine an even more successful future for Canadian science, what does success look like and how should it be measured?
18. Are there any other issues or questions that you would like to raise and address?

B. Researchers

1. Is the federal funding ecosystem meeting the needs of the Canadian research community? As the needs change, is the ecosystem able to adapt and accommodate?
2. Are you currently receiving (or have you received) funding for your research from federal sources? Tell us about your experience including information about the program and size of the award; the award and stage(s) in your career when you received funding; relative changes over time in the amount of any federal funding you obtained; flexibility of the program; and whether you had to seek funds from elsewhere to fully fund your project. How could your experience be improved?
3. Are you currently receiving funding for your research from sources other than the federal government? If so, what are other sources of funding available to you? Please comment on the process for obtaining the funding and competitiveness of this funding source.
4. Could the application processes for funding be improved? If so, what would you suggest? Are there issues with the matching programs associated with various funding programs? If so, how could this be improved?
5. Does the federal science funding community (e.g. the granting councils, the CFI agencies or organizations that distribute funds supporting investigator-led research) consult the research community to ensure that their programs are aligned to the changing needs of researchers? If so, how? If not, should it and how should it?
6. Comment on the coordination between the programs being provided by the granting councils and other funding organizations, provinces, and/or amongst themselves. Are there areas for improvement?
7. Is there a need for the federal government to improve the balance across funding elements (e.g. investments in principal researchers, funding of research staff and other direct costs of research, funding of infrastructure and equipment operations and maintenance, and reimbursement of indirect costs)? If so, how can this balance be achieved? What is the appropriate federal role in supporting infrastructure operating costs? Do CFI and granting councils programs work in a complementary fashion?
8. Comment on career supporting funding versus project-based funding. What are the pros and cons of each structure? Should support structures be higher at the front end of careers and less so as they are established?
9. What should the balance be between funding risky, novel, or emerging research versus research with established lines of inquiry? Do current programs and review processes achieve the right balance?
10. What should the balance be between funding research to meet government priorities and having research priorities determined by the research community? Do current programs and review processes achieve the right balance?
11. Can you identify the peer-review processes (federal or otherwise) that you have participated in, either as an applicant or a reviewer? Do you have suggestions to improve the process in terms of rigour, fairness, and effectiveness?
12. Do current federal programs encourage and support domestic collaboration?
13. To what extent do you collaborate internationally and how important is this to your work? Is there sufficient flexibility in granting council or other funding programs for participation in international collaborations? Are there particular research areas where more emphasis on international collaboration is needed?
14. Are current federal programs supporting the needs of multidisciplinary researchers? If not, how can the situation be improved? Does the funding ecosystem work collaboratively and effectively across disciplines?

15. Is current support for major science initiatives or "Big Science" including large international collaborations and facilities effectively meeting the needs of researchers? If not, how can this be improved?
16. What is the best way to fund areas of strategic interest such as emerging, transformative or potentially disruptive technologies, and/or areas of broader societal interest? Are granting councils well placed to fund/support these areas or are separate mechanisms required?
17. Identify the unique barriers that the following groups face in obtaining support for investigator-led research. Do current programs address these barriers? What else could be done to address these barriers?
    a) students, trainees, and early career researchers
    b) women
    c) aboriginals and other underrepresented groups
18. Are there international programs, structures, models, or best practices that Canada should consider adopting? If so, please explain why these should be considered.
19. What should the vision be for Canadian science? If we imagine an even more successful future for Canadian science, what does success look like and how should it be measured?
20. Are there any other issues or questions that you would like to raise and address?

C. Institutions and Administrators

1. From the perspective of research, are Canadian universities keeping pace internationally? If not, what changes or new programs are needed to close the gap?
2. Is the federal funding ecosystem meeting the needs of researchers in your institution(s)? As the needs change, is the ecosystem able to adapt and accommodate?
3. Does the federal science funding community (e.g. the granting councils, the CFI and other agencies or organizations distributing federal funds for research) consult institutions to ensure that their programs are aligned to the needs of administrators? If so, how? If not, should it and how should it?
4. Comment on the coordination between the programs being provided by the granting councils and other funding organizations, provinces, and/or amongst themselves. Are there areas for improvement?
5. Could the application processes for funding be improved? If so, what would you suggest? Are there issues with the matching programs associated with various funding programs? If so, how could this be improved?
6. Is there a need for the federal government to improve the balance across funding elements (e.g. investments in principal researchers, funding of research staff and other direct costs of research, funding of infrastructure and equipment operations and maintenance, and reimbursement of indirect costs)? If so, how can this balance be achieved? What is the appropriate federal role in supporting infrastructure operating costs? Do CFI and granting councils programs work in a complementary fashion?
7. What should the balance be across funding risky, novel, or emerging research areas and research with important established lines of inquiry? Do current programs and review processes achieve the right balance?
8. What should the balance be across funding of research to meet broad government priorities and having research priorities determined primarily by the ideas of the research community? Do current programs and review processes achieve the right balance?
9. Do current federal programs encourage and support domestic collaboration? Is there sufficient flexibility in federal funding programs for participation in international collaborations? Are there particular research areas where more emphasis on international collaboration is needed?
10. Are current federal programs supporting the needs of multidisciplinary research programs? If not, how can the situation be improved? Does the funding ecosystem (funding councils and other agencies) work collaboratively and effectively across disciplines?
11. Does your institution participate in major science initiatives or "Big Science," including large international collaborations and facilities? Why or why not? If your institution does participate, , how is your participation funded? Are there challenges in identifying or securing funding sources?
12. What is the best way to fund areas of strategic interest such as emerging, transformative or potentially disruptive technologies, and/or areas of broader societal interest? Are granting councils well placed to fund/support these areas or are separate mechanisms required?
13. Identify the unique barriers that the following groups face in obtaining support for investigator-led research. Do current programs address these barriers? What else could be done to address these barriers?
    a) students, trainees, and early career researchers
    b) women
    c) aboriginals and other underrepresented groups
14. Are there international programs, structures, models, or best practices that Canada should consider adopting? If so, please explain why these should be considered.
15. What should the vision be for Canadian science? If we imagine an even more successful future for Canadian science, what does success look like and how should it be measured?
16. Are there any other issues or questions that you would like to raise and address?

D. Students, Trainees, and Postdoctoral Fellows

1. Is the federal science funding ecosystem meeting the needs of the Canadian post-secondary students and fellows? As the needs change, is the ecosystem able to adapt and accommodate?
2. Have you applied for federally funded awards, grants, fellowships or scholarships? Tell us about your experience: What was the program? What worked well? What did not work well? Has your funding changed over time? How flexible are the programs? Did you need to seek funds from elsewhere? How could your experience be improved?
3. Are you currently receiving funding for your research from sources other than the federal government? If so, what are other sources of funding available to you? Please comment on the process for obtaining the funding and competitiveness of this funding source.
4. Could the application processes for funding be improved? If so, what would you suggest? Are there issues with the matching programs associated with various funding programs? If so, how could this be improved?
5. Does the federal science funding community (e.g. the granting councils, the CFI and agencies or organizations that distribute funds supporting investigator-led research) consult with students and follows to ensure that their programs are aligned to the changing needs of researchers? If so, how? If not, should it and how should it?
6. Could the application processes for funding be improved? If so, what would you suggest? Are there issues with the matching programs associated with various funding programs? If so, how could this be improved?
7. Do current federal programs provide opportunities to collaborate with other Canadian researchers?
8. Do current federal programs provide opportunities to collaborate with international researchers? Are there particular research areas where more emphasis on international collaboration is needed?
9. Do current federal programs provide opportunities to collaborate across disciplines (i.e. do they support multidisciplinary research)?
10. Do current federal programs support both risky, novel, or emerging research and research with established lines of inquiry? Do current programs and review processes achieve the right balance?
11. What is the best way to fund areas of strategic interest such as emerging, transformative or potentially disruptive technologies, and/or areas of broader societal interest? Are granting councils well placed to fund/support these areas or are separate mechanisms required?
12. Identify the unique barriers that the following groups face in obtaining support for investigator-led research. Do current programs address these barriers? What else could be done to address these barriers?
    a) students, trainees, and early career researchers
    b) women
    c) aboriginals and other underrepresented groups
13. Are there international programs, structures, models, or best practices that Canada should consider adopting? If so, please explain why these should be considered.
14. What should the vision be for Canadian science? If we imagine an even more successful future for Canadian science, what does success look like and how should it be measured?
15. Are there any other issues or questions that you would like to raise and address?

E. Facilities

1. Are Canadian research facilities keeping pace internationally? If not, what changes or new programs are needed to close the gap?
2. Is the federal funding ecosystem meeting the needs of facilities? Is it meeting the needs of the researchers who use your facilities? As the needs change, is the ecosystem able to adapt and accommodate?
3. How does your facility identify the needs of the Canadian research community? How do you adapt to meet those needs?
4. Is there a need for high level oversight for Major Science Initiatives in Canada? If so, what would it look like in terms of structure, responsibilities, and scope? Would oversight be provided throughout the full project cycle to decommissioning?
5. Should the approach to oversight and funding for MSI projects be more uniform for all the projects in Canada? If so what would you suggest?
6. Please comment on the coordination between the programs being provided by the granting councils and other funding organizations, provinces, and/or amongst themselves. Are there areas for improvement?
7. Are there issues with the matching programs associated with various funding programs, including the MSI program at CFI? If so, how could this be improved? Could the application processes for the many sources of funding be improved? If so, what would you suggest?
8. Is there a need for the federal government to improve the balance across funding elements (e.g. investments in principal researchers, funding of staff and other direct costs of research, funding of infrastructure and equipment operations and maintenance, and reimbursement of indirect costs)? If so, how can this balance be achieved? What is the appropriate federal role in supporting infrastructure operating costs? Do CFI and granting councils programs work in a complementary fashion?
9. What are the ways that your facility encourages or performs multidisciplinary research? Do you partner with other organizations, facilities or institutions to perform your research? How do these partnerships occur and how are resources allocated between partners? Are there barriers to partnerships or collaboration that your facility is facing?
10. How important is international collaboration and/or funding to your organization and users of your facility? Do you face any barriers to enhanced international collaboration? Please comment on your international collaboration efforts and initiatives.
11. Are there international programs, structures, models, or best practices that Canada should adopt? If so, please explain why these should be considered.
12. What should the vision be for Canadian science? If we imagine an even more successful future for Canadian science, what does success look like and how should it be measured?
13. Are there any other issues or questions that you would like to raise and address?

APPENDIX 3

INNOVATION: METRICS AND REFLECTIONS

This appendix has been compiled to address a number of issues that bear more directly on innovation and business-facing elements of research. These issues are outside our primary mandate, but as noted in Recommendation 1.1, the Panel supports the position of the Advisory Council on Economic Growth regarding the need for a systematic evaluation of innovation-oriented programming inside and outside ISED. The material here provides the Panel's rationale for that recommendation and, more generally, some useful context for our report. We address the following four issues: business enterprise expenditures on research and development (BERD), Canada's patent outputs, scope of spending on supports for business R&D/innovation, and the finding and recommendations of the Growth Council regarding the need for a review of business-facing programs and spending.

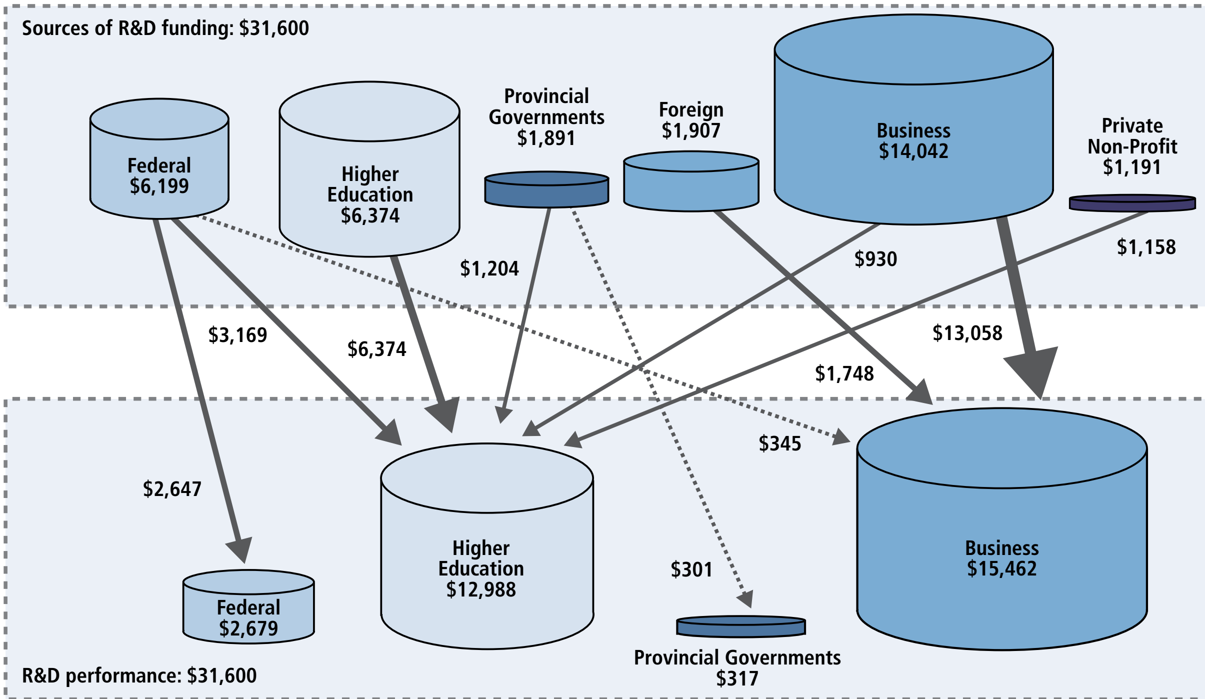
A3.1 Unbundling BERD

As outlined in Chapter 3, GERD intensity is the gross domestic expenditures on R&D from all sources divided by GDP, while BERD and HERD represent business enterprise expenditures and higher education expenditures respectively. The Panel was particularly interested to understand more about Canada's persistently low levels of BERD, and the flow of BERD to universities and research hospitals. The overarching issue was whether there was any evidence that BERD had been stimulated, given the recent major redirection of investigator-led research towards partnerships, knowledge translation, and commercialization.

We begin by revisiting GERD for overall context.

Recall that Exhibit 3.1 showed that Canadian GERD intensity has been falling over the last 15 years in contrast to peer nations. Exhibit 3.2 showed that Canada's BERD was approximately half the OECD average. We spent some time dissecting the origins of research funds (or sources), and their destinations (commonly termed "performers" of research). Exhibit A3.1 provides a quick snapshot for all sources of research funds and the performers of research in Canada for 2015, including foreign contributors.

Exhibit A3.1: GERD Matrix – Major Flows of Funding, Canada ($ Millions)



Note: Data are for 2015. Only flows higher than $300 million are shown.
Source: Statistics Canada, CANSIM table 358-0001. Funding figures refer to intentions and not final expenditures.

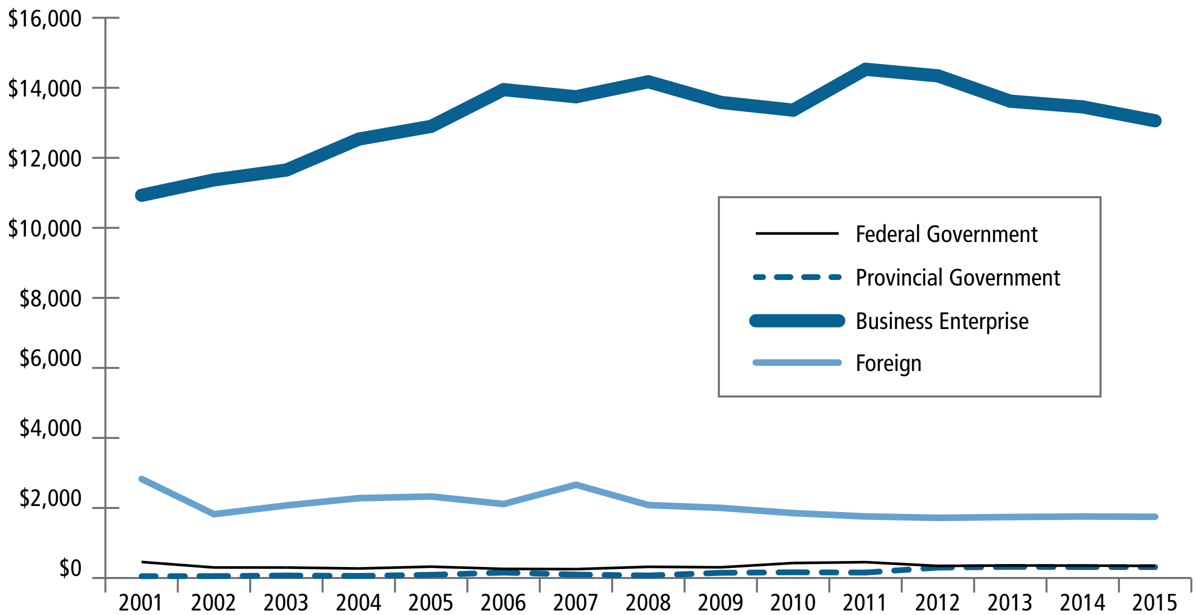
For ease of reference, the domestic performers of R&D, the sources of GERD funding, and the amounts funded by each sector were as follows:[i]

Sector	Domestic Performers of R&D ($ Millions)		Sources of GERD Funding ($ Millions)	
	2011	2015	2011	2015
Federal Government	$2,649	$2,679	$6,220	$6,199
Provincial Government	$300	$285	$1,788	$1,885
Provincial Research Organizations	$32	$32	$4	$6
Business Enterprise	$16,894	$15,462	$15,586	$14,042
Private Non-Profit	$127	$158	$1,153	$1,191
Higher Education	$11,832	$12,988	$5,193	$6,374
Foreign	N/A	N/A	$1,891	$1,907

i Not all figures match those in Exhibit A3.1. The exhibit only shows amounts greater than $300 million and some categories have been combined.

Turning now to BERD, it should be understood that the industrial sector is defined widely to include spending by public utilities and government-owned firms that are market-facing, and incorporated consultants providing scientific and engineering services. Industrial research institutes located at Canadian universities are considered to be in the university sector. Exhibit A3.2 tracks trends in sources of R&D funding to the business enterprise sector over a 15-year period from 2001 to 2015.

Exhibit A3.2: Sources of R&D Funding to the Business Enterprise Sector, by Funding Sector, 2001 to 2015 ($ Millions)



Source: Statistics Canada, CANSIM table 358-0162.

Overall R&D funding in the business enterprise sector increased from $14.266 billion in 2001 to a peak of $16.894 billion in 2011, before, as noted in the body of the report, declining steadily to $15.462 billion in 2015. The business enterprise sector largely self-funds its R&D activities. Internal funding accounted, on average, for 84 per cent of R&D activities from 2001 to 2015 (see Exhibit A3.2). The foreign sector was the second largest funder of business enterprise R&D, accounting for $1.748 billion in 2015; much of this inflow reflects multinational corporations headquartered elsewhere that have flowed funds into R&D within Canada. Direct funding from the federal government is modest at $0.345 billion, while provincial supports total $0.311 billion.

Funding is an input, not an output or outcome. Thus, for HERD, we examined output measures related to scholarly and scientific research in Chapter 3. BERD is generally seen to be linked to broad indices of economic performance, productivity, and innovation. In this respect, Canada's low BERD has been linked to low productivity and innovation indices. It was in part this phenomenon that led advocates and funders alike to characterize the major investments in R&D by the Chrétien government as part of an "innovation agenda". The hope was that by boosting spending on extramural R&D there would be a fairly prompt improvement in innovation indices and in Canada's BERD levels. This did not occur, and more nuanced explanations for Canada's lagging BERD have emerged from two federal reports.

The 2008 federal Competition Policy Review Panel[1] observed that a variety of regulatory and protectionist measures had arguably served Canada's national interests in decades past; but those measures now required rapid reform so that Canadian industry could be better positioned to compete in a globalizing economy. The 2011 Review of Federal Support for R&D[2] argued for a restructuring of Canada's program of tax credits for business R&D and for innovation-friendly procurement. It also advocated refocusing the National Research Council so that its basic research work would connect more closely with academe while its industry-facing institutes and programs would become more dependent on external contracts and align more closely with models such as Germany's Fraunhofer Institutes. Relevant to this Panel's work is the fact that the 2011 report also warned against mission drift occurring as granting councils were funded to do more innovation-oriented and partnership-focused activities, and were compelled to migrate away from basic and independent applied research.

As reported in multiple sources, including the 2016 reports from the Growth Council, Canada continues to lag on indices of productivity and innovation. Overall economic performance, in contrast, has been above the OECD average. This situation reflects a well-known paradox: Canadian BERD along with productivity and innovation indices have actually been low for decades, even as economic indices have remained comparatively sound, and Canadian firms have been relatively profitable.

This disconnect has been studied from different perspectives. BERD, for example, has been observed to vary by sector and region. This has led to hypotheses that Canada's economic dependence on natural resource industries may explain our relatively low BERD. However, other major economies also show sectoral and regional variation, and quantitative analyses suggest that the mix of industries accounts for only a moderate fraction of Canada's relatively low BERD.

A more nuanced explanation is provided in the 2013 CCA report, *Paradox Lost: Explaining Canada's Research Strength and Innovation Weakness*.[3] The CCA report, lead-authored by Dr Peter Nicholson, locates this phenomenon in a complex matrix of causes, not least our integration with the U.S. economy and the steering effect on the Canadian private sector arising from its variable position in U.S. supply chains, be it shipping commodities with limited value added or producing finished goods in manufacturing branch-plants. The 2013 CCA report also sends a clear warning that our economic position may be at risk, owing to four factors: the growth of a multilateral economy with reduced U.S. dominance, rising emphasis in global trade on knowledge-intensive products and services, greater volatility in demand for commodities and energy that have been Canada's traditional strength, and population aging.

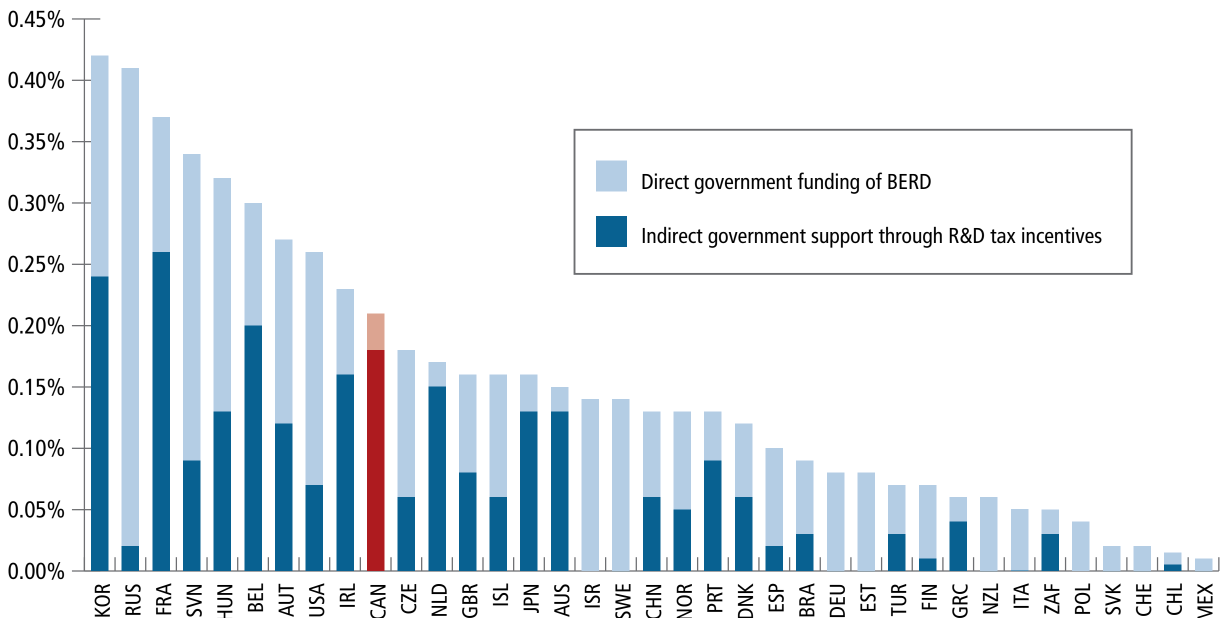
Two other issues related to BERD bear consideration here.

First, there continues to be a concern that business–university interfaces are underdeveloped. The World Economic Forum's annual *Global Competitiveness Report* for 2016-17[4] ranks Canada's university-industry collaboration in R&D 23rd worldwide, as contrasted with a 12th place ranking in 2001. The problem with this measure is that it is based on an executive opinion survey, and as such may be influenced by perceptions rather than hard evidence. Among the factors shaping those perceptions may be the reaction that occurred after the investments in research made between 2000 and 2008 did not bear immediate fruit. A related factor is the focus of successive governments on Canada's low and falling BERD intensity. For leaders of major Canadian companies, weakness at the university–industry interface may become the logical fallback explanation for an otherwise puzzling phenomenon.

Looking at actual spending data, the industry-funded share of HERD was 7.2 per cent in 2014, ranking Canada 14th out of 41 countries, despite our low BERD intensity and high overall HERD ranking. Canada's ranking of industry-funded R&D to the higher education sector was actually higher than many high BERD-intensity countries such as Israel, Japan, United States, and France where the industry-financed HERD ratios stood at 6.8 per cent, 2.6 per cent, 4.8 per cent, and 2.8 per cent, respectively. However, Canada is lower than high BERD-intensity countries such as Germany (14.1 per cent) and the Republic of Korea (11.2 per cent). Furthermore, the 2014 percentage represents a decline from 8.2 per cent in 2011.[5]

Second, direct government funding to business for R&D is comparatively low. OECD data for 2013 (Exhibit A3.3) show the ratio of direct government funding of BERD to indirect government support through R&D tax incentives. The Panel echoes the 2011 federal review of industrial R&D support in wondering if Canada's direct supports are fully tallied—a point to which we return below. What is interesting is that the Scientific Research and Experimental Development (SR&ED) tax credit program has indeed shrunk in response to criticisms made in the 2011 Review of Federal Support for R&D, now registering at approximately $3.0 billion as contrasted to $3.5 billion in 2010.

Exhibit A3.3: Direct Government Funding of Business R&D and Tax Incentives for R&D, 2013 (as a Percentage of GDP)



Note: Data on indirect government support through R&D tax incentives are not available for Israel and Poland.

Source: OECD Science, Technology and Industry Scoreboard 2015, OECD Publishing, Paris.
Available from: http://dx.doi.org/10.1787/sti_scoreboard-2015-graph156-en

An OECD analysis comparing 2006 to 2013 shows a shift in the ratios of direct to indirect supports. In that period, 16 of 28 countries under study increased the relative share of funding for industry from tax credits as compared to BERD-eligible direct expenses. Canada, along with Portugal, started with a high level of indirect support that was rebalanced during this period towards more direct support.[6] It is obvious from Exhibit A3.3, however, that convergence is still very limited. The OECD's summary follows: "In Canada, a review of federal R&D support led to a small rebalancing of central government support. However, Canada continues to place significant emphasis on tax support, surpassed only by the Netherlands in 2013."[7]

The Panel's overall conclusions are therefore straightforward.

First, funding flows at the university–industry interface are more robust than is widely appreciated in Canada. However, between 2011 and 2015, when the growth in partnership and innovation-friendly programs was continuing inside the federal extramural funding system, the share of industry funding of HERD actually fell, raising concerns that the net effect was to displace and/or dilute spending rather than augment it.

Second, more generally, the attempt by the Harper government to drive BERD by shifting funds from investigator-led to priority-driven and partnership-oriented research appears to have had little impact on broader business innovation indices, perhaps because it represented an intensification of what has been described as a "supply-push" or "research-push" mode originating with researchers and research institutions. That shift, unfortunately, appears to have harmed the fabric of Canadian independent research given findings in the body of the report.

Last, Canada remains an outlier in its extent of reliance on SR&ED tax credits or indirect supports rather than direct funding of industry-facing or industry-friendly R&D programming. The changes recommended by the 2011 federal review have led to a drop in tax revenues foregone through the SR&ED program. However, the concomitant growth in direct supports has been minimal. Given the relative profitability of Canadian business, and the consistent record of low R&D spending associated with indirect support through SR&ED tax credits, it is unsurprising that the Growth Council has recommended experimentation with measures that provide more direct supports, and that would promote a "demand-pull" model wherein industry is incented to actively seek R&D collaborations, especially for pre-competitive research.

A3.2 Brief Profile of Canadian Patents

Patent counts are also frequently taken as useful indicators of the combined performance of research and innovation ecosystems in any given nation. Exhibit A3.4 provides a snapshot of Canada's performance based on triadic patent families. These measures are derived by searching patents taken at the "triad" of patent authorities—the European Patent Office, the Japanese Patent Office, and the U.S. Patent and Trademark Office—to find patents that share claims to one or more priorities. The indicator arguably favours those countries that are part of this triad, but many other non-triadic countries outperform Canada.

Exhibit A3.5 provides a longitudinal view based on five-year brackets from 1999 to 2013, and complements the previous exhibit by drawing on filings approved under the Patent Cooperation Treaty (PCT). PCT has been in force since 1978 and has a more or less global reach. Canada's filings are growing, measured as patents per million people, and our worldwide ranking has climbed slightly in recent years. However, our overall performance remains weak compared to peers.

Exhibit A3.4:
Triadic Patent Data, 2013

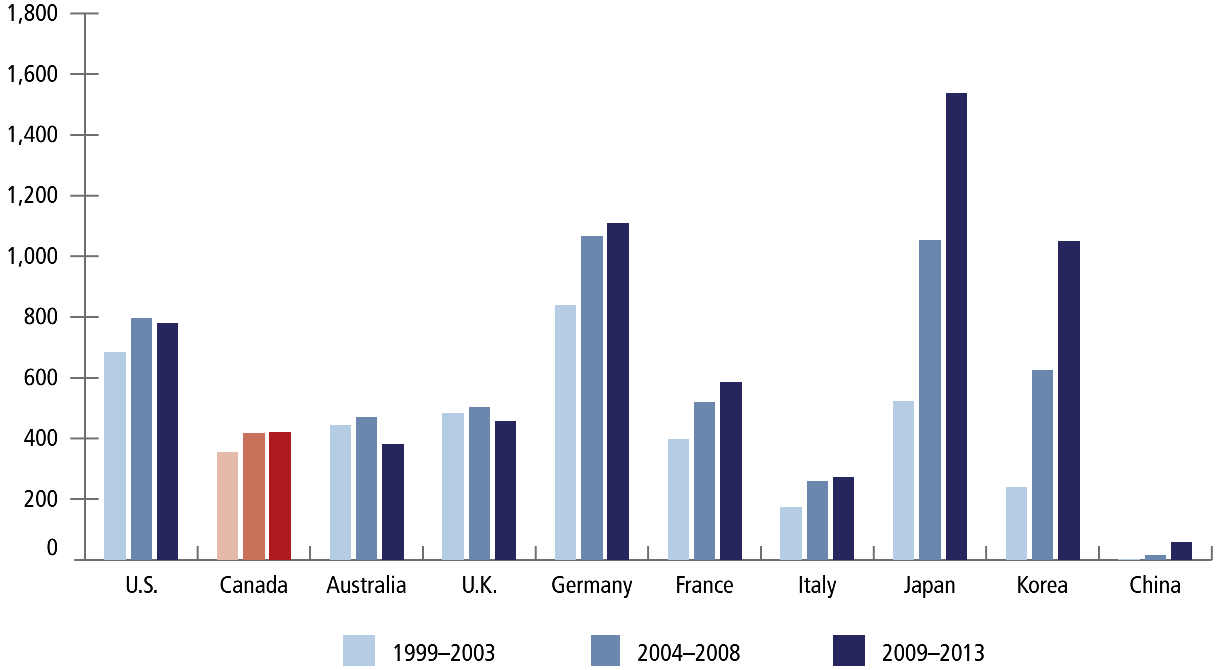
Country	Triadic Patent Families
Canada	0.42
United States	1.12
Australia	0.34
United Kingdom	0.68
Germany	1.71
France	0.96
Italy	0.28
Japan	3.17
Republic of Korea	1.54
China	0.03
Netherlands	1.41
Belgium	1.05
Sweden	1.61
Switzerland	3.77
Austria	1.47
Israel	1.27
Taiwan	0.49
Singapore	0.64

Note: Data are normalized for population, and relative to the OECD averages, which are set to 1.0.

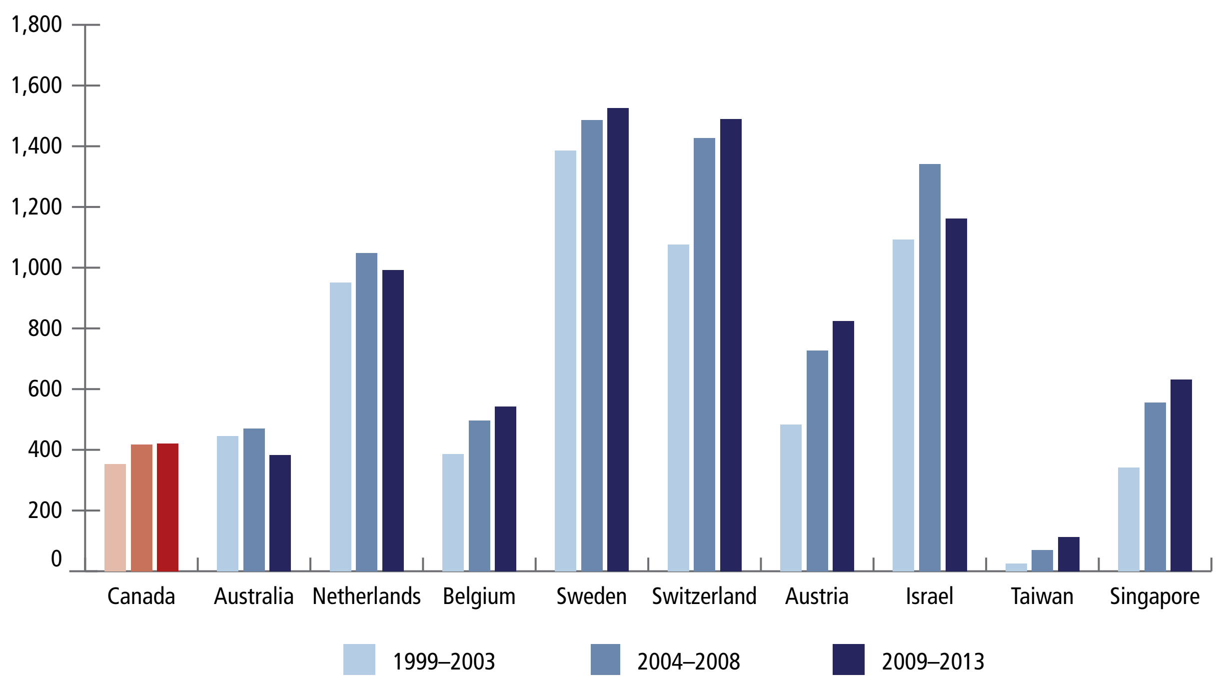
Source: OECD, Main Science and Technology Indicators, 2013. Available from: http://www.oecd.org/science/inno/msti.htm Supplemented with data from the Taiwan Statistical Data Book, National Development Council. Available from: http://www.ndc.gov.tw/en/News.aspx?n=607ED34345641980&sms=B8A915763E3684AC

Exhibit A3.5: Patent Cooperation Treaty (PCT) Patent Applications per Million People, by Country of Inventor

A. Canada as compared to select G7 countries, Australia, and key east Asian countries



B. Canada as compared to smaller peer countries

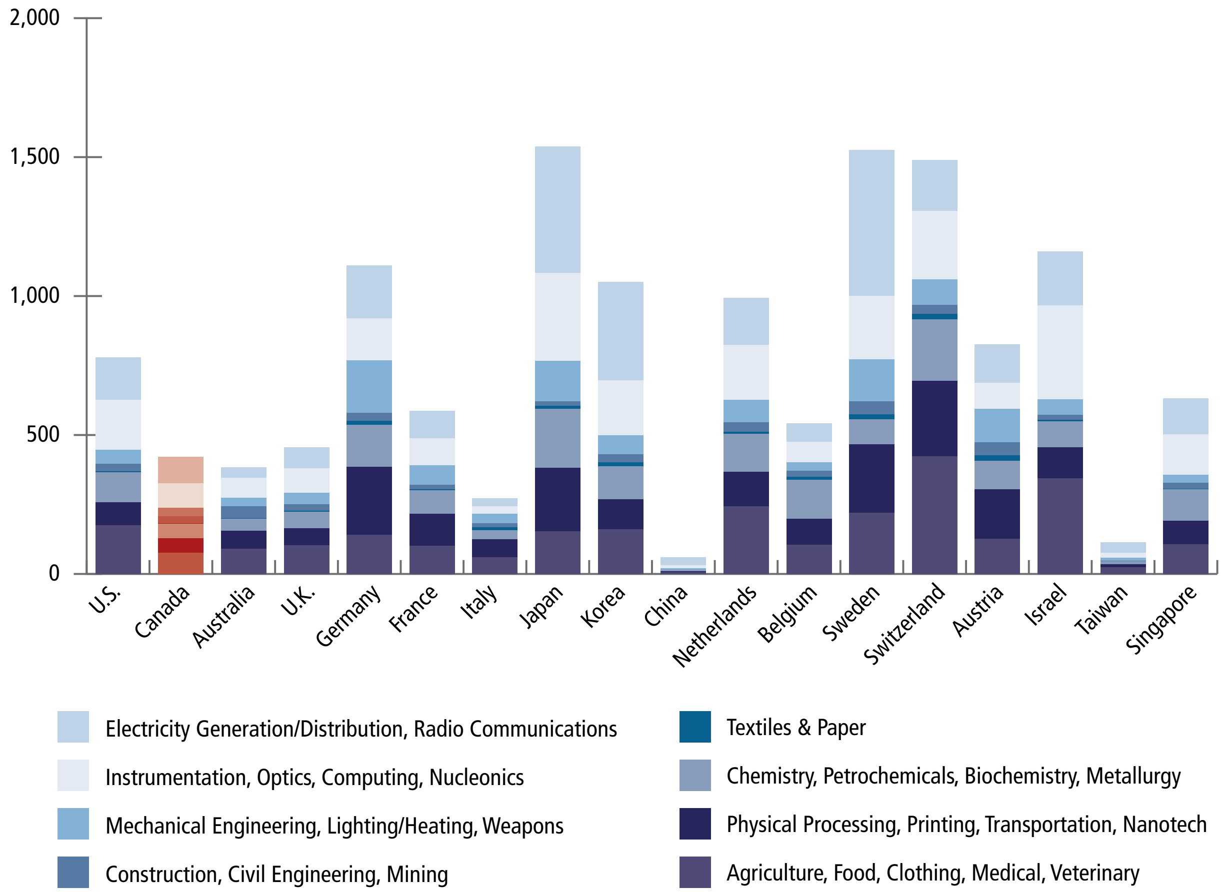


Source: OECD, Science Technology and Patents, Patent Statistics. Available from: http://stats.oecd.org. Population data from United Nations Department of Economic and Social Affairs. Available from: https://esa.un.org/unpd/wpp/Download/Standard/Population/ Supplemented with the Taiwan Statistical Data Book, National Development Council. Available from: http://www.ndc.gov.tw/en/News.aspx?n=607ED34345641980&sms=B8A915763E3684AC

Exhibit A3.6 examines patents per million population for the five years from 2009 to 2013, and breaks them down according to the eight major technology sections determined under the International Patent Classification administered by the World Intellectual Property Organization. Narrower breakdowns show that Canada's performance is generally weak. The top five areas appear to be: (i) earth or rock drilling; obtaining oil, gas, water, soluble or meltable materials or a slurry of minerals from wells; (ii) cracking hydrocarbon oils; production of liquid hydrocarbon mixtures; (iii) production or refining of metals; (iv) structural elements; building materials; and (v) harvesting; mowing. These findings underscore two points. First, innovation sweeps across many domains, including mining, oil and gas, infrastructure, and agriculture. Second, in the face of the Government of Canada's avowed interest in making Canada a hotbed for high technology, the areas of greatest strength speak for themselves.

The conclusions seem clear. Canada's patent filings are growing faster than the population, but we lag many peer countries. A closer analysis by sector and source/origins of patents seems warranted as part of any innovation review.

Exhibit A3.6: PCT Patent Applications per Million People, by Technology Area, 2009 to 2013



Source: OECD, Science Technology and Patents, Patent Statistics. Available from: http://stats.oecd.org. Population data from United Nations Department of Economic and Social Affairs. Available from: https://esa.un.org/unpd/wpp/Download/Standard/Population/. Supplemented with the Taiwan Statistical Data Book, National Development Council. Available from: http://www.ndc.gov.tw/en/News.aspx?n=607ED34345641980&sms=B8A915763E3684AC. For details of the IPC classification see http://www.wipo.int/ipcpub/

A3.3 Overall Funding for Business-facing Programs

As indicated in Chapter 1, our mandate excluded components within the four pillar agencies designated as primarily relating to innovation or business-facing programs. However, Genome Canada, as noted in Chapter 5, funds activities that span research and innovation through its partnership programs. Mitacs arguably also fits better in the innovation domain.

These all fall under HERD because of the site of "performance" of the research or recipients of funds (e.g., to graduate students from Mitacs). However, they also support business innovation. This type of ambiguity raises questions about other programs and where and how they should be counted as between HERD, BERD, and so-called GOVERD (i.e., Government R&D). Certainly in the case of the U.S., the national laboratories, military research, and specialized procurement programs like ARPA under the Department of Energy all have important industrial impacts and connections. In Canada the National Research Council not only runs a concierge program and funds small-scale projects for small business through its Industrial Research Assistance Program (IRAP), but also does larger-scale R&D in partnership with industry. In sum, as noted earlier, it may well be that supports for BERD are underestimated in Canada—and in other jurisdictions—by current OECD counting rules.

If one sweeps in not only R&D programming, but broad supports for business innovation, the totals mount up quickly as shown in Exhibit A3.7, which includes an attributed costing for industry-academic partnership programs across NSERC, CIHR, Genome Canada, and Mitacs. This total does not include any allowance for the opportunity costs of venture capital investments totalling in the hundreds of millions of dollars deployed by the Business Development Bank of Canada (BDC) and Export Development Canada (EDC). It also does not account for some tens of billions of dollars in financing to business through BDC, EDC, and Farm Credit Canada. Many of the foregoing loan programs support business development very broadly, arguably a worthy goal, but their effect on innovation is uncertain and direct impact on R&D even less clear.

Last, SR&ED tax credits are associated with some $3 billion of foregone tax revenue.

The Panel offers three conclusions from this brief review.

First, measured against what at minimum appears to be $5 billion per year of direct and indirect support for business-facing innovation alongside tens of billions of dollars in loans, we do not think that the proposed reinvestments in extramural research can be viewed as creating an imbalance in the combined research and innovation portfolio.

Second, some of these programs may fall outside the BERD counting rules, and it does seem reasonable to conclude that Canada's support for business-facing innovation is more generous than might be inferred from counting only direct grants. However, some other countries are likely to be constrained by similar counting rules. On balance, it seems unwise to downplay the reality of Canada's outlier status (along with the Netherlands) in extent of reliance on tax credits to incent business R&D spending.

Third, the federal government's recent consultation on innovation provided stakeholder views on strengths and weaknesses in general in Canadian innovation, but did not generate an in-depth view of the function of these various programs or returns on the many investments summarized above. Such a review would seem both timely and appropriate. CCA's 2013 report discussed above does highlight that the causes of Canada's persistently low BERD are likely to be complex. However, having spent a number of months reviewing the extramural research funding system, the Panel is left in little doubt that similar scrutiny would be worthwhile to examine this array of spending as well as the SR&ED program.

Exhibit A3.7: Innovation Grants and Contributions Programming[a]

Program Category	Existing Programs	Envelope (2015-16)[b]
R&D Grants	**Sectoral Programs** **ISED:** Automotive Innovation Fund, Automotive Supplier Innovation Program, Strategic Aerospace and Defence Initiative, Technology Demonstration Program **FedDev Ontario:** Advanced Manufacturing Fund[c] **NRCan:** Investments in Forest Industry Transformation, ecoENERGY Innovation Initiative **SDTC:** SD Tech Fund **AAFC:** AgriInnovation	$415 million
	Regional Programs **ACOA:** Atlantic Innovation Fund, Business Development Program **CED-Q:** Québec Economic Development Program **FedDev Ontario:** Southern Ontario Prosperity Initiatives, Advanced Manufacturing Fund[c] **FedNor:** Northern Ontario Development Program **WD:** Western Innovation Initiative	$515 million
Advisory Services	**AAFC:** Growing Forward 2 – cost-shared strategic initiatives **NRC:** Industrial Research Assistance Program, Business Innovation Access Program (now terminated)	$360 million
Industry–Academia R&D Collaborations	**Multiple agencies:** Automotive Partnerships Canada (being phased out) **Tri-Council:** College and Community Innovation Program, Business-Led Networks of Centres of Excellence **NSERC:** Strategy for Partnerships and Innovation **CIHR:** Proof of Principle, Industry-Partnered Collaborative Research (being phased out) **Genome Canada:** Genomics Applications Partnership Program **Regional development agencies** can also support industry-academia partnerships through business programming	$320 million
Industry–Government R&D Collaborations	**NRC:** Technology Development and Advancement Program **NRCan:** Forest Innovation Program **AAFC:** AgriInnovation	$405 million
Networks & Ecosystems	**NRC:** Canada Accelerator and Incubator Program, Concierge Service **Tri-Council:** Centre of Excellence for Commercialization and Research **SDTC:** Virtual incubator, mentoring and networking services	$50 million
Procurement Policies	**CSA:** Space Technology Development Program **DRDC:** Defence Industrial Research Program **PWGSC:** Build in Canada Program	$40 million
Training / Internships	**Industry Portfolio:** Support for the Industrial R&D Internships and Mitacs Elevate and Accelerate programs **NSERC:** Industrial research scholarships **NRC:** Youth Employment Strategy under IRAP	$50 million
TOTAL		**$2.2 billion**

[a] Figures reported are from the 2015-16 Mains Estimates with some adjustments for known developments. The figures do not reflect transfers to and from innovation programs taking place within government throughout the year. The criteria used to compile information for this exhibit vary from those used by the Panel, so figures are not directly comparable.

[b] Figures are rounded to the nearest $5 million.

[c] FedDev Ontario's Advanced Manufacturing Fund is shared evenly between the sectoral and regional categories.

A3.4 Alignment with the Growth Council

As noted in Chapter 1, the Advisory Council on Economic Growth was appointed by the Minister of Finance in March 2016 and is chaired by Mr Dominic Barton, global managing partner of McKinsey & Company. The Council's first report contained three parts: *Unleashing Productivity Through Infrastructure, Bringing Foreign Investment to Canada,* and *Attracting the Talent Canada Needs Through Immigration*.[8] A second report was released in February 2017.[9]

This Panel has liaised with the Growth Council and agreed on interlocking directions for two recommendations. The Growth Council has endorsed the concept of an arm's-length oversight and advisory body addressing both research and innovation. Chapter 4 presents our elaboration of that concept. The Growth Council and Panel also agreed on the need for a comprehensive review of the federal suite of programs that support business along the innovation continuum. As the Growth Council writes, "The current portfolio of programs delivers funding through a wide range of activities, from support for academic and industrial research to demonstration projects that lead to commercialization and from local sales to export assistance." It observes that despite substantial investment, "Canada continues to lag on key innovation measures, including business investment in R&D and productivity."[10]

The Growth Council comments further that:

> Programs are sometimes duplicative, and can be challenging for businesses to navigate. Moreover, it is unclear whether the program portfolio delivers the right balance between "supply push" versus "demand pull" or between direct versus indirect R&D support to foster commercialization and productivity enhancement. … Canada lacks the data about program effectiveness to make evidence-based policy choices about how to allocate funding.[11]

The proposed mechanism is that the review be directed by the Treasury Board Secretariat, as the relevant programming cuts across many departments beyond ISED or Finance. This may also provide a faster track to implementation as contrasted with a fully external review.

As noted in Chapter 1, the Panel fully supports the Growth Council's call for "reviewing and retooling Canada's innovation programs to support Canada's 21st century inclusive growth ambitions."[12]

ENDNOTES

1 Compete to Win [Internet]. Ottawa: Industry Canada; 2008. Available from: http://www.ic.gc.ca/eic/site/cprp-gepmc.nsf/eng/home

2 The Independent Panel on Federal Support to Research and Development. Innovation Canada: A Call to Action. Ottawa: Industry Canada; 2011. Available from: http://rd-review.ca/eic/site/033.nsf/vwapj/R-D_InnovationCanada_Final-eng.pdf/$FILE/R-D_InnovationCanada_Final-eng.pdf

3 Council of Canadian Academies Advisory Group. Paradox Lost: Explaining Canada's Research Strength and Innovation Weakness. Ottawa: Council of Canadian Academies; 2013. Available from: http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/synthesis/paradoxlost_en.pdf

4 World Economic Forum. The Global Competitiveness Report 2016–2017. Geneva: World Economic Forum; 2016, p. 139. Available from: http://www3.weforum.org/docs/GCR2016-2017/05FullReport/TheGlobalCompetitivenessReport2016-2017_FINAL.pdf

5 OECD, Main Science and Technology Indicators (MSTI 2016-1), June 2016. Available from: http://www.oecd.org/science/msti.htm

6 R&D Tax Incentive Indicators [Internet]. Paris: OECD; 2016. Available from: https://www.oecd.org/sti/rd-tax-incentive-indicators.htm

7 Ibid.

8 Advisory Council on Economic Growth [Internet]. Ottawa: Department of Finance; 2016. Available from: http://www.budget.gc.ca/aceg-ccce/home-accueil-en.html

9 Advisory Council on Economic Growth [Internet]. Ottawa: Department of Finance; 2017. Available from: http://www.budget.gc.ca/aceg-ccce/home-accueil-en.html

10 Advisory Council on Economic Growth. Unlocking Innovation to Drive Scale and Growth. Ottawa: Department of Finance; 2017. Available from: http://www.budget.gc.ca/aceg-ccce/pdf/innovation-2-eng.pdf

11 Ibid.

12 Ibid.

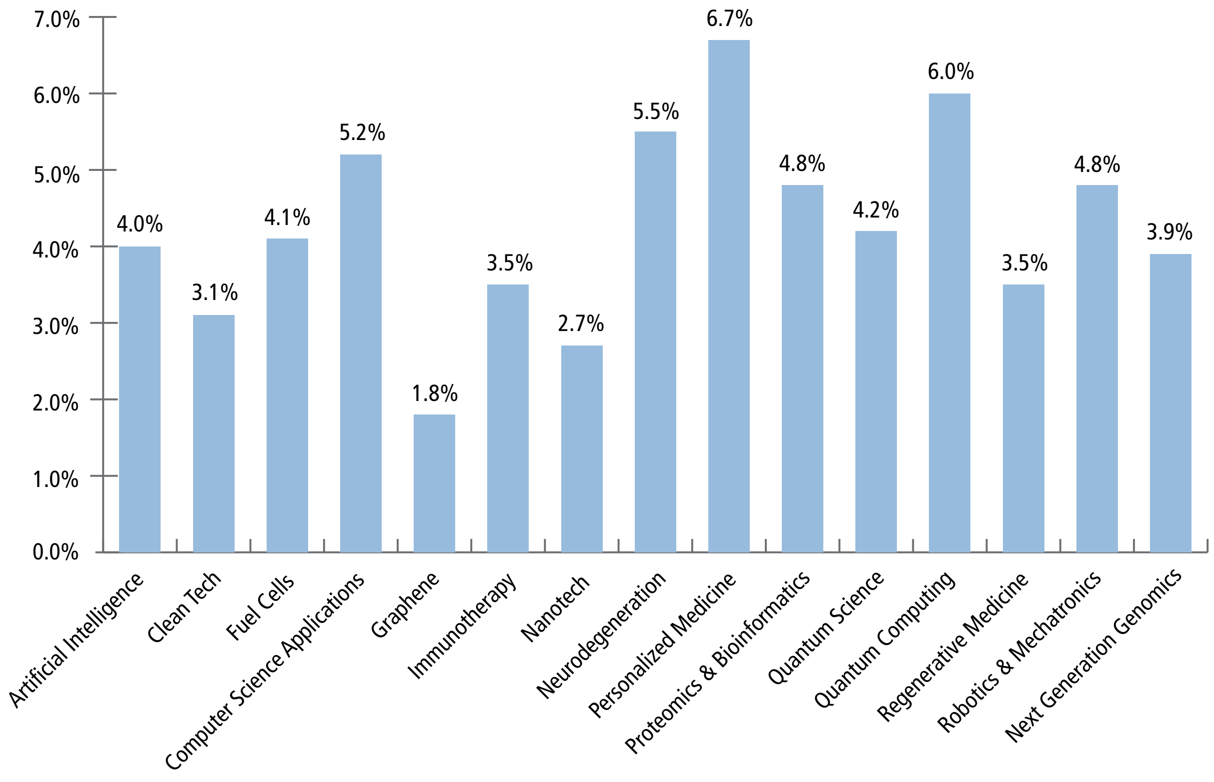
APPENDIX 4

EMERGING RESEARCH AREA PROFILES

This appendix profiles various emerging research areas as measured by publications and citations to those publications when compared to other countries. Exhibit A4.1 shows a summary of papers with a Canadian author in 15 emerging research areas as the share of all publications in those areas. Note that research is frequently conducted collaboratively and many of the papers containing a Canadian author will also include authors from other countries.

As research output may vary by country and region, Canada's world share may be affected by the output, or lack thereof, in other parts of the world. For a better understanding of the context of research output, please see the profiles of individual research areas that follow.[i]

Exhibit A4.1: Canada's World Share of Publications for Selected Emerging Research Areas, 2011 to 2015



Source: Clarivate Analytics, Web of Science.

i Data for these analyses are from InCites, provided by Clarivate Analytics. See Annex A for data sources, methodology and indicator definitions, and Annex B for keywords and search syntax.

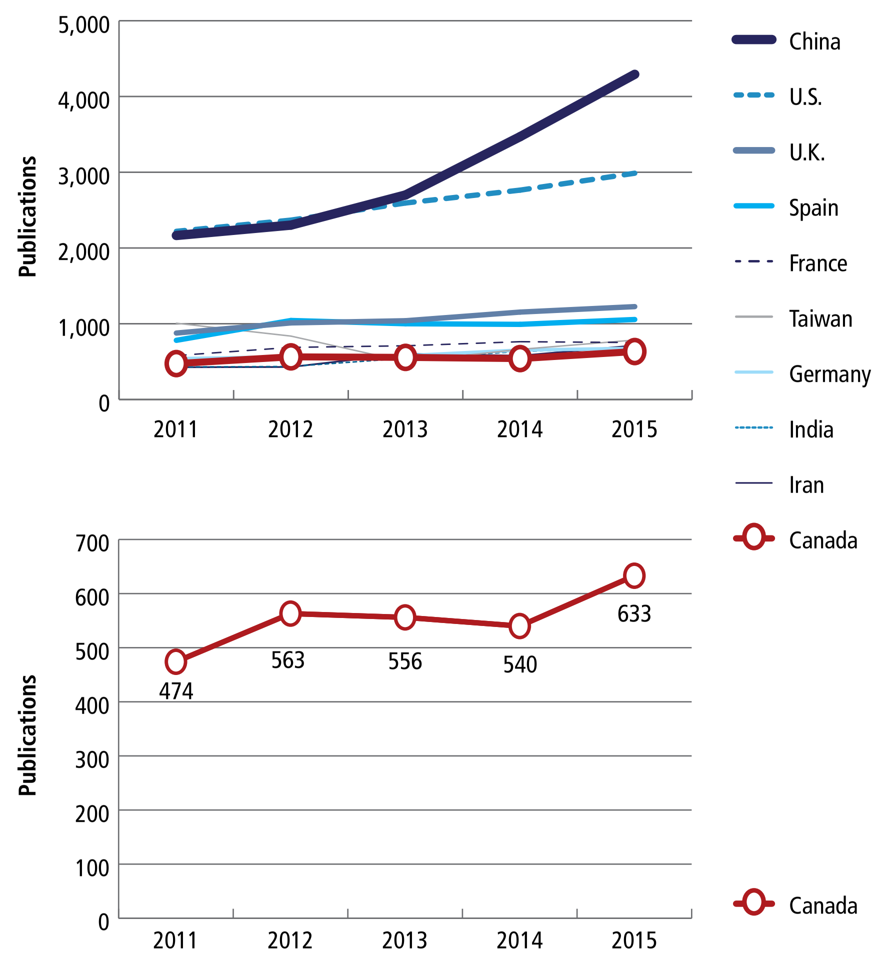
A4.1 Artificial Intelligence

This data set includes all publications containing the terms *Artificial Intelligence, Machine Learning* and *Neural Networks* (only when relevant to non-biological systems), combined with all articles from journals relating to Artificial Intelligence (as defined by the *Web of Science* subject category). This hybrid search strategy includes research into the field of artificial intelligence and research topics that utilize artificial intelligence techniques.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
China	14,930	120,442	8.1	2,715	34%
U.S.	12,933	110,957	8.6	2,074	48%
U.K.	5,308	49,206	9.3	949	61%
Spain	4,872	33,524	6.9	700	47%
France	3,492	27,563	7.9	494	53%
Taiwan	3,790	24,460	6.5	476	16%
Germany	3,009	24,852	8.3	455	57%
India	2,724	17,434	6.4	332	24%
Iran	2,751	17,621	6.4	403	43%
Canada	2,766	21,446	7.8	401	52%
Italy	2,650	17,074	6.4	359	51%
Australia	2,303	22,754	9.9	376	46%
Korea	2,201	12,580	5.7	253	36%
Turkey	2,120	13,789	6.5	259	22%
Japan	2,006	10,592	5.3	171	45%
Hong Kong	1,821	19,316	10.6	377	37%
Singapore	1,457	17,963	12.3	330	70%
Netherlands	1,304	10,897	8.4	204	49%
Brazil	1,270	6,504	5.1	141	32%
Poland	1,123	6,211	5.5	152	47%

Source: Web of Science/InCites, provided by Clarivate Analytics.



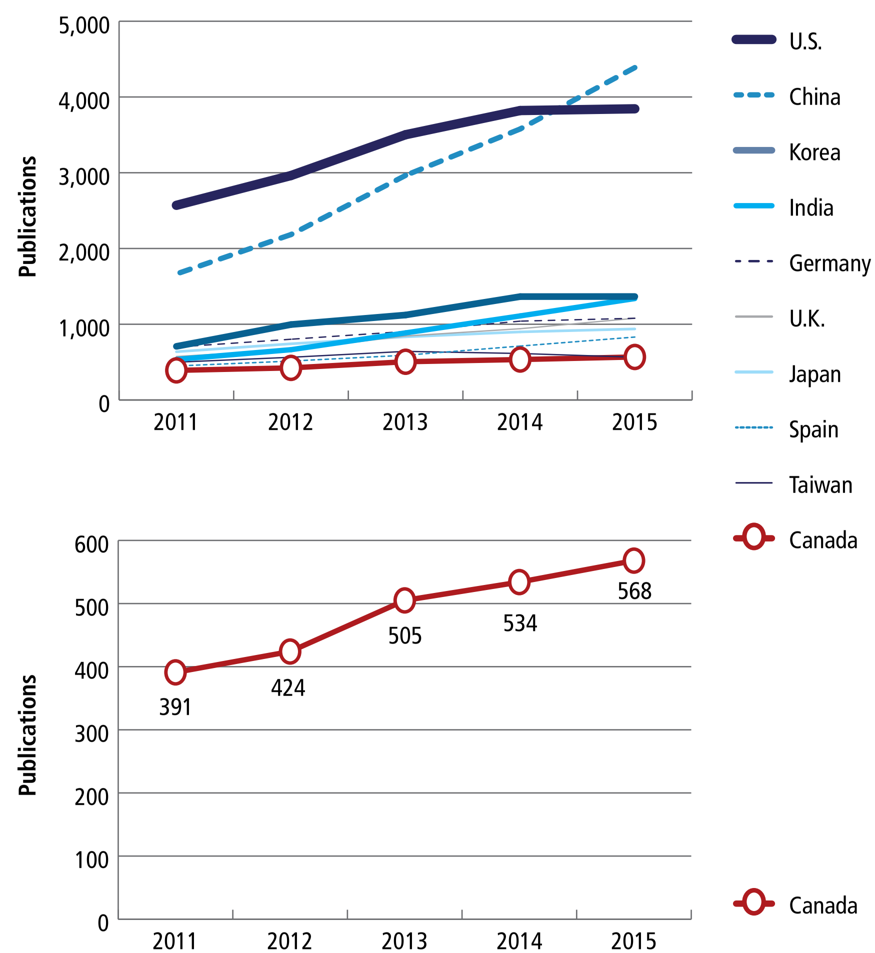
A4.2 Clean Tech

This data set includes all publications containing the terms relating to *Clean Tech, Green Tech, Green Chemistry, Sustainable Energy, Environmental Engineering, Solar Power, Wind Power, Biofuels* and others. It does not specifically contain search term relating to *Fuel Cells* as that term has many different applications. See section A4.3 for more information on Fuel Cell research.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
U.S.	16,700	295,583	17.7	4,280	36%
China	14,779	176,398	11.9	2,921	26%
Korea	5,557	57,601	10.4	819	26%
India	4,535	36,186	8.0	554	25%
Germany	4,526	67,644	14.9	996	49%
U.K.	4,102	68,541	16.7	973	57%
Japan	4,050	55,372	13.7	664	34%
Spain	3,097	39,209	12.7	639	46%
Taiwan	2,884	33,292	11.5	438	19%
Italy	2,798	36,977	13.2	572	40%
France	2,654	32,038	12.1	490	57%
Canada	2,422	35,263	14.6	522	46%
Australia	2,370	32,931	13.9	505	53%
Brazil	1,814	10,187	5.6	160	30%
Iran	1,655	11,483	6.9	257	21%
Netherlands	1,447	24,076	16.6	383	60%
Sweden	1,407	18,511	13.2	313	59%
Turkey	1,329	11,463	8.6	164	26%
Malaysia	1,278	13,746	10.8	205	46%
Singapore	1,248	24,629	19.7	337	52%

Source: Web of Science/InCites, provided by Clarivate Analytics.



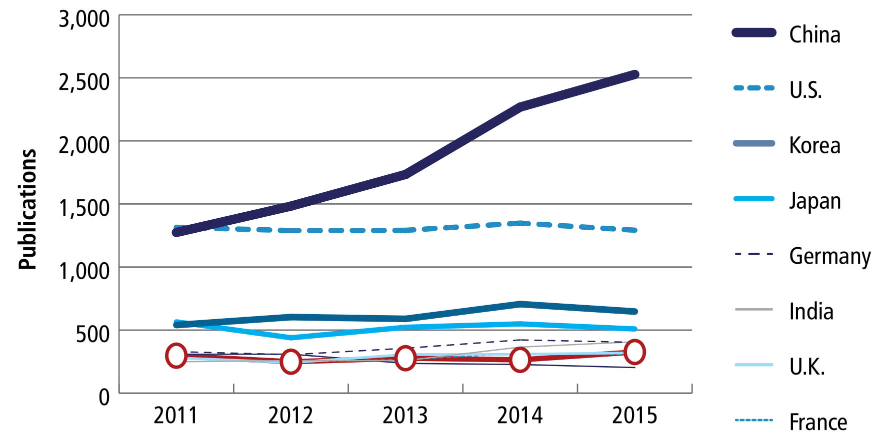
A4.3 Fuel Cells

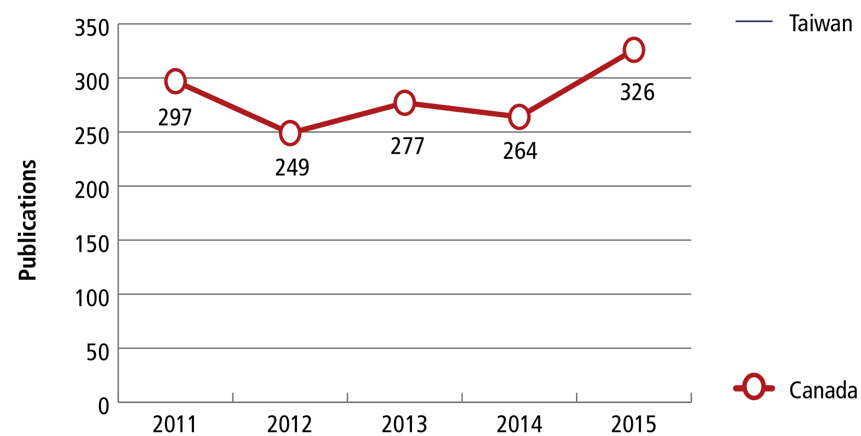
This data set is based only on papers that contain the term *Fuel Cell* and variants.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
China	9,286	108,404	11.7	1,513	27%
U.S.	6,535	104,767	16.0	1,305	38%
Korea	3,085	28,665	9.3	345	26%
Japan	2,584	24,415	9.4	258	30%
Germany	1,815	24,373	13.4	287	48%
India	1,537	12,166	7.9	156	22%
U.K.	1,456	16,960	11.6	211	53%
France	1,414	14,454	10.2	164	51%
Canada	1,413	20,372	14.4	232	43%
Taiwan	1,283	10,469	8.2	102	19%
Italy	1,186	11,545	9.7	146	44%
Spain	1,093	9,933	9.1	117	49%
Iran	863	6,074	7.0	107	19%
Australia	743	11,495	15.5	152	70%
Brazil	532	4,108	7.7	35	40%
Russia	532	2,496	4.7	22	37%
Denmark	524	6,396	12.2	102	46%
Singapore	475	9,780	20.6	126	59%
Turkey	435	2,959	6.8	40	27%
Switzerland	430	4,778	11.1	66	59%

Source: Web of Science/InCites, provided by Clarivate Analytics.





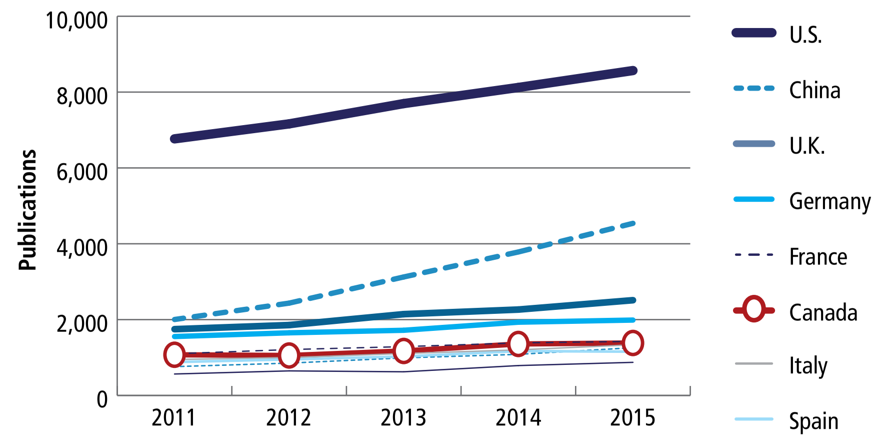
A4.4 Computer Science Applications

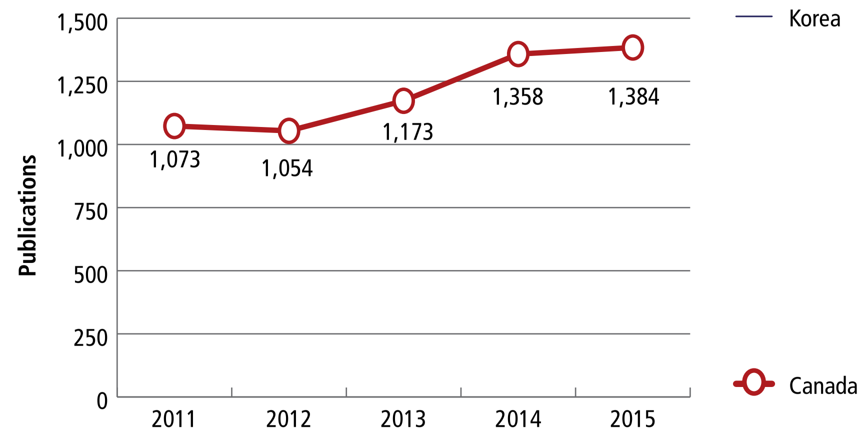
This data set contains publications that include terms such as *Big Data, Data Analysis, Data Mining, Computer Modelling* and *Algorithm* (when combined with Data or Computing). It will by nature contain overlap with the Artificial Intelligence research areas. The intention is to capture research that is utilizing computer science and data analysis rather than focus on research into computer science.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
U.S.	38,316	327,077	8.5	5,508	37%
China	15,886	71,520	4.5	1,509	35%
U.K.	10,525	91,808	8.7	1,629	60%
Germany	8,845	79,986	9.0	1,360	56%
France	6,409	53,660	8.4	911	62%
Canada	6,042	48,443	8.0	839	55%
Italy	5,592	46,785	8.4	814	53%
Spain	5,184	42,612	8.2	698	51%
Australia	4,948	38,407	7.8	776	58%
Korea	3,499	17,569	5.0	292	38%
Japan	3,479	43,570	12.5	327	43%
India	3,473	16,185	4.7	277	30%
Netherlands	3,380	38,020	11.2	641	65%
Taiwan	2,884	14,954	5.2	263	28%
Switzerland	2,782	31,177	11.2	529	71%
Brazil	2,774	11,651	4.2	176	36%
Iran	2,733	9,835	3.6	185	26%
Belgium	2,003	17,894	8.9	328	65%
Poland	1,943	12,642	6.5	238	39%
Russia	1,871	10,952	5.9	140	41%

Source: Web of Science/InCites, provided by Clarivate Analytics.





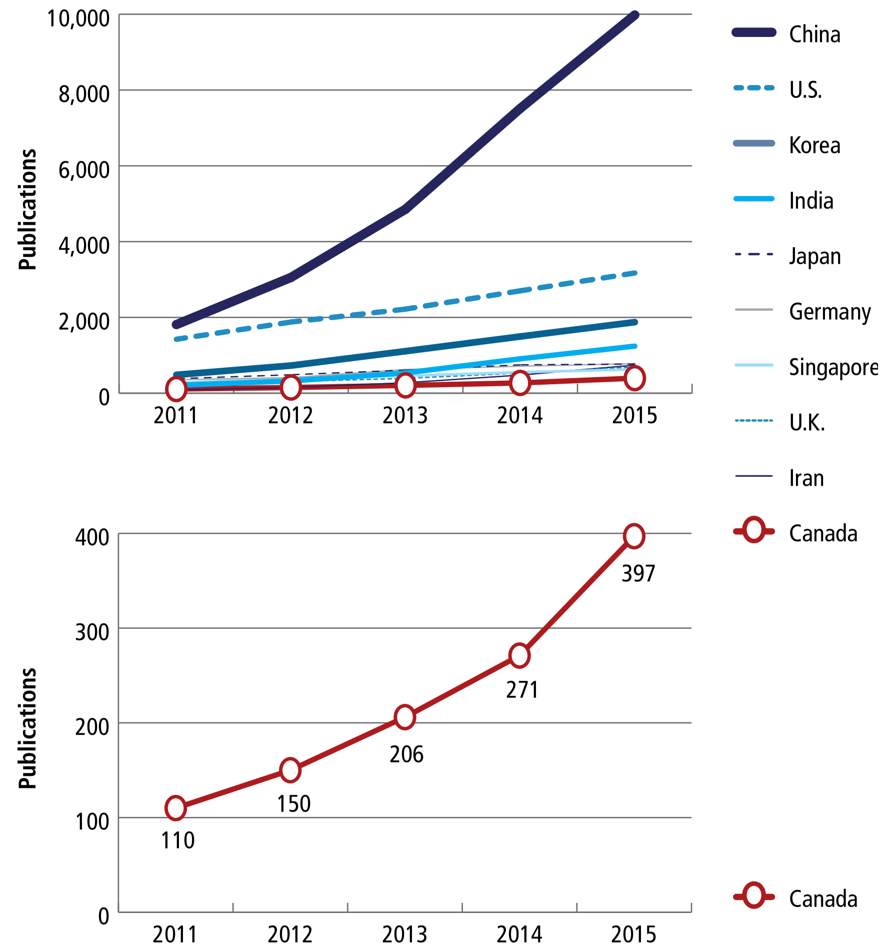
A4.5 Graphene

This data set contains all publications that include the keyword *Graphene* and variants.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
China	27,216	453,692	16.7	8,479	21%
U.S.	11,395	296,033	26.0	3,985	52%
Korea	5,694	93,497	16.4	1,546	31%
India	3,218	35,171	10.9	650	31%
Japan	2,997	45,454	15.2	668	50%
Germany	2,884	57,021	19.8	822	68%
Singapore	2,311	74,747	32.3	992	60%
U.K.	2,174	50,948	23.4	636	71%
Iran	1,732	12,225	7.1	316	23%
Australia	1,658	35,145	21.2	565	71%
Taiwan	1,654	26,739	16.2	431	34%
Spain	1,596	27,101	17.0	421	64%
France	1,528	24,534	16.1	357	73%
Russia	1,441	13,201	9.2	166	51%
Italy	1,426	19,884	13.9	287	62%
Hong Kong	1,153	21,563	18.7	404	27%
Canada	1,134	18,836	16.6	312	60%
Brazil	745	7,143	9.6	92	55%
Sweden	696	9,453	13.6	158	74%
Saudi Arabia	682	9,256	13.6	227	82%

Source: Web of Science/InCites, provided by Clarivate Analytics.



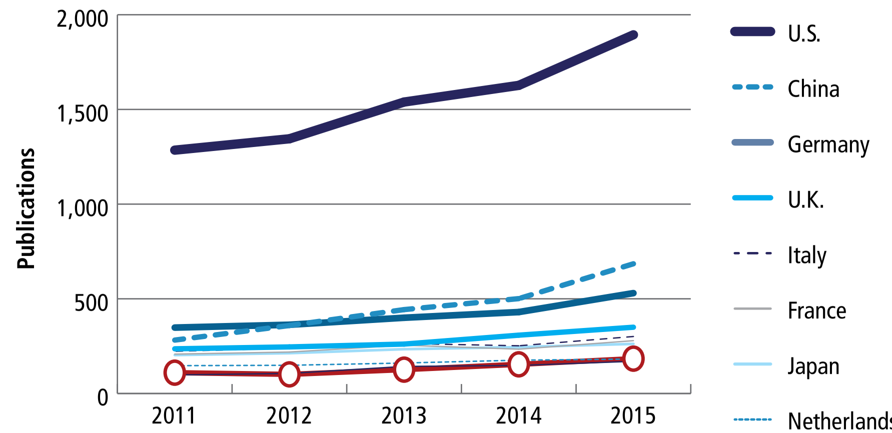
A4.6 Immunotherapy

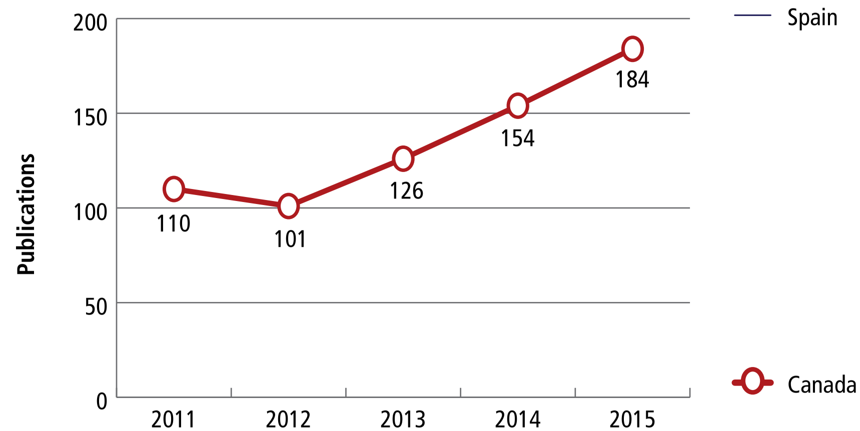
This data set contains all publications that include the keyword *Immunotherapy* and variants.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
U.S.	7,690	144,618	18.8	1,712	32%
China	2,270	15,867	7.0	183	26%
Germany	2,071	28,019	13.5	340	48%
U.K.	1,401	23,773	17.0	327	59%
Italy	1,279	18,152	14.2	214	46%
France	1,195	22,701	19.0	252	50%
Japan	1,157	12,808	11.1	149	28%
Netherlands	815	16,046	19.7	187	54%
Canada	675	12,367	18.3	138	57%
Spain	665	11,345	17.1	126	52%
Australia	583	12,147	20.8	144	52%
Switzerland	538	10,165	18.9	141	71%
Korea	411	3,919	9.5	46	26%
Belgium	401	7,765	19.4	82	63%
Sweden	363	5,596	15.4	79	67%
Austria	345	5,666	16.4	71	70%
India	287	2,723	9.5	18	23%
Poland	272	3,911	14.4	42	37%
Denmark	254	4,586	18.1	62	65%
Brazil	239	2,403	10.1	27	46%

Source: Web of Science/InCites, provided by Clarivate Analytics.





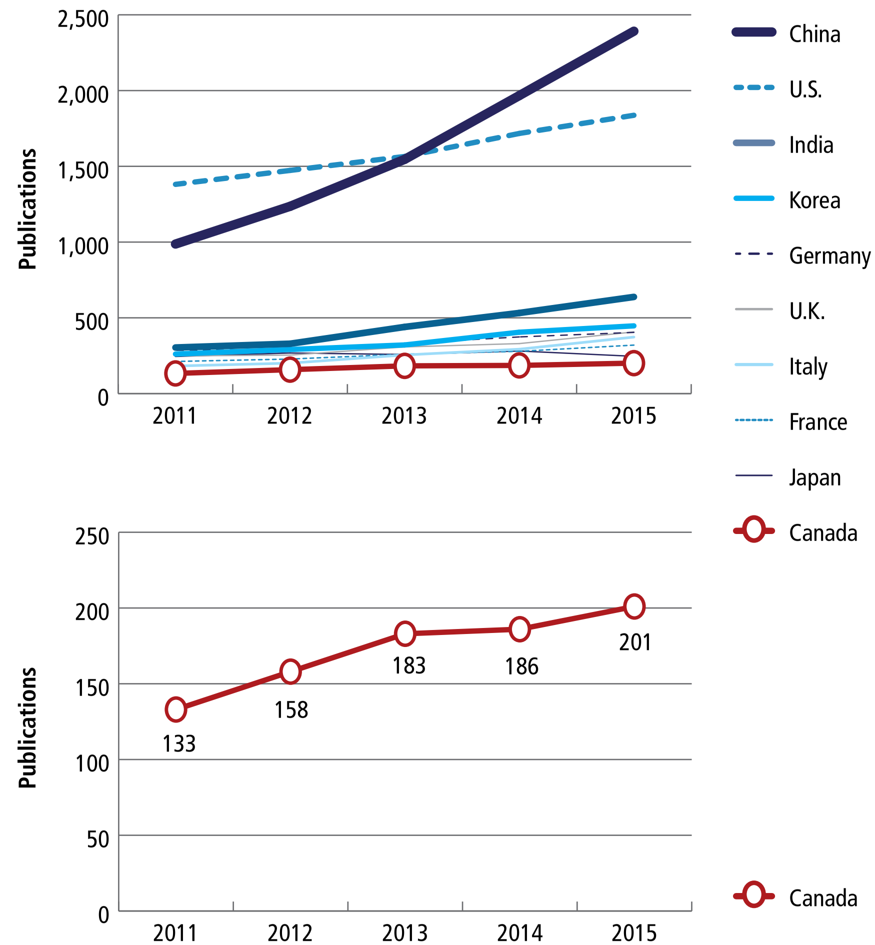
A4.7 Nanotech

This data set contains all publications that include the keywords *Nanotechnology*, *Nanoengineering* or *Nanomaterials* and variants.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
China	8,128	118,611	14.6	1,821	25%
U.S.	7,973	152,871	19.2	2,054	38%
India	2,243	21,957	9.8	353	27%
Korea	1,725	24,231	14.0	308	33%
Germany	1,687	27,418	16.3	383	60%
U.K.	1,548	25,747	16.6	381	64%
Italy	1,304	15,121	11.6	253	49%
France	1,299	17,804	13.7	258	57%
Japan	1,298	19,134	14.7	185	37%
Spain	1,095	15,595	14.2	229	54%
Australia	895	15,695	17.5	229	57%
Canada	861	13,874	16.1	188	47%
Iran	860	7,553	8.8	121	25%
Singapore	718	19,821	27.6	289	54%
Taiwan	644	7,433	11.5	104	32%
Brazil	621	4,256	6.9	60	30%
Russia	603	3,228	5.4	49	35%
Switzerland	528	9,298	17.6	149	60%
Poland	493	3,393	6.9	56	42%
Saudi Arabia	486	5,264	10.8	98	78%

Source: Web of Science/InCites, provided by Clarivate Analytics.



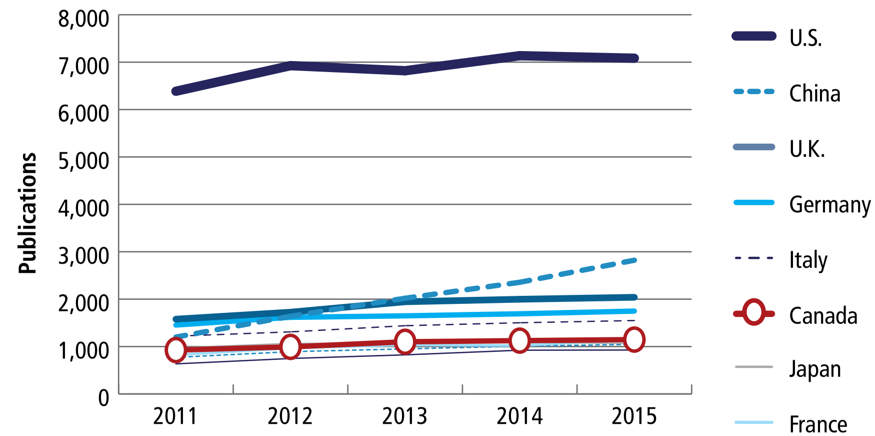
A4.8 Neurodegeneration

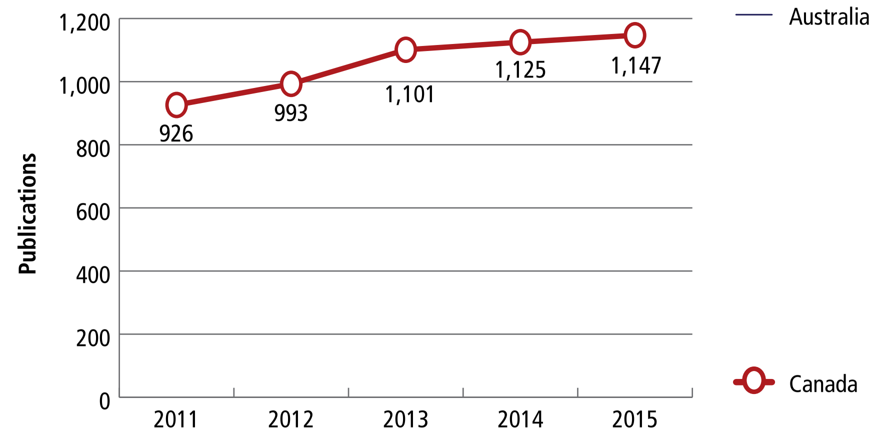
This data set contains all publications that include the keywords *Neurodegeneration, Alzheimer, Parkinson, Huntington* or *Lewy Body* and variants.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
U.S.	34,350	503,910	14.7	7,259	37%
China	10,035	77,268	7.7	1,116	30%
U.K.	9,285	148,142	16.0	2,181	61%
Germany	8,158	108,448	13.3	1,544	57%
Italy	7,020	84,888	12.1	1,151	45%
Canada	5,292	76,909	14.5	1,008	54%
Japan	5,265	52,424	10.0	594	29%
France	4,995	67,673	13.5	963	56%
Spain	4,669	54,088	11.6	821	46%
Australia	4,058	55,238	13.6	785	50%
Korea	3,530	26,821	7.6	331	28%
Netherlands	3,258	53,519	16.4	782	61%
Sweden	2,950	44,882	15.2	663	70%
India	2,505	19,987	8.0	240	24%
Brazil	2,129	16,435	7.7	199	38%
Switzerland	2,073	30,421	14.7	498	75%
Taiwan	1,610	11,732	7.3	161	26%
Belgium	1,449	23,597	16.3	307	69%
Poland	1,417	13,617	9.6	158	41%
Israel	1,240	18,125	14.6	215	55%

Source: Web of Science/InCites, provided by Clarivate Analytics.





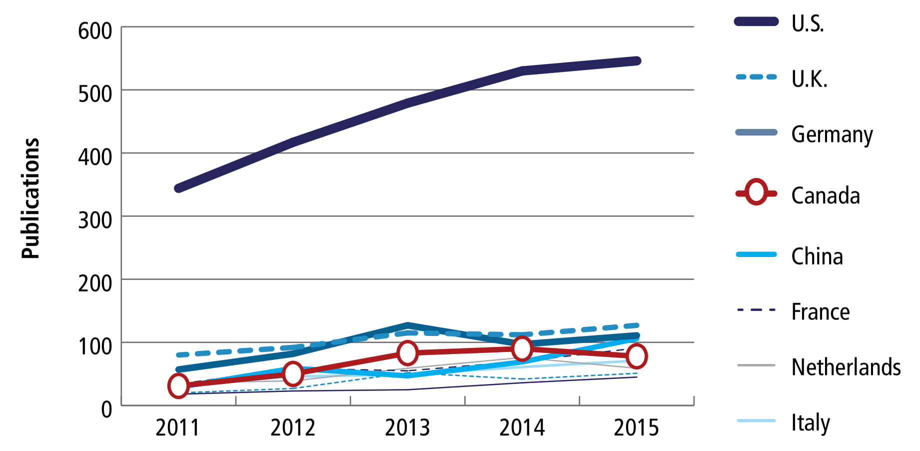
A4.9 Personalized Medicine

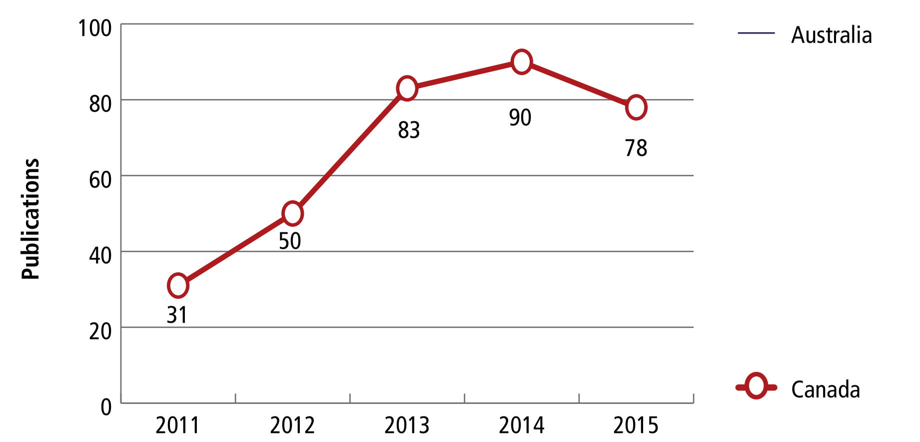
This data set contains all publications that contain the keywords *Personalized Medicine* or *Molecular Medicine* and variants. Because of the small size of this data set, there may be more variance in the comparisons than is observed for the other larger data sets.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
U.S.	2,316	30,792	13.3	415	29%
U.K.	526	9,293	17.7	107	53%
Germany	474	4,366	9.2	61	44%
Canada	332	3,143	9.5	51	48%
China	310	3,267	10.5	51	45%
France	309	3,351	10.8	44	43%
Netherlands	269	3,078	11.4	43	60%
Italy	259	3,184	12.3	44	54%
Spain	192	2,618	13.6	35	56%
Australia	147	1,401	9.5	29	59%
Switzerland	137	1,902	13.9	26	69%
Japan	134	1,496	11.2	17	36%
Sweden	114	1,333	11.7	19	75%
Korea	105	1,384	13.2	13	33%
Belgium	102	1,038	10.2	20	66%
Denmark	70	2,680	38.3	14	73%
Greece	67	560	8.4	9	63%
India	65	314	4.8	1	38%
Austria	63	925	14.7	20	78%
Israel	63	1,140	18.1	12	40%

Source: Web of Science/InCites, provided by Clarivate Analytics.





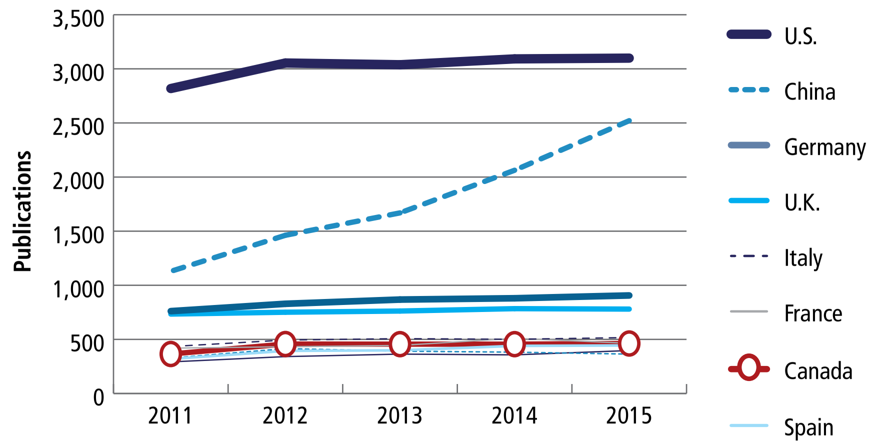
A4.10 Proteomics & Bioinformatics

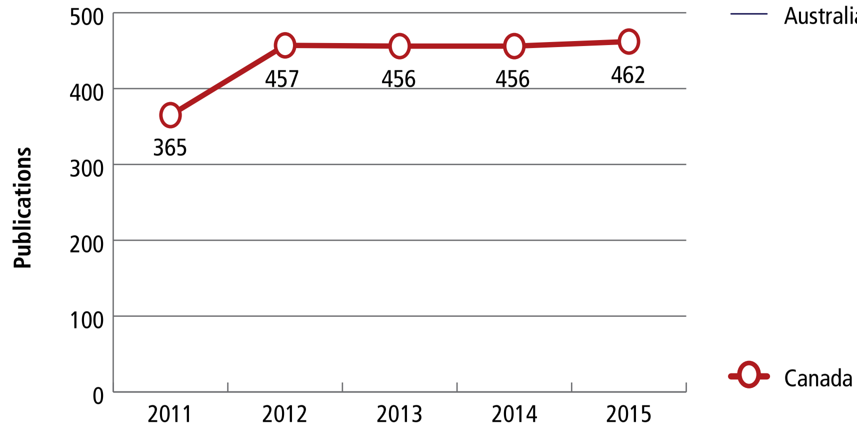
This data set contains all publications that include the keywords *Proteomics* or *Bioinformatics* and variants.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
U.S.	15,101	213,401	14.1	2,806	40%
China	8,844	57,136	6.5	896	23%
Germany	4,244	64,153	15.1	888	59%
U.K.	3,811	55,044	14.4	781	64%
Italy	2,453	23,568	9.6	298	48%
France	2,269	26,544	11.7	370	59%
Canada	2,196	27,753	12.6	395	54%
Spain	1,996	20,158	10.1	288	54%
Japan	1,879	38,756	20.6	197	37%
Australia	1,751	20,944	12.0	303	60%
Korea	1,453	9,963	6.9	110	34%
India	1,444	9,660	6.7	99	32%
Netherlands	1,429	21,005	14.7	301	68%
Switzerland	1,155	20,531	17.8	283	75%
Sweden	1,085	13,820	12.7	189	69%
Brazil	1,006	6,446	6.4	87	48%
Taiwan	883	6,256	7.1	71	27%
Denmark	867	13,902	16.0	199	75%
Belgium	830	9,755	11.8	151	69%
Austria	617	9,154	14.8	126	70%

Source: Web of Science/InCites, provided by Clarivate Analytics.





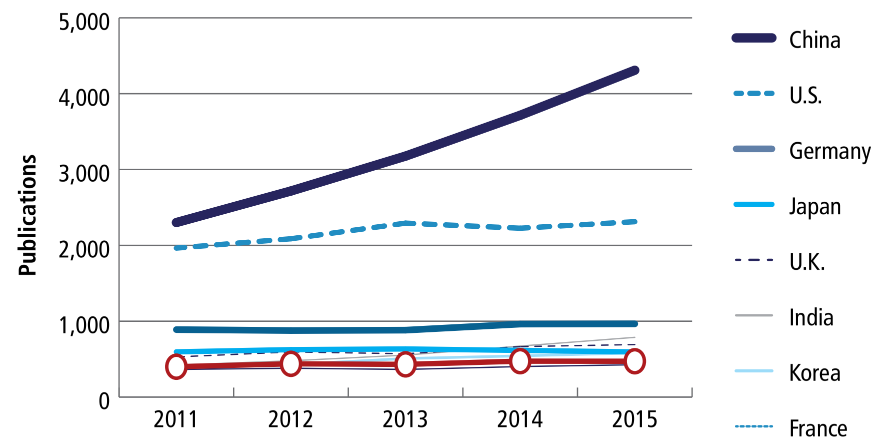
A4.11 Quantum Science

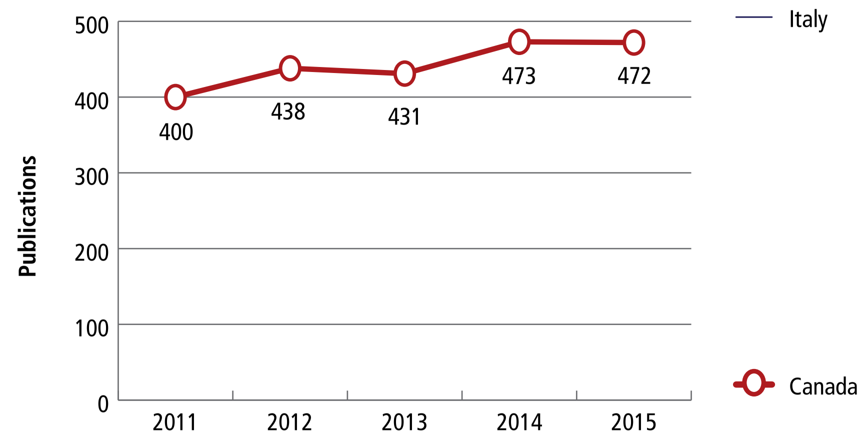
This data set contains all publications that include the keywords *Quantum Dot, Quantum Teleportation, Quantum Entanglement, Quantum Computing, Quantum Cryptography* or *Quantum Information* and other quantum effects.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
China	16,219	199,825	12.3	2,958	20%
U.S.	10,882	197,946	18.2	2,492	45%
Germany	4,575	66,381	14.5	895	65%
Japan	3,065	35,068	11.4	451	41%
U.K.	3,052	48,468	15.9	692	68%
India	2,912	25,001	8.6	331	26%
Korea	2,467	30,024	12.2	379	37%
France	2,215	30,921	14.0	421	65%
Canada	2,214	37,166	16.8	529	60%
Italy	1,936	22,895	11.8	333	58%
Russia	1,883	10,421	5.5	113	45%
Spain	1,810	29,676	16.4	380	66%
Australia	1,419	22,652	16.0	313	67%
Singapore	1,186	23,284	19.6	319	73%
Taiwan	1,142	13,190	11.5	177	32%
Iran	1,139	7,551	6.6	102	18%
Switzerland	1,066	22,420	21.0	322	71%
Poland	1,048	7,431	7.1	92	49%
Brazil	921	7,068	7.7	96	46%
Netherlands	801	16,848	21.0	208	74%

Source: Web of Science/InCites, provided by Clarivate Analytics.





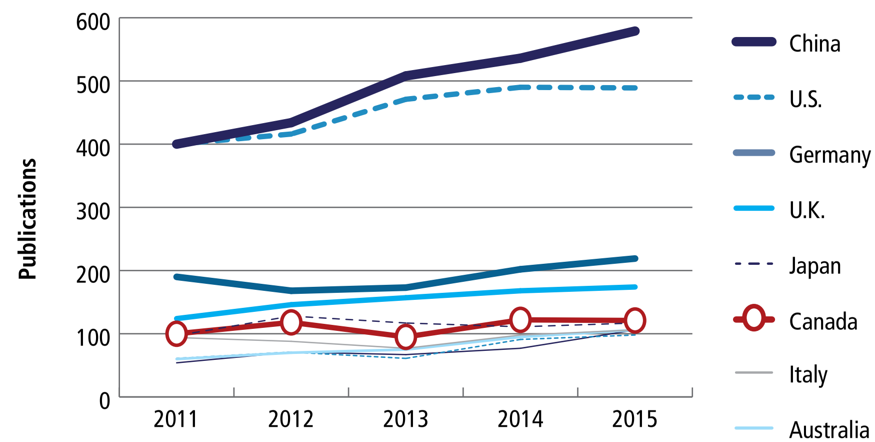
A4.12 Quantum Computing

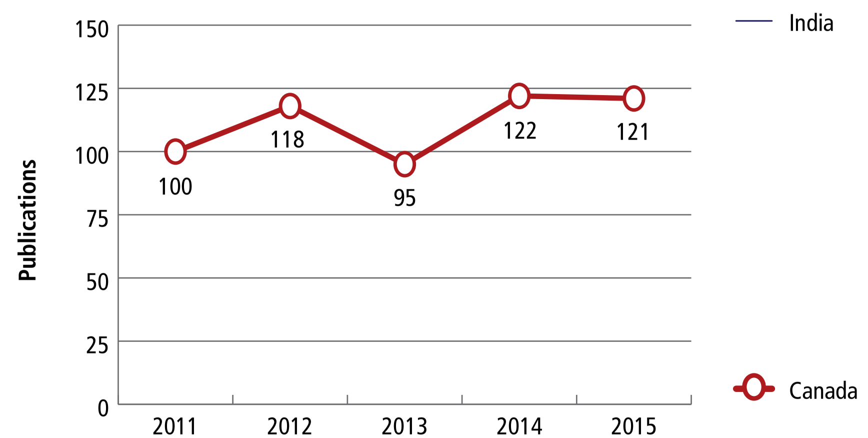
This data set contains all publications that include the keywords *Quantum Computing* and variants. Because of the small size of this data set, there may be more variance in the comparisons than is observed for the other larger data sets.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
China	2,457	14,612	5.9	271	24%
U.S.	2,266	33,035	14.6	521	48%
Germany	952	14,475	15.2	234	66%
U.K.	769	10,177	13.2	199	70%
Japan	570	6,284	11.0	96	58%
Canada	556	6,944	12.5	111	65%
Italy	463	4,446	9.6	85	57%
Australia	406	6,094	15.0	101	67%
France	382	4,564	11.9	83	66%
India	376	1,862	5.0	39	31%
Spain	355	4,434	12.5	70	72%
Russia	281	1,338	4.8	26	45%
Singapore	254	2,209	8.7	45	82%
Poland	241	1,579	6.6	28	53%
Brazil	232	1,892	8.2	35	44%
Switzerland	225	4,026	17.9	82	73%
Korea	185	1,294	7.0	21	55%
Austria	175	3,538	20.2	48	74%
Iran	174	578	3.3	10	18%
Netherlands	141	2,899	20.6	49	73%

Source: Web of Science/InCites, provided by Clarivate Analytics.





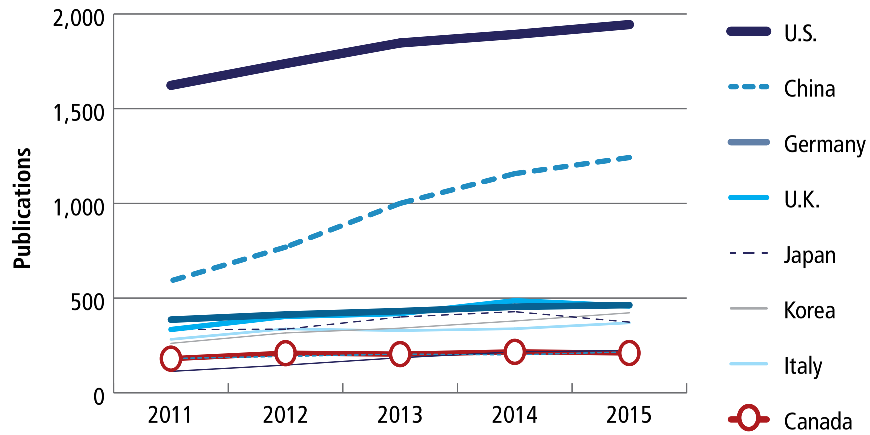
A4.13 Regenerative Medicine

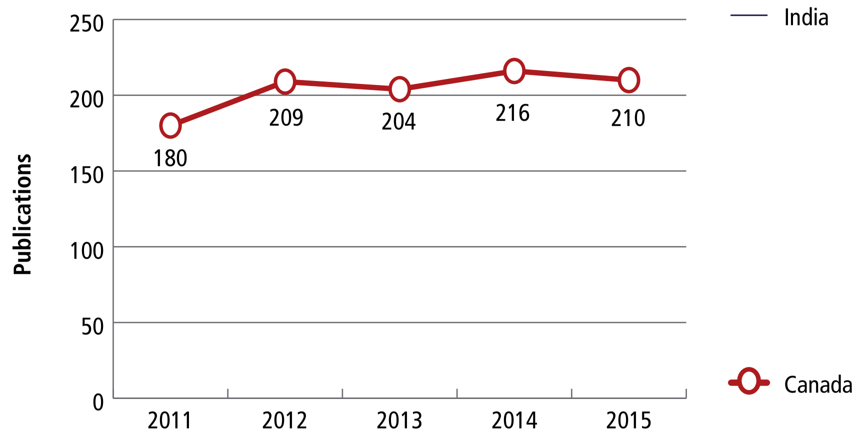
This data set contains all publications that include the keywords *Regenerative Medicine, Tissue Engineering* or *Cell Therapy* and variants.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
U.S.	9,044	133,428	14.8	1,971	34%
China	4,759	41,491	8.7	651	28%
Germany	2,147	22,624	10.5	328	50%
U.K.	2,099	23,381	11.1	346	52%
Japan	1,870	19,409	10.4	261	30%
Korea	1,719	17,671	10.3	268	32%
Italy	1,654	18,961	11.5	283	43%
Canada	1,019	11,010	10.8	155	43%
France	993	10,348	10.4	143	47%
India	883	8,690	9.8	130	32%
Australia	882	11,053	12.5	172	53%
Spain	879	9,161	10.4	129	45%
Netherlands	827	11,048	13.4	158	52%
Iran	706	5,135	7.3	80	24%
Switzerland	597	6,723	11.3	125	66%
Singapore	594	7,610	12.8	114	55%
Taiwan	592	5,630	9.5	89	29%
Brazil	537	3,495	6.5	43	31%
Portugal	504	6,576	13.0	101	49%
Belgium	406	5,486	13.5	69	57%

Source: Web of Science/InCites, provided by Clarivate Analytics.





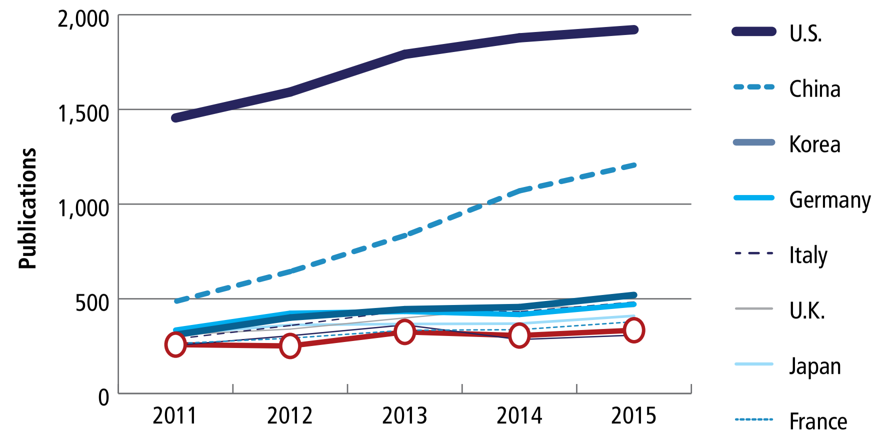
A4.14 Robotics & Mechatronics

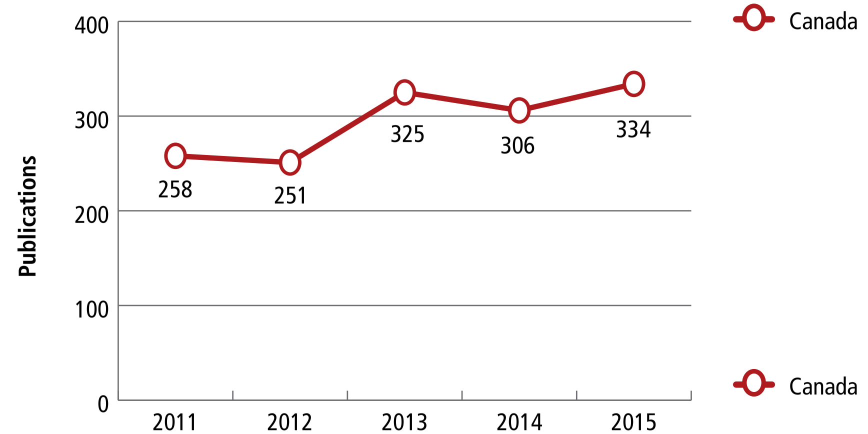
This data set contains all publications that include the keywords *Robotics* and *Mechatronics* and variants.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
U.S.	8,637	63,846	7.4	1,411	30%
China	4,240	14,586	3.4	355	32%
Korea	2,132	9,812	4.6	214	25%
Germany	2,080	13,648	6.6	294	47%
Italy	2,000	13,858	6.9	345	48%
U.K.	1,963	12,456	6.3	278	56%
Japan	1,822	6,838	3.8	134	32%
France	1,606	8,212	5.1	186	48%
Spain	1,514	6,754	4.5	154	37%
Canada	1,474	7,882	5.3	176	48%
Taiwan	802	3,321	4.1	81	13%
Australia	775	5,774	7.5	109	49%
Switzerland	745	6,035	8.1	142	60%
Iran	611	1,755	2.9	42	23%
Netherlands	572	4,708	8.2	88	55%
Turkey	516	2,062	4.0	52	30%
Mexico	500	1,797	3.6	38	34%
India	491	1,705	3.5	49	34%
Singapore	420	2,351	5.6	70	63%
Belgium	416	3,557	8.6	86	65%

Source: Web of Science/InCites, provided by Clarivate Analytics.





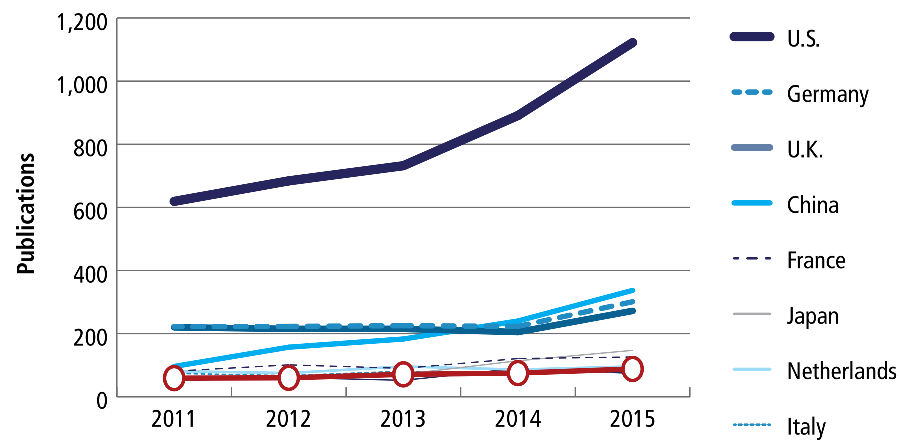
A4.15 Next Generation Genomics

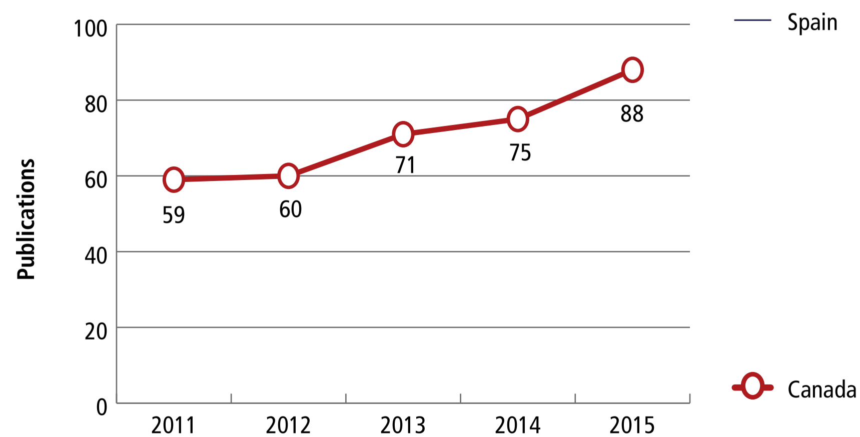
This data set contains all publications that contain the keywords *Systems Biology, CRISPR, CAS Systems, Genome Editing* or *Genome Engineering* and variants. Because of the small size of this data set, there may be more variance in the comparisons than is observed for the other larger data sets.

Key performance indicators:

Countries	Publications	Citations	Citations / Publication	Top Cited Publications	International Collaboration
U.S.	4,048	85,561	21.1	1,176	35%
Germany	1,194	20,042	16.8	285	55%
U.K.	1,127	18,799	16.7	262	63%
China	1,013	13,462	13.3	229	41%
France	519	10,415	20.1	136	65%
Japan	447	5,330	11.9	94	31%
Netherlands	434	8,297	19.1	112	64%
Italy	376	4,025	10.7	59	53%
Canada	353	7,081	20.1	103	59%
Spain	328	4,471	13.6	65	61%
Switzerland	307	6,145	20.0	88	67%
Australia	277	2,967	10.7	60	61%
Sweden	228	6,752	29.6	71	76%
Denmark	214	3,298	15.4	59	79%
Korea	190	3,510	18.5	52	41%
India	176	1,227	7.0	21	38%
Austria	153	4,089	26.7	40	69%
Israel	145	3,158	21.8	39	63%
Belgium	135	2,314	17.1	39	70%
Taiwan	105	972	9.3	11	28%

Source: Web of Science/InCites, provided by Clarivate Analytics.





Annex A: Data Sources, Methodology, and Indicator Definitions

Source:

- Clarivate Analytics, InCites™, accessed July 20 to November 17, 2016.
- Publications are limited to those published between 2011 and 2015 (five years) and original Research Articles or Review Articles.
- Databases used: Science Citation Index Expanded, Social Science Citation Index, Arts & Humanities Citation Index.

Methods:

- Keywords were used to search Clarivate Analytics Web of Science™ records. The results were exported from the Web of Science to InCites. InCites provides additional data cleaning, unification and benchmarking of indicators.
- Article and citation counts are based on the "whole counting" method where each paper is fully counted towards each country regardless of co-authorship.
- For details of the coverage of the Web of Science, including scope notes of subject areas, please see: http://ip-science.thomsonreuters.com/mjl/

Definitions of indicators:

Indicator	Definition	Significance / Comments
Publications	Total number of research articles and review papers associated with that country.	A broad indicator of research output. Scholars in different disciplines will have different publication behaviour, for example scholars in the life and medical sciences will typically publisher more than engineers, therefore comparisons between research areas are not recommended.
Citations	The total number of times the publications were cited by other publications.	An indication of the total influence and impact that the research has had upon the broader research community. Citations rates will vary for different disciplines.
Citations / Publication	The total number of citations divided by the total number of publications.	An indication of how impactful the research has been regardless of volume.
Top Cited Publications	The total number of publications that are among the most cited (top 10%) compared to papers that are in the same research area (Web of Science subject categories) and publication year.	An indication of the volume of excellence in research that is normalized for subject mix and the age of publication.
International Collaboration	The percentage of publications that contain one or more co-authors from outside of Canada.	An indication that the paper is of international significance. International collaborations may be influenced by a number of factors such as geographical location, language and the domestic research capacity. Caution should be used when comparing entities in different countries.

Annex B: Keywords and Search Syntax for Emerging Research Areas

The following search queries were used for the Emerging Research Area profiles.

Artificial Intelligence:
TS = ("machine learning" OR "artificial* intelligen*" OR ("neural net*" AND ("comput* OR artificial* OR algorith* or software"))) OR WC = "Computer Science, Artificial Intelligence"

Clean Tech:
TS = (cleantech* OR "clean tech*" OR "clean energy" OR "clean chemi*" OR "green tech*" OR "green energy" OR "green chemi*" OR "environment* entrepren*" OR "environment* engineer*" OR "sustainable industr*" OR "sustainable energy" OR "low emission" OR "zero emission" OR "solar power" OR "solar energy" OR "solar cell" OR "photovoltaic" OR "photo voltaic" OR biofuel OR "wind power" OR "wind turbine" OR "hydro power" OR "hydroelectric" OR "hydro electric")

Fuel Cells:
TS = "Fuel cell*"

Computer Science Applications:
TS = ("big data" OR "data analy*" OR "data mining" OR "high performance computing" OR "predictive analy*" OR algorithm* NEAR/5 data OR algorithm* NEAR/5 comput* OR model* NEAR/5 comput* OR data NEAR/5 visuali*)

Graphene:
TS = (Graphene OR "Carbon Nanoplate*" OR "Carbon Nanoribbon*" OR "Carbon Nanosheet*")

Immunotherapy:
TS = (immunotherap* OR "chimeric antigen receptor*" OR ((car OR cars) NEAR/5 ("t-cell" OR "t-cells")) OR (therapy AND ("pd-1" OR "ctla-4" OR "pd-l1" OR "41BB" OR "Tim-3" OR "LAG-3")) OR "checkpoint blockade" OR "adoptive t-cell therapy" OR "TCR transduction")

Nanotech:
TS = (nanotech* OR nanoeng* OR nanomater*)

Neurodegeneration:
TS = (huntington* OR parkinson* OR alzheimer* OR "lewy bod*" OR neurodegenerat*)

Personalized Medicine:
TS = ("molecular* medic*" OR "personal* medic*")

Proteomics & Bioinformatics:
TS = (proteomic* OR bioinformatic*)

Quantum Science:
TS = ((quantum NEAR/5 comput*) OR qubit OR "quantum crypt*" OR "quantum informat*" OR "quantum communic*" OR "quantum key*" OR "quantum security" OR "quantum dot*" OR (quantum NEAR/5 photo*) OR "quantum entangle*" OR "photon entangle*" OR "quantum superposit*" OR "quantum teleport*" OR "quantum metro*" OR "quantum squeez*" OR "quantum control" OR "quantum device*" OR "quantum measure*")

Quantum Computing:

TS = ((quantum near/5 comput*) OR qubit)

Regenerative Medicine:

TS = ("regenerat* medic*" OR "tissue engineer*" OR "cell therap*")

Robotics & Mechatronics:

TS = (robot* OR mechatron*) OR WC= "Robotics"

Next Generation Genomics:

TS = ("Systems biology" OR CRISPR OR CAS9 OR "Cas system*" OR "Genome edit*" OR "Genome engineer*")

Notes:

- TS = Topic Search: searches the titles, abstracts, keywords and KeyWords + of the articles.
- WC = Web of Science Subject Category.
- * = truncation, will search any character, combination of characters, or no characters. For example, "Comput*" will retrieve computer, computers, computed, computing, computational etc.
- The Web of Science search engine uses standard Boolean operators such as OR, AND and NOT, but also uses a proximity operator known as NEAR. The number following the operator indicators the level of proximity, for example NEAR/5 will only retrieve results when the two search terms are five words or fewer away from each other.
- Because the Web of Science is a dynamic database and corrections may be applied at any time, slight differences in publication counts may be observed. Citation counts accumulate over time and will not be consistent with this report.

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