Powering Discovery

The Expert Panel on International Practices for Funding Natural Sciences and Engineering Research

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The Council Of Canadian Academies
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The project that is the subject of this report was undertaken with the approval of the Board of Directors of the Council of Canadian Academies (CCA). Board members are drawn from the Royal Society of Canada (RSC), the Canadian Academy of Engineering (CAE), and the Canadian Academy of Health Sciences (CAHS), as well as from the general public. The members of the expert panel responsible for the report were selected by the CCA for their special competencies and with regard for appropriate balance.

This report was prepared in response to a request from the Natural Sciences and Engineering Research Council of Canada (NSERC). Any opinions, findings, or conclusions expressed in this publication are those of the authors, The Expert Panel on International Practices for Funding Natural Sciences and Engineering Research, and do not necessarily represent the views of their organizations of affiliation or employment, or the sponsoring organization, NSERC.

Library and Archives Canada

ISBN: 978-1-926522-91-3 (book)
978-1-926522-90-6 (electronic book)

This report should be cited as:

Council of Canadian Academies, 2021. *Powering Discovery*, Ottawa (ON). The Expert Panel on International Practices for Funding Natural Sciences and Engineering Research, Council of Canadian Academies.

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This assessment was made possible with the support of the Government of Canada

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The Expert Panel on International Practices for Funding Natural Sciences and Engineering Research

Under the guidance of its Scientific Advisory Committee, Board of Directors, and founding Academies, the CCA assembled the Expert Panel on International Practices for Funding Natural Sciences and Engineering Research to undertake this project. Each Panel member was selected for their expertise, experience, and demonstrated leadership in fields relevant to this project.

Shirley M. Tilghman, O.C., FRS (Chair), President Emeritus and Professor, Molecular Biology and Public Affairs, Princeton University (Princeton, NJ)

Janice Bailey, Scientific Director, Fonds de recherche du Québec – Nature et technologie (FRQNT) (Québec, QC)

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Denis Thérien, Vice-President Research and Partnerships, ServiceNow Element AI (Montréal, QC)

Message from the President and CEO

When NSERC first approached the CCA in early 2020 about conducting an assessment on research funding practices, we agreed to do so with the same enthusiasm and seriousness we apply to every project. Indeed, having recently completed reports on the increasing risks from climate change and the frightening consequences of antimicrobial resistance, we were looking forward to focusing on a topic that was less ominous. One challenge we had not anticipated, however, was undertaking an assessment during a global pandemic.

By the time the Panel first convened in the spring of 2020, the world had changed. COVID-19 had forcefully disrupted daily life in Canada and around the world, limiting travel, commerce, education, family, and professional life. It constrained our existence and interfered with the social systems, institutions, and exchanges that society so crucially depends on. We continue to witness its devastating impact, knowing this is a tragedy that we, as Canadians and as global citizens, will be grappling with for years to come.

Yet while COVID-19 changed many things, it did not change everything. It did not eliminate the need for research of the type funded by NSERC. On the contrary, the pandemic underscored just how vital scientists and their work are to safeguarding society (from threats known and unknown), and how challenging it is for funders to balance responding to immediate needs with preserving support for fundamental, curiosity-driven research. Such agencies face complicated decisions when considering how to structure their funding programs and maximize their impact. NSERC's interest in ensuring its funding approaches are grounded in the best available evidence, guided by experts with experience across a wide variety of funding systems and research domains, is very much to its credit.

A second thing that COVID-19 did not change, thankfully, is the CCA's ability to do what we do best: convene experts, assess evidence, and inform decisions. Since March 2020, the CCA, like many organizations, has been operating in the virtual environment. This is the CCA's first assessment undertaken entirely online. With CCA staff in Ottawa and Victoria, and with panel members on three continents spanning multiple time zones, the assessment was not delayed at any stage. I am awestruck by the professionalism of our staff and the rigour of the Panel, led expertly by Shirley M. Tilghman. In thanking the Panel for its work, I also extend gratitude and appreciation to NSERC for referring this assessment to the CCA. The future we all face will be shaped by the research supported by funding agencies like NSERC, and I have no doubt that the insights in this report will prove their value as a guide to this critically important work for many years to come.

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

Message from the Chair

Science and engineering play essential roles in modern society. Discoveries made decades ago underpin the technologies we now use routinely in our day-to-day lives, while others wait in the wings for opportunities to catalyze future breakthroughs. Science also calls upon our curiosity and captures our imagination, continually reminding society of what remains unknown as researchers re-draw the map of human knowledge to extend its boundaries and trace new paths.

The organizations tasked with supporting natural sciences and engineering research, however, face formidable challenges today. Even as public investment in research has slowed in many countries, the remit of many funding agencies has expanded. New programs are created and old ones are adapted or eliminated, often in response to the societal needs of the day. Recent efforts to confront the COVID-19 pandemic epitomized this process, underscoring the importance of flexibility as funders pivoted to accelerate research that addressed immediate needs, without forgetting the fundamental, curiosity-driven research of the kind that made novel mRNA-based vaccines possible. Funding agencies also inhabit a central position in the research landscape, affording them a unique ability to promote scientific norms and support a robust and resilient workforce at a time when once-standard conventions and practices are increasingly being challenged.

This report highlights many practices used internationally to achieve these and other goals, as well as the tensions and trade-offs that accompany them. Drawing on experiences from a diverse range of funding agencies and countries, our report depicts a spectrum of approaches for supporting researchers and different kinds of research. It also sheds light on promising and novel approaches for reducing administrative burdens, increasing funding efficiency, and promoting and measuring impact, while stressing how limited and partial the evidence is for assessing these approaches. Of course, not all practices work in every context. Differences across countries are unavoidable, and often make it difficult to identify ready-made "best practices." Nevertheless, regardless of jurisdiction or circumstance, today's research funders share many of the same challenges, and the practices described here offer promising avenues for experimentation by both Canadian funding agencies and their international counterparts.

It was my great pleasure to lead this expert panel, which made the most of a virtual format, and also made steady progress despite challenging circumstances. I would like to thank my colleagues on the Panel for the perspectives and insights they shared during our enriching discussions. Without exception, panellists spoke passionately of the opportunities ahead for funding agencies, and I speak for the Panel in saying that I look forward to observing how the discussion unfolds.

Shirley M. Tilghman, PhD, O.C., FRS
Chair, The Expert Panel on International Practices for Funding Natural Sciences and Engineering Research

Acknowledgements

Over the course of its deliberations, the Panel reached out to a number of individuals who shared their experiences and knowledge. The Panel wishes to thank the following people for their participation:

Carlos Henrique de Brito Cruz, Senior VP Research Networks, Elsevier; Professor, Physics Institute, Unicamp; former Scientific Director of the São Paulo Research Foundation (FAPESP), Brazil

Wei Yang Cheong, Deputy Secretary (Special Projects), Ministry of Health, Singapore; former Deputy CEO of the National Research Foundation, Singapore

Andrew Cleland, Chief Executive, Royal Society Te Apārangi, New Zealand

Suzanne Fortier, Principal and Vice-Chancellor, McGill University, Canada

Peter Strohschneider, former President, Deutsche Forschungsgemeinschaft (DFG), Germany

Wim van Saarloos, President 2018-2020, Royal Netherlands Academy of Arts and Sciences, Netherlands

Koen Vermeir, Research Professor, Centre national de la recherche scientifique (CNRS); former Co-Chair, Global Young Academy, France

Sir Mark Walport, former Chief Executive, UK Research and Innovation (UKRI); former Director, Wellcome Trust, United Kingdom

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Translator, En-Fr	Rossion, Inc.

Peer Review

This report was reviewed in draft form by individuals selected by the CCA for their diverse perspectives and areas of expertise. The reviewers assessed the objectivity and quality of the report. Their confidential submissions were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring panel and the CCA.

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

Elizabeth Croft, FCAE, Professor and Dean, Faculty of Engineering, Monash University; Honorary Affiliate Professor, University of British Columbia (Melbourne, Australia)

Peter Gruss, President and CEO, Okinawa Institute of Science and Technology Graduate University; former President, Max Planck Society (Okinawa, Japan)

Vincent Larivière, Canada Research Chair on the Transformations of Scholarly Communication, and Professor, Information Science, Université de Montréal (Montréal, QC)

Margaret Sheil, Vice-Chancellor and President, Queensland University of Technology; former CEO, Australian Research Council (Brisbane, Australia)

Arian Steenbruggen, Director Domain Science, Dutch Research Council (NWO) (The Hague, Netherlands)

Neil Turok, O.C., FRSC, Emeritus Director, Perimeter Institute for Theoretical Physics; Higgs Chair of Theoretical Physics, University of Edinburgh (Edinburgh, United Kingdom)

The peer review process was monitored on behalf of the CCA's Board of Directors and Scientific Advisory Committee by **John Hepburn, FRSC,** CEO and Scientific Director, Mitacs. The role of the peer review monitor is to ensure that the Panel gives full and fair consideration to the submissions of the peer reviewers. The Board of the CCA authorizes public release of an expert panel report only after the peer review monitor confirms that the CCA's report review requirements have been satisfied. The CCA thanks Dr. Hepburn for his diligent contribution as peer review monitor.

Abbreviations

ARC	Australian Research Council
CFI	Canada Foundation for Innovation
CIHR	Canadian Institutes of Health Research
DARPA	Defense Advanced Research Projects Agency (United States)
DFG	German Research Foundation
DORA	San Francisco Declaration on Research Assessment
ECR	early-career researcher
EDI	equity, diversity, and inclusion
EPSRC	Engineering and Physical Sciences Research Council (United Kingdom)
ERC	European Research Council
ESRC	Economic and Social Research Council (United Kingdom)
FAPESP	São Paulo Research Foundation (Brazil)
HFSPO	International Human Frontier Science Program Organization
JIF	journal impact factor
NARCH	Native American Research Centers for Health (United States)
NIH	National Institutes of Health (United States)
NSE	natural sciences and engineering
NSERC	Natural Sciences and Engineering Research Council (Canada)
NSF	National Science Foundation (United States)
NWO	Dutch Research Council
OECD	Organisation for Economic Co-operation and Development
PI	principal investigator
R&D	research and development
RCN	Research Council of Norway
REF	Research Excellence Framework (United Kingdom)
SSHRC	Social Sciences and Humanities Research Council (Canada)
UKRI	UK Research and Innovation

Executive Summary

At the request of the Natural Sciences and Engineering Research Council of Canada (NSERC), the Council of Canadian Academies (CCA) convened an expert panel to review what is known about successful practices for supporting natural sciences and engineering (NSE) research around the world, and how some of these funding practices could be applied in Canada. Drawing on published evidence and input from research funding experts in many jurisdictions (notably Australia, Brazil, Canada, France, Germany, Japan, the Netherlands, New Zealand, Singapore, the United Kingdom, and the United States), the Panel explored funding practices related to improving support for research in various ways, including: supporting researchers across their careers; enhancing equity, diversity, and inclusion in the research community; supporting interdisciplinary and high-risk research; fostering research flexibility; and improving research funding efficiency and impact.

Main Findings

The Changing Social and Scientific Landscape

Concerns about heightened competition for funding are increasing in many countries as government research and development (R&D) spending fails to keep pace with growing researcher populations and needed investments.

Global R&D spending continues to grow steadily, led by rapid expansion in Asia and increasing business R&D investment. However, flat or declining government R&D investment in many OECD countries (including Canada), coupled with growing researcher populations, has led to increased pressure on applicants and declining funding success rates (i.e., the portion of applicants who receive funding) at many public funding agencies, heightening concerns about hyper-competition. In addition, the funding landscape has become more complex as the lines between major types of government funding (*competitive*, grant-based funding versus *institutional* or block funding) have been blurred by a proliferation of hybrid mechanisms. Governments consequently have access to a wider array of funding models, which can be used (singly or in combination) to meet specific research needs and objectives. Research funding from industry and philanthropies is also of growing importance in many regions and areas of research, particularly biomedical science.

In a changing social and scientific landscape, research funding agencies are becoming more active as promoters of scientific norms and practices.

As attention to the interactions between science and society has grown, funding agencies are becoming more active in developing norms for domains such as research publishing and assessment practices; data sharing and open science; research ethics and integrity; equity and diversity; and public science outreach and engagement. Public funding agencies operate at the interface among government, higher education, industry, and other stakeholders; their centrality provides them unique leverage to influence research practices and norms. Taking on such responsibilities often requires active, ongoing engagement with the scientific community and the development of new mechanisms and competencies. These roles took on new urgency in response to the COVID-19 pandemic, which rapidly altered the scientific landscape, enhancing the speed and scale of collaboration in some domains, while simultaneously increasing stress on researchers, exacerbating pre-existing inequities, and raising concerns about the erosion of traditional checks on research quality and rigour. COVID-19 also underscored the importance of fostering public trust in science and scientific institutions. With the long-term implications of the pandemic still uncertain, NSE funders will have to monitor developments carefully as they adapt to the changing needs of the research community, decision-makers, and the public.

Promising and Successful NSE Funding Practices

Cultivating a robust, resilient, and diverse scientific workforce is central to the development of a nation's research capacity and requires supporting researchers throughout their careers.

The success of future research funding hinges on effective training and support for the next generation of researchers. Heightened competition and lower funding success rates in many countries have had adverse effects on early-career researchers and on researchers from underrepresented or disadvantaged groups Early-career researchers can be better supported through many adjustments to standard funding programs, but segmenting awards so that applicants compete with others at similar career stages is particularly effective in supporting career development and cultivating an adaptable workforce. Promising practices that funders can use to better support equity, diversity, and inclusion in the research community include explicit diversity targets; dedicated funding programs for disadvantaged applicants; equality charters (which can be linked to institutions' funding eligibility); and practices that reduce bias in peer review. Indigenous research and researchers encounter unique challenges. Review panels often lack experience in evaluating Indigenous research, and many aspects of typical grants, such as fixed timelines or requirements for data sharing, are unsuited to Indigenous research practices. These challenges are best addressed through specialized grant programs, dedicated review committees, funding for community research teams, and related practices specifically tailored to Indigenous research and researchers.

Innovations in application and review processes, such as longer grants and expanded support for collaboration, can benefit interdisciplinary and high-risk research.

Some types of NSE research benefit from departures from standard funding approaches built around disciplinary review panels and typical timeframes. Multi- and interdisciplinary research, for example, benefit from expanded support for networking and collaboration; carefully tailored calls for proposals; adaptations to existing organizational structures and review processes; overarching frameworks such as "Grand Challenges;" and support for ongoing meetings and collaboration. Many grant application and review practices also discourage high-risk/high-reward proposals due to a conservatism inherent in the review process, a tendency that becomes more problematic as competition intensifies. Numerous practices have been employed in dedicated high-risk programs, such as shortened proposals with anonymized applicants to attract less conventional proposals. Longer-term grants with built-in flexibility, including problem-oriented initiatives, also encourage risk-taking among researchers by providing stability while also allowing for greater responsiveness to external developments. COVID-19 demonstrated the value of building responsiveness and flexibility into funding portfolios. To that end, funding agencies can reserve resources to provide timely support, or use continuous application cycles.

Enhancing the efficiency of funding processes, and supporting efforts to catalyze a broad range of impacts, helps funders better leverage their resources.

Traditional grant application processes often place large burdens on applicants and reviewers. As NSE funding environments become more competitive, funders are scrutinizing standard review processes to reduce administrative burdens and time requirements. Practices such as pre-screening and short pre-proposals have been successful in this regard. Greater experimentation with novel alternatives such as distributed review and partial lotteries (combined with rigorous data collection on these experiments) can help NSE funders better assess the costs and benefits of new approaches. To enhance research use and impact, funders can improve access to findings by supporting open-access principles and infrastructure, including article and data repositories. Agencies can also stimulate greater engagement between science and society by using consultations to define strategic initiatives, and targeted programs to encourage outreach and education. Researchers can alternatively be encouraged to identify potential societal impacts in their proposals, and provided with training to help them make these impacts a reality. Avoiding overly narrow evaluative criteria helps ensure that diverse (and unanticipated) forms of impact are not missed.

Applying Successful NSE Funding Practices in Canada

NSE funding practices are context dependent; adapting practices from abroad to Canada requires carefully tailoring them to Canada's diverse funding environment.

Canada's NSE funding landscape is multifaceted. The number of funders involved (including federal and provincial/territorial agencies) increases the options for researchers, but effective coordination is required to reduce inefficiencies and avoid misalignment. Persistently low levels of industrial R&D constrain opportunities for collaboration with the private sector, and underscore the centrality of university-based research. Many aspects of the research environment are outside of funders' direct control. However, Canadian funding agencies can play important supporting roles in reducing demographic and institutional barriers for early-career researchers, increasing diversity in the professoriate, attracting and retaining research talent, and mitigating the negative impacts of unequal funding distributions across regions. Funding agencies also face competing priorities, and an ongoing need to balance funding levels and success rates. While grants that are too small risk being unproductive and increase application burdens, most empirical evidence supports prioritizing broader distribution of funds and higher success rates. This is consistent with NSERC's provision of modest "grants-in-aid" through the Discovery Grants program, though the effectiveness of this approach depends on a supporting ecosystem of supplementary funding options. While international experience does not suggest a single "correct" balance between investigator-led and priority-driven research, NSERC and other NSE funders should be wary of allowing the latter to become overly dominant, given that today's investigator-led research may be vital in addressing tomorrow's priorities.

Improving the Evidence Base for Future NSE Funders

More experimentation with alternative funding practices, alongside data sharing and rigorous evaluations, could provide funders with a better understanding of their options.

Evidence on the effectiveness of most NSE funding practices is limited. The Panel's discussion of these practices was frequently constrained by a lack of evidence documenting their outcomes — a deficit amplified by the challenge of attributing research successes or failures to a single funding source. Many funding practices seem promising but are not substantiated by rigorous evaluations. When comparing different practices with common objectives, it is rarely possible to determine which is superior, and differences among jurisdictions complicate attempts to compare (and transfer) funding practices. New opportunities are emerging, however, to improve this evidence base. Increased data collection and sharing by funding agencies could help link specific funding practices and approaches with research outcomes in controlled studies. Broader and more extensive evaluations can also enhance accountability and clarify the relative efficacy of different funding approaches (though care needs to be taken to avoid excessively burdening the research community). By supporting experimentation with alternative funding practices and approaches, funding agencies can ensure that the evidence base continues to expand and improve over time, providing a clearer picture of the NSE funding practices most likely to succeed in any given context.

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Introduction

Public agencies that fund research in the natural sciences and engineering (NSE) face a growing set of challenges. With limited resources, how can publicly supported funding agencies maximize opportunities for new scientific discoveries and breakthroughs while also fostering the development of the next generation of researchers? In a rapidly changing environment (now being affected by a global pandemic), how can funders ensure their investments are responsive to government priorities and societal needs, while also providing ample support for curiosity-driven research? How can they balance support for different disciplines and different aspects of the research enterprise and work with other funders to ensure a well-functioning system? And how can they better support researchers from marginalized groups to ensure ongoing improvement with respect to diversity and equity?

Such questions are difficult to answer because, despite calls for a "science of science policy" (Marburger, 2007; Lane *et al.*, 2011), the evidence base related to many of these issues is limited. Efforts to evaluate past funding programs have been inconsistent and have had mixed results; this is complicated further by the formidable challenge of evaluating research outcomes when their full impacts often take decades (or longer) to emerge. Research funding agencies frequently differ in their approaches as a result. Current suites of programs and practices can become historically and socially entrenched, creating formidable barriers to change. While some funders are more open to innovation than others, past approaches are too often perpetuated because change would be disruptive rather than because they reflect an evidence-based appraisal of the best possible approaches.

Addressing these types of questions methodically is daunting, but it is also critical for getting the most out of public investments in science. Canada's federal government invests over $2.9 billion per year in NSE research. Since the global financial crisis of 2007–2008, however, government budgets for research and development (R&D) in many OECD countries have largely stagnated, putting increasing pressure on researchers and scientific institutions. In the context of a global pandemic, the role of science in responding to major social challenges has never been more apparent, as are the fiscal constraints on future research spending, which are likely to become more acute. Rigorously and transparently exploring funding practices is essential to ensure that future investments in NSE research are guided by the best available evidence and practices.

1.1 The Charge to the Panel

The Natural Sciences and Engineering Research Council of Canada (NSERC), the Social Sciences and Humanities Research Council (SSHRC), and the Canadian Institutes of Health Research (CIHR) are the Government of Canada's primary providers of competitive, grant-based funding for research. NSERC's current strategic plan was intended to guide the agency's operations through the end of 2020 (NSERC, 2015b). NSERC is now developing a new strategic plan that will provide direction for the agency over the course of the next 5 to 10 years.

Recognizing how important it is that its updated strategy be informed by an assessment of current practices for funding scientific research, NSERC asked the Council of Canadian Academies (CCA), in the spring of 2020, to convene an expert panel to assess how NSE research is supported in other jurisdictions, and what lessons Canada can draw from those experiences. NSERC specifically asked the CCA to form an expert panel to address the questions below:

What is known about successful practices for funding natural sciences and engineering (NSE) research internationally, and how could such practices be applied to funding for NSE research in Canada?

- What major trends in NSE research, nationally and globally, are most relevant to how NSE should be supported going forward?
- What role(s) do NSE funding agencies play in supporting research ecosystems, and how are these roles changing?

1.2 The Panel's Approach

In response to this request, the CCA convened a multidisciplinary, eight-person expert panel (hereafter the Panel), composed of members with broad experience in research funding and administration, both within Canada and in other countries. The Panel's work began in the months following the onset of the global COVID-19 pandemic, and its process was carried out virtually as a result. The Panel met six times over the course of nine months to review evidence, discuss implications, and deliberate on its charge. As with all CCA assessments, the Panel's report was also subjected to an extensive peer-review process prior to publication.

Throughout this process, the Panel's deliberations were informed by two primary sources of evidence: a literature review, and a series of additional interviews and discussions with other experts.

Literature Review

A structured literature review surveying recent research on funding practices supported the Panel's work, and was designed in accordance with the scope of the assessment. This review relied on the Institute for Scientific Information's *Web of Science (WoS)* database, covering peer-reviewed articles and conference proceedings across numerous disciplines. An initial search was conducted using a query of ("science funding" OR "scientific" OR "research grants" OR "research funding") AND ("collaborat*" OR "allocat*" OR "trend*"), restricted to sources published between 2015 and 2020. The search output was then analyzed using an open-source bibliographic software (VOSviewer), and search terms were iteratively adjusted to refine the output.[1] Additional filtering to eliminate out-of-scope references resulted in a final working collection of 95 articles on research funding agencies and practices, research impacts and evaluation, historical funding trends, research collaboration, scientific productivity, and other topics of relevance to the charge. This review was supplemented by additional references identified by panel members based on their own professional activities and expertise, by CCA staff, and through extensive use of grey literature in the form of government reports and documents, strategic plans, environmental scans conducted by international research funders, and state-of-knowledge assessments from not-for-profit organizations.

Expert Interviews and Discussions

To supplement the published evidence and expand its understanding of funding practices in different countries, the Panel also organized a series of discussions with additional experts. During a meeting in July 2020, eight individuals participated in these discussions. Participants had experience from a range of nations and regions, including Brazil, Canada, France, Germany, the Netherlands, New Zealand, Singapore, and the United Kingdom.[2] Invited experts were chosen both for their general knowledge and experience of research funding systems, and to share insights on practices of interest to the Panel (e.g., supporting early-career researchers or Indigenous researchers).

1 Exclusions included: ("health research" OR "disease" OR "care" OR "cancer" OR "global health" OR "medicine" OR "humanities" OR "social science" OR "biomedical-research" OR "biodiversity" OR "serum" OR "efficacy" OR "safety" OR "diagnosis").

2 See the list of participants on p.xii.

1.3 Assessment Scope

Early discussions with NSERC clarified the assessment's scope and goals. These were (i) to provide an overview of how funding agencies around the world support NSE research, and (ii) to identify any lessons Canada can draw from those agencies' experiences. The Panel's orientation was primarily international as a result. Much of this report focuses on funding practices employed in other jurisdictions, though Canadian examples and experience are also considered. The assessment focuses on funding practices mainly related to competitive, grant-based funding rather than institutional or block funding (Section 2.2), and to extramural (out-of-house) research funding rather than funding for research performed at government labs and facilities. The assessment is not an evaluation of NSERC, its funding programs, or the adequacy of research funding in Canada. Nor is it intended to substitute for a broader consultation with the Canadian research community. As is standard for the CCA, this report does not provide direct policy recommendations for NSERC, but rather a synthesis of the current state of knowledge as informed by the insights and expertise of the panel members involved.

The Panel's charge focused on funding practices for NSE research, consistent with the disciplines supported by NSERC. These disciplines include basic and applied research across the life sciences, physical sciences, mathematics and computer science, and engineering. Many challenges and practices for research funding are common to other disciplines as well, however, including clinical medicine and the social sciences. The Panel consequently considered practices from all disciplines (and the funding agencies that support them), where they were judged to be relevant to informing NSE funding practices; examples drawn from non-NSE initiatives and funders therefore also feature throughout this report. In the Panel's view, a willingness to draw from the experiences of funding agencies operating in other domains is helpful for understanding how to effectively support multi- and interdisciplinary research. However, in reviewing such examples, the Panel's emphasis was on extracting lessons applicable to NSE funders.

The study's scope was multifaceted since most funding agencies, including NSERC, have multiple objectives, including supporting researcher education and training, stimulating new scientific discoveries, and encouraging collaboration with industry and other partners. NSERC signalled a particular interest in practices related to supporting equity, diversity, and inclusion (EDI) in the research community, as well as Indigenous research and researchers. The Panel therefore considered funding practices related to a wide range of objectives.

The Panel's review of funding practices for supporting PhD students, however, was deliberately limited. Practices that support early-career researchers (ECRs) are considered, and there is a limited examination of the role that fellowships can play in supporting researchers as they start their careers. A full exploration of challenges related to graduate research education, and the role of research funding agencies in addressing those challenges, warrants a separate study. For more detailed consideration of issues and challenges relating to research training and labour market transitions for PhD graduates, readers are referred to another recently published CCA report (CCA, 2021) or similar studies focused on other jurisdictions (Tilghman *et al*., 2012; Auriol *et al*., 2013; Boman, 2017).

What is a "successful" practice?

For this assessment, the Panel considered *successful* practices to be those where there is strong evidence (typically based on formal program evaluations and peer-reviewed studies) that these practices achieved one or more of their stated goals. The evidence available did not always support a definitive judgment in this regard. *Promising* practices were those the Panel expected would meet one or more intended objectives, but where the evidence of success to date is limited; many practices of this type are related to programs currently in progress. *Problematic* practices, meanwhile, consist of those that have either been demonstrated to be ineffective (i.e., unsuccessful) at achieving their goals or, alternatively, have resulted in unintended and counterproductive consequences.

Best practices, understood as those definitively shown to be superior to other practices with the same or similar goals, are mostly absent from this assessment. The systematic comparison and ranking of research funding practices is hampered by limited evidence on long-term effectiveness, inconsistencies among comparable programs, and the absence of counterfactuals. As a result, very rarely is there sufficient evidence to justify labelling a current funding approach a "best" practice. Contextual differences across jurisdictions add to this complexity, as the success achieved with a practice in one place will not necessarily be replicated if the same practice is adopted elsewhere. In the absence of more conclusive evidence, the Panel reviewed a diverse array of funding approaches and practices alongside real-world examples, to highlight the opportunities — and pitfalls — of particular approaches.

1.4 Report Structure

Chapters 2 through 5 have a predominately international focus, consistent with the Panel's charge. Chapter 2 examines changes in the research context for NSE funders, and the implications of these changes for funding agencies as they take on new roles and objectives. Chapters 3, 4, and 5 review what is known about research funding practices pertaining to a range of goals, including supporting researchers across their careers; increasing EDI; supporting multi-, inter-, and transdisciplinary research and high-risk research; and improving funding efficiency and impact.

Chapter 6 explores the Canadian NSE funding landscape and how practices that proved effective elsewhere might be applied in the Canadian context. Chapter 7 concludes the report by summarizing the Panel's key findings in relation to its charge.

2

The Changing Context for Research Funding

Chapter Findings

- Flat or declining government R&D investment in many OECD countries, coupled with growing researcher populations, has led to increased pressure and declining success rates for many public research funding agencies, heightening concerns about hyper-competition.
- A proliferation of hybrid funding models is challenging the traditional distinction between *competitive* and *institutional* research funding, providing governments with more choices as they tailor funding instruments to specific objectives.
- Funding agencies are playing increasingly active roles as arbiters of scientific norms and practices in domains such as research assessment, open science and open access, equity and diversity, research ethics, and public science engagement and education.
- COVID-19 rapidly and dramatically altered the scientific landscape, enhancing the speed and scale of collaboration in many domains, while simultaneously exacerbating pre-existing inequities and raising concerns about the erosion of traditional checks on research quality and rigour.

NSERC was established in 1978, at a time when cellular phones and personal computers were widely regarded as emerging curiosities. Other funding agencies, such as the National Science Foundation (NSF) in the United States, were founded earlier, building on the successes of defence-related research in the post-World War II era. These agencies face a markedly different landscape than when they were first established, having transitioned from earlier periods of rapid growth into more stable configurations. Scientific breakthroughs and new technologies have also catalyzed new ways of working, communicating, and collaborating. Researchers and funding agencies have also frequently needed to adapt to social, economic, and geopolitical developments. The global financial crisis beginning in 2008 heavily impacted research communities in many countries, challenging funders as they dealt with stimulus spending and subsequent calls for austerity. More recently, the emergence of COVID-19 and a global pandemic led to a vast mobilization of scientific resources, altering many of the practices and norms of scientific research in the process. This chapter explores the context in which NSE funders operate, including how that context is changing and how the roles of these agencies are evolving in response.

2.1 The Changing Global Landscape for Science

Research is becoming more multipolar and collaborative as global R&D investment grows, driven primarily by spending in businesses, and in Southeast Asia.

Funding agencies such as NSERC are just one source of investment in NSE research. Worldwide R&D spending has grown by 6 to 7% per year since 2000, reaching a total US$2.1 trillion in 2017 (NSB, 2020b). This growth can be attributed to two main sources. First, in many wealthier economies, businesses have been increasing their R&D spending. Across OECD members, the business sector accounted for more than 70% of growth in R&D spending between 2000 and 2017 (OECD, 2020b), and businesses now perform the large majority (70 to 80%) of R&D in many countries, including China, Japan, South Korea, and the United States (NSB, 2020a).[3] Second, rapidly increasing levels of R&D investment in Asia continue to reshape the global research environment. In 2000, countries in East and Southeast Asia collectively accounted for 25% of worldwide R&D. By 2017, their combined share was 42%. China's growth in R&D spending has been particularly rapid and sustained, increasing at an average rate of 17% per year between 2000 and 2017 (NSB, 2020b).

These and related trends are changing the global scientific landscape. While businesses are increasing R&D investments, their willingness to support fundamental, basic research appears to have diminished as they prioritize applied research with clear commercial viability (Larivière *et al.*, 2018). The jurisdictions participating in the production of research are also now more numerous and more diverse, reflecting the increasing prominence of China and other emerging economies. Between 2000 and 2018, China's share of world science and engineering journal articles rose from 5 to 21% (NSB, 2019), and China has long since surpassed the United States as the world's largest producer of NSE doctoral degrees (NSB, 2020a). As noted in a 2014 report, "[t]he global research landscape of the past decade has become so dynamic as to be described in terms of tectonic movements" (Thomson Reuters, 2014). As shares of research funding and scientific activity in Europe, Japan, and North America have declined, the research landscape has become proportionately more multipolar (European Commission, 2012b).

At the same time, science is becoming more internationally collaborative. In 2000, 14% of published science and engineering journal articles included authors from two or more countries. By 2018, the share had risen to 23% (NSB, 2020a), and in many countries the rates of international collaboration are far higher. Australia, Canada, France, Germany, Spain, and the United Kingdom all have international collaboration rates over 50%. Even in the United States, which collaborates less

3 Canada is a notable exception to this trend (Section 6.2).

because of its larger pool of domestic researchers (CCA, 2018), rates of international collaboration nearly doubled between 2000 and 2018, rising from 19 to 39% (NSB, 2020a). The scale of research collaborations (including in the health and social sciences) is also growing (Adams, 2012). Since 1950, the mean team size on scientific publications rose from less than two to more than five (Fortunato *et al.*, 2018). These collaborations range from peer-to-peer networks among individual researchers, to formal institutional partnerships and multinational agreements (European Commission, 2012b). As such collaborations grow in number and importance, funding agencies are having to become more deliberate in how they support and enable researchers to work with peers in other countries.

Science is changing due to other technological and social trends as researchers take advantage of new digital technologies and funders respond to larger social priorities.

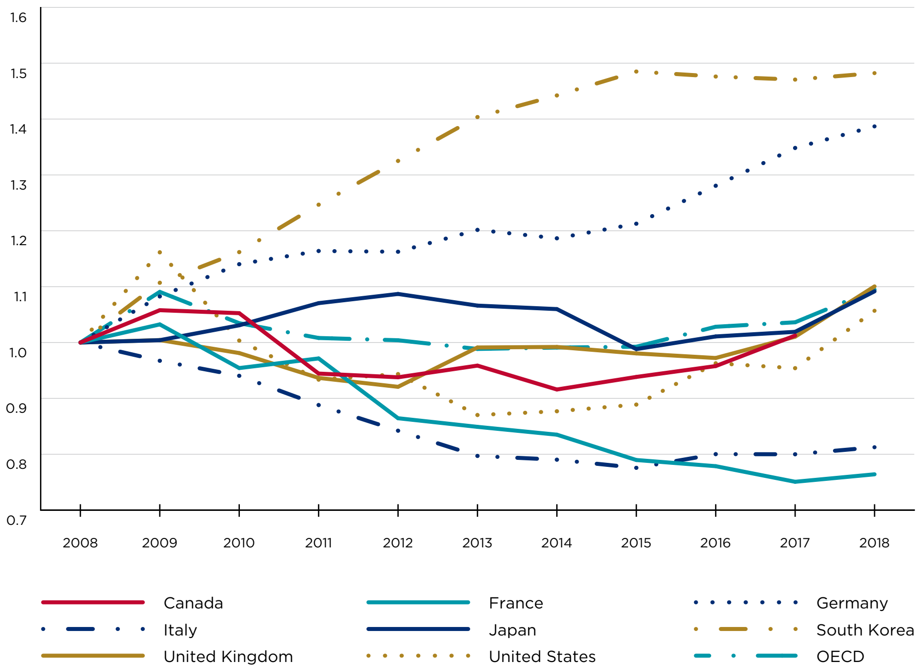
Advances in computing and communication technologies are also changing the way science is conducted, and the ways that funding agencies support it. Digital technologies have made it increasingly easy to share data and research across large distances, making new collaborations possible (OECD, 2018b), and the combination of extensive data collection and algorithmic screening techniques could play a role in automating aspects of funding allocation (Ioannidis, 2011; Ebadi & Schiffauerova, 2016). At the same time, surging interest in some technologies, particularly artificial intelligence and its applications, has raised important questions about their ethical and social implications. An expansion of computational capacity, coupled with breakthroughs in machine learning and related fields, has made many areas of research more data-intensive, contributing to the need for clear protocols for sharing and safeguarding those data. Calls for "open data" have coincided with support for the growing "open science" movement, leading many funders to explore ways to make research results more broadly accessible (Lyon, 2016; Pasquetto *et al.*, 2016).

Funders also find their priorities shaped by changing economic, environmental, and social circumstances. Climate change is a dominant issue on national and international agendas, underscoring the ongoing need for research that can support decision-makers as they take steps to mitigate greenhouse gas emissions and adapt to a changing climate. Demographic trends are also influencing policy and research priorities due to concerns about aging populations and associated impacts on productivity, health care systems, and fiscal capacity (UN, 2020). Countries have also directed research funding with targeted funding initiatives aimed at "Grand Challenges" (Varmus *et al.*, 2003; Omenn, 2006; Hicks, 2016) or through research excellence initiatives (OECD, 2014). These initiatives are often multi- or interdisciplinary by design (Maxwell & Benneworth, 2018), seeking to create new partnerships among social scientists, natural scientists, engineers, policy-makers, and civil society.

Government R&D spending in many OECD countries has been flat or declining since the 2008 financial crisis, contributing to increased competition for funding.

While many countries — China in particular — and businesses have increased R&D spending over the past decade, government R&D investment in many OECD countries has been flat or declining. Following the global financial crisis of 2007 and 2008, many governments increased research and innovation expenditures as part of national stimulus packages (OECD, 2018a; Rehm, 2018). Such increases, however, were often temporary, and slowed or reversed in subsequent years. Economic growth often resumed without accompanying increases in public research spending, leading to declining research expenditures at higher education institutions and public research institutions among OECD countries (OECD, 2018a) (Figure 2.1). More than a decade later, government R&D investment remained near or below 2009 levels in many countries. In Canada, government budget appropriations for R&D remained below their 2009 peak until after 2017. Some countries, such as France and Italy, experienced significant declines that have yet to be reversed. Germany and South Korea are among the few exceptions to this trend, benefiting from relatively stable growth over the past decade.

Flat or declining public R&D investment has added to the stresses faced by public research funding agencies, particularly as declining government R&D investment was coupled with continued growth in the researcher population. The worldwide expansion of higher education systems in the 20th century has led to rising student enrolments and higher rates of educational attainment (Schofer & Meyer, 2005). While growth is moderating in some countries, the overall pattern of expansion persists. Across the OECD, the share of young people (age 25 to 34) who attained a college or university degree climbed from 36% in 2009 to 45% in 2019 (OECD, 2020f). Increases in enrolment have not always been met by growth in the number of faculty at post-secondary institutions. In Canada, the number of tenure-track professors has been largely stable since 2009; to meet the demand for teaching many institutions have introduced “teaching stream” positions with reduced research responsibilities (Sanders, 2011; StatCan, 2019a). Some E.U. jurisdictions have seen a contraction in the number of staff, forcing some faculty to take on additional teaching loads at the expense of their research (Eurydice Report, 2017). That said, the number of researchers in OECD countries continues to grow, increasing by approximately 20% between 2009 and 2017 (the latest year for which there are data) (OECD, 2020b).



Data Source: OECD (2020b)

Figure 2.1 Government Budget Appropriations for R&D Among OECD and Selected Countries Relative to 2008 Levels

Funding levels are expressed as a percentage of 2008 appropriations, calculated based on constant purchasing power parity (PPP) dollars. Data are for R&D investment in all disciplines, including the health and social sciences. The OECD does not report data on this series for China, but total government R&D in China more than doubled during this 10-year period.

Stagnant funding levels and growth in the researcher population have increased competition for research grants in many jurisdictions, reducing success rates among applicants and raising concerns about the negative impacts of hyper-competition (Alberts *et al.*, 2014; Baum *et al.*, 2017; OECD, 2018d). In Canada, for example, Baum *et al.* (2017) show that, between 2005 and 2015, the average grant size in NSERC's Discovery programs declined by 15% and success rates declined by 10% (from 75 to 65%), while the total number of grants awarded changed little.

Researchers are adapting to more diverse sources of support, including philanthropies and businesses, as governments re-examine traditional funding models.

A constrained funding environment is leading many researchers to look for other sources of support. Funding from philanthropic organizations plays an important role in some areas of science, such as biomedical research (Murray, 2013; Michelson, 2020). Philanthropies contribute over US$4 billion annually to operations, endowment, and infrastructure (e.g., buildings, labs) devoted to research at U.S. universities; this collectively accounts for roughly 30% of annual research funds at leading universities (Murray, 2013).[4] Major philanthropies can consequently be a critical source of external support, reflecting a variety of interests, preferences, and strategies on the part of donors. Businesses are also active funders in many areas of R&D. Their support often requires researchers and institutions to overcome a range of barriers to intersectoral collaboration, including intellectual property negotiations, different incentives for data publication and transparency, and constraints on access to facilities and equipment. In this diversifying funding landscape, governments and agencies are increasingly re-examining traditional, competitive funding models as they try to achieve new efficiencies while preserving their historical focus on research excellence (OECD, 2018d).

2.2 The Roles of Public Research Funding Agencies

Governments traditionally relied on two main types of research funding: competitive, project-based grants, and institutional block funding.

Public research funding agencies operate in a complicated institutional landscape as one of many organizations involved in supporting research. While the Canadian system is complicated by the division of responsibilities across the federal and provincial/territorial governments (Chapter 6), governments have traditionally relied on two main types of research funding:

- *Competitive research funding* programs allocate funding for research activities based on competitive processes. These typically include a call for proposals, a panel assessment, peer review, scoring, awarding of funding for a limited time, and follow-up (OECD, 2018a). Funding allotments can be for different amounts and durations, and directed to individuals, projects, or organizations. Competitive funding is often allocated through dedicated research funding agencies or councils such as NSERC.

4 Philanthropic funding is less significant in Canada (Section 6.1), though researchers based in Canada do benefit from support provided by organizations based in other countries.

- *Institutional or block funding* is aimed at providing general, long-term support for research-performing institutions (OECD, 2018a). Such funding is most often distributed on an annual basis through government transfers (often based on a formula using quantitative characteristics such as the number of researchers or historical funding levels). It provides support for day-to-day operations such as staff salaries, infrastructure, and maintenance for research and education facilities.

The balance between competitive and institutional funding varies widely, and the distinction is blurring as competitive elements increasingly appear in both types.

Reliance on these two types of funding varies widely across countries (van Steen, 2012; OECD, 2018d), and some evidence suggests that the share of research funding awarded through competitive mechanisms is gradually increasing worldwide (OECD, 2018d).[5] However, distinctions between competitive and institutional funding are less pronounced since the introduction of funding approaches that combine elements of both types. Institutional funding arrangements are incorporating elements of competition, where a portion of that funding is "performance-based" and allocated based on quantitative indicators, sometimes in combination with peer review and often based on peer-reviewed outputs (e.g., publications, grants). In countries such as Norway and Sweden, institutional funding has also increasingly been aligned with national priorities, becoming more directed over time while still attempting to preserve a degree of institutional autonomy (OECD, 2018a). Governments are also progressively adopting "research excellence initiatives," which are competitive processes used to allocate multi-year funding to research institutions based on national research goals or priorities.[6] Approximately two-thirds of OECD countries have established these types of initiatives (OECD, 2014, 2018a).

These trends point to the need for a more nuanced classification system that accounts for the full spectrum of institutional arrangements. OECD (2018a) proposes an alternative framework for categorizing funding programs, one that takes into account the extent of competition (or competitive intensity); their granularity (i.e., the unit to which funding is allocated); the level of funding (i.e., within the organization); the type of assessment and selection criteria; and the extent to which funding is directed towards priority areas or issues. Figure 2.2 illustrates this spectrum, focusing on three of these dimensions: competitive

5 Such comparisons and trends should be interpreted with caution. A lack of uniformity and standardization in the data makes cross-country comparisons potentially misleading. Many countries do not formally collect or report statistics based on these distinctions (OECD, 2018d).

6 Such initiatives come in many forms and are difficult to define precisely. In the Canadian context, research funding offered on a competitive basis through Genome Canada and its regional partners could be considered an example of a research excellence initiative.

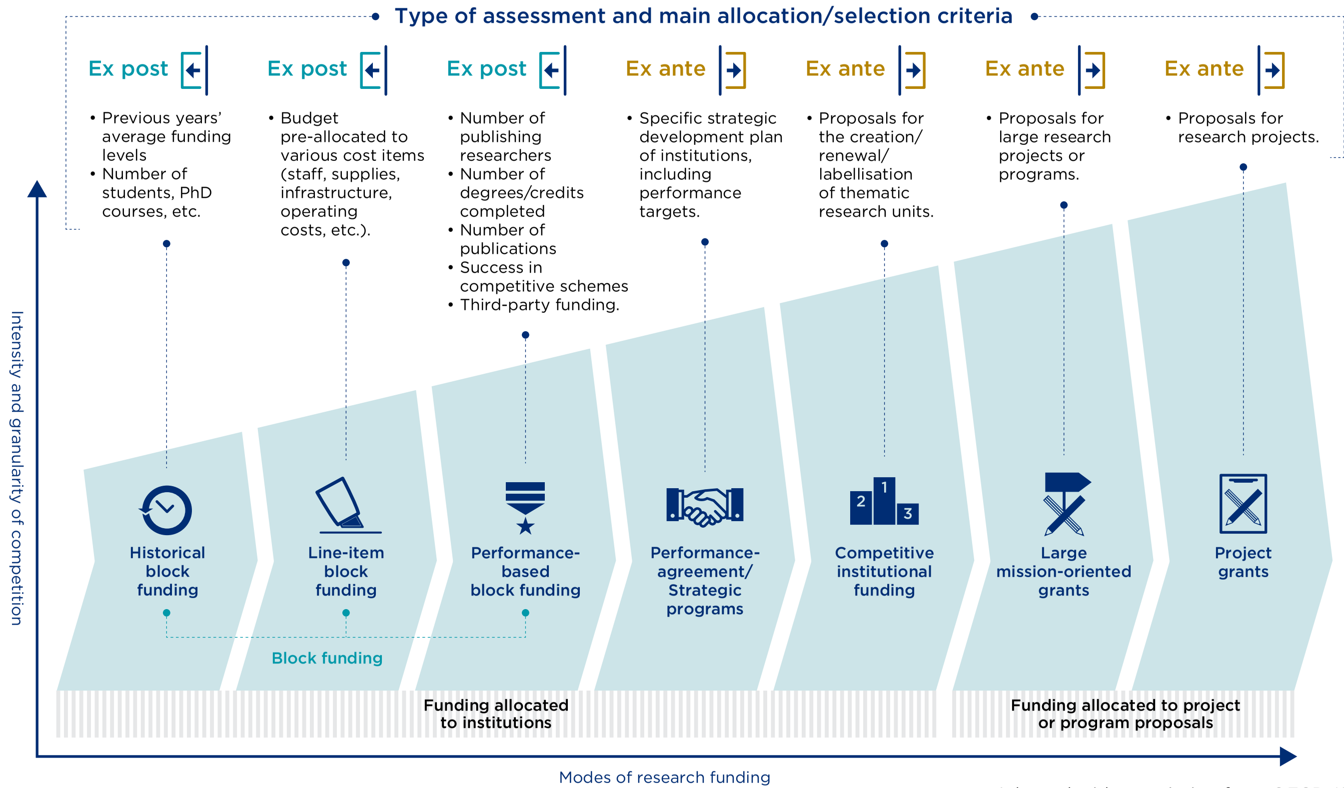
intensity, granularity of funding, and assessment type (*ex post* or *ex ante*).[7] Formerly confined to the periphery of this spectrum, governments increasingly complement traditional funding models with hybrids such as performance-based block funding; competitive, institutional funding mechanisms such as research excellence initiatives; and large mission-oriented grants.

Access to a greater array of funding options raises questions about the comparative strengths and weaknesses of different approaches. Competitive, project-based funding is generally viewed as being better suited for steering research to priority areas through scoping of calls for proposals, and for its traditional focus on producing high-quality research (OECD, 2018a). It may be less appropriate for supporting longer-term, higher-risk research, due to limited funding durations and the conservatism of peer-review processes (Section 4.2). A lack of certainty about long-term funding may also hinder long-term planning, particularly when such funding is characterized by low success rates (OECD, 2018a). Institutional funding may provide a greater level of certainty over longer timeframes, and increased flexibility for researchers to define their own agendas. In practice, researchers and research institutions often benefit from a combination of funding types (or intermediary models), blending the features and benefits of each side of the spectrum.

Funding agencies have many objectives, with the overarching goal of supporting research excellence.

As providers of project- or investigator-based funding, the overarching goal of funders is often expressed in terms of cultivating research excellence (OECD, 2018d). Other commonly identified purposes include "promoting frontier knowledge," "supporting 'blue-sky' and investigator-initiated research," and "supporting interdisciplinary research" (OECD, 2018d). However, funding agencies frequently pursue supplementary goals as well, either through the structuring of their programs (e.g., evaluation and eligibility criteria), or through dedicated, supplementary programs. Other common goals include "promoting international collaboration; responding to societal challenges; [improving] economic competitiveness; and capacity building (infrastructure, human resources)" (OECD, 2018d). Funding agencies often operate scholarship programs in addition to their main funding programs, where researcher training and education are primary goals.

7 *Ex ante* assessment involves assessing research proposals before they are funded. *Ex post* assessment entails assessing the impacts of funded research after it is carried out.



Adapted with permission from OECD (2018a)

Figure 2.2 Spectrum of Research Funding Types

The traditional typology of competitive, project-based funding and institutional, block funding is becoming less accurate due to a shift towards funding models that combine elements of both types. This figure depicts a spectrum of funding arrangements based on three dimensions: competitive intensity, granularity of funding, and assessment type (*ex post* or *ex ante*).

Research funders also use programs to incentivize collaboration, by requiring larger teams, involving multiple institutions (or disciplines), or requiring co-funding. Approximately two-thirds of research funding initiatives in OECD countries have some form of collaboration requirement, and a recent survey of competitive funding programs found that approximately half had an explicit co-funding requirement (OECD, 2018d). Such requirements can include cash or in-kind contributions, but typically exclude uncovered or waived overhead costs or other implicit co-funding. In the Canadian context, programs requiring co-funding with an industrial partner have been seen as a strategy for incentivizing greater collaboration among researchers, higher education institutions, and industry in support of the federal government's goal to enhance business innovation (NSERC, 2009).

National research funding agencies are increasingly active in shaping research practices and norms.

Funding organizations have always needed to consider how research is conducted in their funding decisions; however, they have over time become more involved in initiatives that directly or indirectly shape research practices and norms, reflecting their unique role and ability to induce systemic changes. Some of these initiatives have focused on mitigating problematic practices in publishing or research assessment. For example, with the development of Plan S (a consortium of research funding agencies that require grant recipients to publish in open-access journals or repositories), funding agencies used their collective ability to better support open-access publishing policies and ensure that the results of publicly supported research were widely accessible (Vermeir, 2020) (Section 5.2). Another example of active engagement is the adoption of the San Francisco Declaration on Research Assessment (DORA) by many funders (including Canada's federal granting councils). DORA commits funders (alongside universities and other organizations) to adhere to a set of guiding principles on responsible research assessment practices. Such initiatives can strongly influence both institutional practices and researcher behaviour.

Some funding agencies have taken on more engaged roles in response to growing awareness and discussion of legal, ethical, and social issues surrounding scientific and technological advancements. Owen and Pansera (2019), for example, describe the development and evolution of the Responsible Innovation and Responsible Research and Innovation paradigms, the latter of which emerged from discussions within the European Commission. This agenda was advanced further by the Rome Declaration in 2014, which called on European institutions, E.U. member states, and other bodies to "make Responsible Research and Innovation a central objective across all relevant policies and activities, including in shaping the European Research Area and the Innovation Union" (Owen & Pansera, 2019). Early framing of these discussions was ambiguous, but the vision eventually cohered around five "keys" related to the science culture and practices in which funding agencies are increasingly active (Table 2.1).

Table 2.1 European Commission Responsible Research and Innovation "Keys"

Key	Description and Goals
Public engagement	Promoting a scientifically literate society that can participate in and support (i) democratic processes, (ii) the development of science and technology, and (iii) research and innovation policy agendas, in particular those related to societal challenges. This key emphasizes co-creation, mutual understanding, and iterative, inclusive, and participatory "multi-actor dialogues."
Open access/ Open science	Making findings from publicly funded research (e.g., data, peer-reviewed publications) freely accessible without charge, to improve knowledge circulation, foster innovation, and strengthen the knowledge economy.
Gender	Encouraging girls and women to study science and embrace a career in research; fostering gender balance in research teams; removing barriers that generate discrimination against women in scientific careers; ensuring gender balance in decision-making (e.g., peer review, advisory panels); and integrating the gender dimension in research and innovation content.
Science education	Making science (including education and careers) more attractive to young people, thereby increasing society's appetite for innovation and opening up further research and innovation activities. This key has a strong focus on promoting science, scientific literacy, and innovative pedagogies.
Ethics	Applying established ethical principles and legislation to research involving children, patients, and vulnerable populations; to human embryonic stem cells; to privacy and data protection issues; and to research on animals and non-human primates. This key embraces established principles of research integrity (e.g., data fabrication, falsification, plagiarism, or other research misconduct).

Adapted from: Owen and Pansera (2019)

Funders have responded to this agenda in different ways (Owen & Pansera, 2019). In the United Kingdom, the Engineering and Physical Sciences Research Council (EPSRC) introduced its Framework for Responsible Innovation, which committed the organization to including such considerations in strategic thinking and funding plans, as well as in proposal assessment. This framework was particularly impactful for the agency's program on geoengineering research. At the Research Council of Norway (RCN), the Centre for Digital Life Norway (dedicated to biotechnology) was configured based on Responsible Innovation principles.

The Dutch Research Council (NWO) also created a Responsible Innovation program, with the goal of "identifying ethical and societal aspects of technological innovations — products and services — at an early stage, so that they can be taken into account in the design process" (Owen & Pansera, 2019). The NWO has also taken steps to address the current "replication crisis" in science through a pilot program that supports research aiming to verify the reliability of highly cited publications in social sciences and health innovation research (NWO, 2017b). While Responsible Research and Innovation principles have not been formally incorporated in all jurisdictions, funding agencies are increasingly acting as arbiters of scientific practices and norms. This is not a role that funders can play in isolation; it requires active, ongoing engagement and consultation with the scientific community, often necessitating the development of new competencies and tools.

Programs and initiatives aiming to foster public science engagement are another aspect of this shift. The societal relevance of scientific research is not always readily appreciable and impacts often lag discoveries by years or decades. Greater engagement can provide clarity to stakeholders outside of the research environment to mobilize knowledge and avoid misunderstandings. In Canada, developing a stronger "science culture" was a prominent component of NSERC's most recent strategic plan (NSERC, 2015b), and its PromoScience funding program has provided support for scientists and science educators engaged in public outreach (NSERC, 2020a). In the United States, NSF's use of a "Broader Impacts" criterion signals its intention to support research that can "benefit society and contribute to the achievement of desired societal outcomes." Proposals can demonstrate their potential under this criterion through the direct impacts of the research itself, through related activities such as contributing to researcher education and training objectives, or through public outreach and engagement (NSF, 2020d).

2.3 Supporting Research in a Pandemic

COVID-19 has led to a proliferation of rapid-response funding programs aimed at mitigating the pandemic, underscoring the importance of flexibility among funders.

The emergence of COVID-19 and the ensuing global pandemic suddenly and dramatically altered the context for scientific research. Simply maintaining operations and scheduled funding programs was the priority for many agencies, where mobility and in-person interactions were constrained by public health responses such as border closures and lockdowns. Such constraints impacted agency staff, often forcing them to work remotely, and affected funders' ability to carry out functions such as reviews of grant applications, which require convening scientists from many institutions and regions. Most agencies were able to maintain pre-existing funding calls in the crisis, though some were forced to cancel or delay planned funding calls for 2020 (Stoye, 2020; Webster, 2020). Others have offered short-term extensions to existing grants, and some large-scale research evaluations, such as the United Kingdom's Research Excellence Framework, were delayed (Wilsdon, 2020).

Funding organizations are also striving to actively support accelerated research efforts to mitigate damage from the pandemic. Public funding agencies and major philanthropies have launched rapid or flexible funding mechanisms to support pandemic-related research priorities (Wilsdon, 2020). Some efforts focused on vaccine development (e.g., Gavi, the Vaccine Alliance, or Project Warp Speed in the United States) or therapeutic treatments (e.g., the COVID-19 Therapeutics Accelerator, an initiative supported by the Wellcome Trust and the Bill & Melinda Gates Foundation, among others). Others supported research on the economic and social dimensions of the pandemic. As of June 24, 2020, the OECD identified 174 different COVID-19-related funding programs, representing more than 38 countries or regions, including public, private, and non-profit funders, and totalling over US$7.7 billion (OECD, 2020d).[8]

Operating rapid-response funding programs requires disbursing funds in accelerated timeframes that may require departures from standard grant evaluation and peer-review processes. Funding agencies must balance the flexibility and urgency called for by the situation with the need to maintain procedural requirements that safeguard scientific integrity. As researchers pivot in response to the crisis, funders also face concerns about a rise in opportunistic changes in research direction and the impacts of crisis-related research calls on existing programs. Scientists have expressed concerns about the "covidization" of research (i.e., an excessive focus on COVID-19 research at the expense of other areas) (Pai, 2020a), and how this could jeopardize research essential to addressing other long-term social and environmental challenges (Pai, 2020b; Yoder, 2020).

COVID-19 is accelerating change across the research landscape as scientists find new ways to collaborate, and as researchers and publishers depart from standard practices.

The pandemic has also catalyzed scientific collaboration in some fields on scales and at speeds that would have been previously difficult to imagine. Chinese and Australian researchers published the genome sequence of SARS-CoV-2 less than two months after the emergence of the virus (Doudna, 2020). New open-access

8 Canadian COVID-19 research funding programs in this list include several National Research Council of Canada grant programs; private-sector grants announced by Vale Canada and Roche Canada; and the Canadian 2019 Novel Coronavirus Rapid Research program supported collectively by Canada's granting councils along with the International Development Research Centre and Genome Canada. By the end of June 2020, the Canadian 2019 Novel Coronavirus Rapid Research program received 227 eligible applications, and funded 100 grants for a total investment of $55.3 million (CIHR, 2020b).

resources on the genome of the virus were continually being developed, supporting and accelerating efforts to develop vaccines. The crisis also pushed researchers into adopting new strategies and tools for online collaboration, some of which may become entrenched due to their cost and efficiency benefits. Researchers speculate that the pandemic could lead to some long-term changes, such as conferences and meetings moving permanently online (with resulting environmental benefits and potentially more equitable access) (Viglione, 2020); greater reliance on "collective intelligence" to solve problems (NESTA, 2020); crowdsourcing (Callaghan, 2020); and an increased willingness to experiment with novel modes of funding allocation and research evaluation (Grant, 2020).

Scientific norms for publication and peer review are also being suspended in some cases to accelerate the translation of research into societal benefits. COVID-19 repositories and databases of papers were created to support tracking and analyses of the burgeoning research effort.[9] In many cases, academic publishers and platforms have lifted paywalls for a fixed period or for COVID-19-related research. Publishers have also collaborated in these efforts, with some releasing a joint statement on efforts to speed up publication and review processes (OASPA, 2020). Research results are also increasingly being publicized through pre-prints, prior to full peer review and publication, and sometimes in the absence of access to supporting data. More than 100 new papers on COVID-19 are posted daily on pre-print servers such as bioRxiv and medRxiv (Doudna, 2020). The need to rapidly translate research findings into beneficial therapies and policies may justify this trend; however, in some cases such departures are leading to high-profile reversals and retractions, which risk undermining public faith in scientific institutions and methods.[10] Vaccine reticence, and skepticism about public health messaging and interventions, further underscored the critical issue of public trust in science, prompting new research and reflections on how experts and scientific institutions understand their role in promoting public science engagement, awareness, and literacy (Agley, 2020; Kreps & Kriner, 2020; Eichengreen *et al.*, 2021).

9 As early as June 2020, over 42,700 scholarly articles on COVID-19 had already been published, alongside over 3,100 clinical trials, 420 datasets, and 270 patents (Hook & Simon, 2020); by November 2020, the number of scientific publications on COVID-19 had reached around 75,000 (OECD, 2021b).

10 The retraction of an influential paper on dangers associated with hydroxychloroquine as a COVID-19 treatment is indicative of such risks (Mehra *et al.*, 2020). Other widely publicized research later criticized on methodological grounds include influential modelling from Imperial College London (Ferguson *et al.*, 2020) and a study of antibody prevalence in Santa Clara County in California (Bendavid *et al.*, 2020).

The pandemic and associated public health interventions have been detrimental to many researchers, exacerbating pre-existing inequities in the research system.

While accelerating research efforts in some domains, COVID-19 is also disrupting projects and causing widespread, negative impacts on researcher productivity. New constraints on access to buildings and equipment imposed by lockdowns or physical distancing requirements disrupted research activities in many labs and facilities. Travel bans have also interfered with field work, causing project delays (Yeager, 2020). Negative impacts on research productivity stemming from the crisis are also exacerbating pre-existing inequities in the scientific establishment (Vincent-Lamarre *et al.*, 2020). Researchers with young families and caregiving responsibilities have been particularly impacted by closures of schools and daycares. These burdens fall disproportionately on ECRs and especially women, who are more likely to be responsible for child-care (Myers *et al.*, 2020). Unpublished analyses of trends on pre-print servers bioRxiv and arXiv indicate that the pandemic has disproportionately affected female investigators, as can be seen through a widening gender gap between women and men in the senior authorship position of manuscripts published on those servers (Frederickson, 2020; King & Frederickson, 2020).

With the long-term implications of COVID-19 uncertain, research funders will need to actively monitor and adapt to new developments as the pandemic evolves.

This pandemic could revitalize science in many ways, precipitating more creative and efficient use of the tools that scientists, governments, and research funders already have at their disposal. Expressing a hope that many changes brought on by the crisis will be beneficial and lasting, some researchers argue that “a new era for science” is emerging as scientists collaborate at unprecedented speeds and scales (Doudna, 2020). Yet such hopes are counterbalanced by concerns about a possible erosion of research quality, and the risks of declining research budgets as the economic damage and fiscal costs of the pandemic continue to mount. Others worry that the pandemic could further jeopardize investigator-led research by privileging priority-driven funding calls. The long-term implications of the pandemic remained fundamentally uncertain at the time of the Panel’s work, but funding agencies are now operating in a different environment and will need to carefully monitor and assess how these impacts on the science system continue to unfold in the coming years.

3

Supporting Researchers

Chapter Findings

- Hyper-competition for limited funding can interrupt or end researchers' careers, and has a particularly adverse effect on early-career researchers and on those from underrepresented groups, such as women, racialized individuals, and people with disabilities.
- While early-career researchers could be better supported if standard funding programs were adjusted (e.g., increased success rates), segmenting awards by career stage is particularly effective in supporting career development at all stages.
- Efforts to increase equity, diversity, and inclusion in the research community include diversity targets, targeted funding programs for disadvantaged applicants, linking equality charters to institutions' funding eligibility, and various initiatives to reduce bias in peer review.
- Indigenous research and researchers encounter unique pressures. Review panels often lack experience in evaluating Indigenous research, and many grant conditions, such as timelines, are unsuited to Indigenous research practices. The evidence suggests that these challenges are best addressed through specialized grant programs, dedicated review committees, funding community research teams, and other practices.

The changes in the research environment discussed in the previous chapter are impacting funders and researchers in a variety of ways. Average funding per researcher has decreased in many programs and jurisdictions, manifesting as a combination of declining success rates and smaller grant sizes. Increased competition for limited funds makes establishing or continuing research careers difficult, jeopardizing the development of the next generation of researchers (a central objective of many agencies). Ensuring equitable access to funds is also a challenge; researchers from underrepresented or disadvantaged groups[11] — including women,[12] racialized individuals, Indigenous persons, researchers with disabilities, and members of the LGBTQ2+ community — continue to encounter biases and structural barriers even as institutions increasingly prioritize their participation. Although efforts are growing in several countries to engage Indigenous communities and cultures, Indigenous researchers

11 Most evidence found and reviewed by the Panel focuses on the experiences of women, racialized groups, and Indigenous researchers; however, a lack of evidence pertaining to other groups should not be taken to mean that they do not experience barriers to participation in research.

12 Sources reviewed by the Panel were often inconsistent in their use of gender-based terminology (e.g., women) and sex-based terminology (e.g., female). Gender-based terms are used preferentially in this report.

face distinct challenges. This chapter reviews how funding agencies, such as NSERC, are taking steps to ensure that the scientific workforce thrives by supporting researchers throughout their careers, and by enhancing equity and diversity in the research community.

3.1 Supporting Researchers Throughout Their Careers

As noted in Chapter 2, government support for research has declined or remained flat (adjusting for inflation) in many countries since 2008, including Canada, France, Italy, and the United States (OECD, 2018d). Lower funding amounts per grant, combined with low success rates among applicants, require researchers to spend an increased portion of their time obtaining funding, often from multiple sources (Naylor *et al.*, 2017). Meanwhile, researchers unable to obtain funding may see their careers interrupted or even ended. A competitive funding environment is particularly challenging for early-career researchers (ECRs)[13] in that they are often at a disadvantage competing against more established researchers (Powell, 2016). Similar obstacles apply to researchers whose careers are impacted by caring responsibilities or work outside of research (ARC, 2020a). Because many funding agencies include capacity building among their objectives (OECD, 2018d), they have reason to be concerned when researchers' careers are interrupted or delayed. Various practices have been proposed with the aim of improving the current funding environment for researchers, considering their varying funding needs over the course of their careers.

High levels of funding inequality adversely affect the structure of the research workforce.

The grant review process often produces a cumulative advantage known as the "Matthew Effect." Applied to the context of research funding, this effect results in researchers who received funding in the past having a better chance of succeeding in future competitions (Merton, 1968; Bol *et al.*, 2018).[14] This effect is not solely attributable to increased productivity resulting from the initial grant. First, some

13 While there is no universal definition of *early-career researcher*, this report uses the term to refer broadly to newly independent researchers. As many countries have specialized programs for funding students and postdoctoral fellows, these will also be discussed briefly under the category of "trainees."

14 The Matthew Effect, first defined by Merton (1968) in the context of scholarly recognition, is now used in a variety of contexts to describe a "rich-get-richer" dynamic where possessing an initial wealth of some resource creates an advantage in obtaining more of that same resource. The name is derived from the biblical verse Matthew 25:29 which states "For to everyone who has, more will be given" (Perc, 2014).

grant programs explicitly include past grant successes in evaluation of a researcher's track record (ARC, 2020a). Further, evidence from an analysis of early-career funding competitions in the Netherlands suggests that grant reviewers often perceive past grant winners as more capable researchers, and that researchers who fall just below the funding threshold often become discouraged and are less likely to apply for future grants. As a result, research funding and resources tend to become more concentrated over time (Bol *et al.*, 2018). Funding concentration may also be driven in part by a tendency to use the monetary value and number of awards as markers of excellence or prestige. It has been argued that the criteria used for tenure, promotion, and grant evaluation may therefore motivate scientists to apply for a larger number of grants, and for grants of greater size (Sousa, 2008; Ioannidis, 2011). Some funders recognize or attract leading researchers with highly competitive, high-value awards, which can further amplify funding concentration.[15]

Due to these effects, and to policies focused on promoting scientific excellence, research funding has become more highly concentrated in many countries (Bloch & Sørensen, 2015), including Canada (Mongeon *et al.*, 2016), the United Kingdom (Ma *et al.*, 2015), and the United States (Katz & Matter, 2019). For example, in 2010 the top 10% of National Institutes of Health (NIH) researchers received approximately 40% of grant funds (Katz & Matter, 2019), while in 2018–2019, 10% of NSERC researchers received 57% of funds (NSERC, 2020b). In the latter case, the effect was likely driven by a combination of multiple awards and high-value grant programs, given the relatively high success rates of NSERC's Discovery Grants program.[16] Increasing funding concentration has many implications (Section 6.4). However, in terms of supporting researchers, dispersing funds more broadly throughout the researcher population provides better support for those in the early- and mid-career stages (Peifer, 2017). Given that the Matthew Effect can lead to compounding differences over the course of a career (Bol *et al.*, 2018), funders have investigated various approaches to counteract the trends towards concentration.

15 The Canada Excellence Research Chairs program is one example of this (SSHRC, 2020).

16 Though some Discovery Grants are of larger value, the mean annual value of an Individual Discovery Grant awarded to the 10% best-resourced researchers was $48,500, compared to a mean annual value of $33,000 for these grants when awarded to other researchers (NSERC, 2020b). This difference in mean Discovery Grant values accounts for only 3.6% of the difference in mean total values. The best-resourced 10% of researchers received on average 3.07 NSERC grants, while the rest received on average 1.17 grants.

One possibility is restricting the numbers of grants awarded per researcher, preventing a subset of researchers from accumulating a disproportionate number of grants (Li *et al*., 2017). Alternatively, researchers who receive funding above a certain value could be ineligible for certain grants, as in the Novo Nordisk Foundation's New Exploratory Research and Discovery program (Novo Nordisk Foundation, 2020). The cumulative advantage of the Matthew Effect can also be mitigated by removing information on past grant successes from the grant review process, and by providing appropriate feedback to researchers who narrowly miss funding cut-offs, encouraging them to submit future applications (Bol *et al*., 2018). Providing larger numbers of relatively smaller grants could also reduce inequality and mitigate the Matthew Effect (Bol *et al*., 2018). However, the disadvantages of splitting funding into smaller awards include the risk of researchers receiving grants too small to fund meaningful investigations, and the burden of having to apply for more grants for the same amount of funding. Basic grants have also been suggested to address both funding concentration and the time burdens of the application and peer-review system (Vaesen & Katzav, 2017) (Section 5.1).

Researchers from smaller institutions have unequal access to research funding.

Researchers at small institutions are particularly affected by funding inequality (Ma *et al*., 2015; Murray *et al*., 2016). In the United Kingdom, 90% of EPSRC project funding goes to researchers affiliated with the top 20% of institutions (Ma *et al*., 2015). In Canada, researchers at smaller institutions have less success in obtaining Discovery Grants compared to their counterparts at large institutions; when successful, they receive lower-value grants (Murray *et al*., 2016). Differences in teaching loads, infrastructure, and institutional resources, including access to trainee researchers, all likely play a role in this disparity, as summarized by Owen (1992). However, because this gap affects ECRs (whose research records are primarily based on the resources of their alma maters rather than those of their current institutions), bias also likely plays a part (Murray *et al*., 2016). An institution's reputation for research quality can be affected by biases related to geographic location as well the disciplinary focus of these institutions (Cantwell *et al*., 2020). Institutional inequality is increasing globally, and the concentration of resources in prestigious institutions is particularly high in certain countries, such as the United States (Cantwell *et al*., 2020).

Institutional inequality has the potential to reinforce individual inequality, as economically disadvantaged or underrepresented researchers are less likely to have access to well-resourced universities boasting strong research infrastructure and high graduate school placement rates (Marginson, 2006; Posselt *et al.*, 2012). In the United States, Graduate Research Fellowships Program awardees tend to concentrate at institutions with high research expenditures (Hu, 2019). Due to the tendency of advantages to add up, differences in opportunity beginning at the undergraduate level likely affect access to research training and career opportunities. To reduce the risk of bias in evaluating researchers at smaller institutions, adjustments to review processes could be implemented, including blind review (Murray *et al.*, 2016), or emphasizing the strength of a proposal over the applicant's track record (Section 3.2). Removing or de-emphasizing criteria related to institutional support also increases the accessibility of funding to researchers at less-resourced institutions. Award structures that require institutions to protect a certain amount of research time (discussed later in this section) may alleviate demands on researchers with high teaching loads.

Alternatively, funding envelopes can be set aside to build research capacity in regions that are less competitive. An example of this strategy is the United States' EPSCoR RII Track-1 program, administered by NSF. Jurisdictions that have received relatively little support from NSF over the past three years can apply for these awards to fund projects that build infrastructure or develop highly qualified personnel (NSF, 2020e). Statistical analysis indicated that, while this program increased research capacity, its effect size was modest and it did not meaningfully impact institutional inequality — after 30 years, no participating state has improved its performance in obtaining competitive funding enough to become ineligible for the EPSCoR program (Wu, 2010). The United Kingdom's Strength in Places Fund is another program focused on developing regional capacity by building on local research strengths; evaluation of this program is pending (UK Parliament, 2020).

Bridge funding and permanent staff scientist positions provide researchers with stability and support career advancement.

Sustained funding helps all researchers and may be particularly important in enabling high-impact research (Naylor *et al.*, 2017). Though ideally every deserving proposal would be funded, this is rarely possible, and losing funding can disrupt a research team, causing a loss of capacity (Johnson *et al.*, 2015). Bridge funding can help reduce the impact of such funding gaps. For example, NIH's High Priority, Short-Term Project Award, the R56, provides one or two years of funding to selected projects that narrowly missed the funding cut-off for an R01 grant. This bridge funding is used to gather additional data to support a revised R01 proposal (NIH, 2019a). Bridge funding can give researchers unsuccessful in renewing their grant the opportunity to improve their applications for re-submission rather than halting programs due to cost. Moreover, the number of smaller bridge funds relative to fully funded projects can be adjusted to ensure that a similar number of researchers gain access to some funding even in years with unusually heavy competition (OECD, 2018d).

In many countries, a significant portion of researchers are working in temporary positions such as postdoctoral fellowships with poor long-term job prospects. In a recent international survey, 56% of postdoctoral researchers reported feeling somewhat or extremely negative about their career prospects, naming competition for funding and lack of available jobs as the biggest challenges (Nature, 2020b). Increasing the number of staff scientist positions (i.e., permanent, non-tenure-track researchers) can promote a better balance between numbers of trainee researchers and stable research positions, in contrast to the current over-supply of postdoctoral roles. Though there are costs to this approach, it benefits the research system by better capitalizing on the experience of staff scientists (Tilghman *et al.*, 2012). In particular, staff scientists are well placed to provide long-term technical support in specialized areas, which is a growing need in multiple fields including life sciences and physics (Heiss, 2019; Adami *et al.*, 2020). Recent interviews with staff scientists indicate that the role provides an opportunity to continue to contribute to research, and grow professionally, while removing some of the constraints and pressures associated with the postdoctoral-to-faculty track (Kuo, 2017).

Funding agencies can support staff scientist positions that would otherwise be filled by temporary, postdoctoral fellows through mechanisms in project grants (Tilghman *et al.*, 2012) or through direct salary support such as the EPSRC and the Chan Zuckerberg Initiative fellowships in software engineering and imaging, respectively (CZI, 2020; UKRI, 2020d). Fellowship holders for these programs — who must have PhDs and research experience — are expected to provide timely expert support to multiple research groups and train students to build further capacity in certain technical domains. Such funding for staff scientists could also be paired with an increased salary scale for experienced postdoctoral scholars,[17]

17 Canada is unusual in that it lacks an experience-based postdoctoral salary scale (CAPS, 2016).

minimizing institutions' incentive to rely on these researchers as inexpensive labour past the point at which they are receiving meaningful training (Tilghman *et al.*, 2012). Since postdoctoral researchers in the United States are largely funded by project grants, NSF motivates postdoctoral training by requiring a mentoring plan for any such researchers funded by a project grant proposal (NSF, 2020c). Other mechanisms for improving postdoctoral training opportunities include training grants or specialized types of funding programs (Tilghman *et al.*, 2012) as discussed later in this section. Emphasizing the training purpose of postdoctoral fellowships while encouraging transitions to stable research roles would enhance the value and well-being of the NSE workforce.

Appropriate evaluation criteria, including non-research activities, recognize the variety of contributions researchers make over their careers.

Scientific merit is assessed by funders through the design and application of specific evaluation criteria. While review criteria are tailored to reflect the objectives of each program, the current funding environment tends to reward publications and citations at the expense of other scholarly contributions. Some funding agencies recognize that this discourages researchers from taking on broader roles in the research system or in society. For example, the Netherlands has proposed that the assessment underlying funding decisions should be based on a broader set of criteria, such as teaching, mentoring, entrepreneurship, science communication, and societal impact (Gov. of the Netherlands, 2014). Similarly, NSF requires principal investigators (PIs) and faculty listed on grants to submit biographical sketches that include activities such as "innovations in teaching and training," development of methodologies or databases, and other activities that serve the broader research community (NSF, 2020c). These sketches complement NSF's Broader Impacts criterion for evaluating the impact of research projects (Section 5.2). The Australian Research Council's (ARC) Research Opportunity and Performance Evidence Statement includes patents, industry funding, mentoring, and policy development as evidence of research impact (ARC, 2020a). In implementing such evaluation criteria, it is important to ensure that they do not *require* researchers to excel in every listed area of scholarly contribution. Flexibility in recognizing a variety of different contributions provides an opportunity for researchers to identify those activities most suitable to their skills and area of research (van Drooge & de Jong, 2015; ARC, 2020a; NSF, 2020c).

Criteria related to mentoring can be challenging to implement. Such criteria disadvantage ECRs, who, being new to leading labs, have had less time in which to train highly qualified personnel (Naylor *et al.*, 2017). At the same time, mentoring provides an important contribution to research. Thus it is important to evaluate senior researchers on their mentoring activities, as discussed by the ARC (2018b) in evaluating its Discovery Indigenous grant, and as emphasized in the ARC's prestigious Laureate Fellowships, which evaluate past and expected future mentoring activities (ARC, 2020b). Any reliance on metrics prone to increase over time, such as number of publications, tends to disadvantage ECRs, and it is unclear whether simply informing grant reviewers to take career stage into account would be enough (Flood & Schuett, 2017). Machine learning algorithms have been proposed by Ebadi and Schiffauerova (2016) as an approach to counteract these biases against ECRs, but algorithms may perpetuate other forms of bias from past funding decisions, such as reinforcing the Matthew Effect if previous funding is an input variable. Other approaches are needed to ensure that researchers are evaluated using criteria appropriate to their career stage.

Scholarships, fellowships, and training programs provide students and postdoctoral researchers with independent development opportunities and improved career transitions.

Graduate scholarships and postdoctoral fellowships are important tools for launching recipients on productive research career tracks. Such awards provide trainees with the flexibility to choose their own projects rather than being limited by a supervisor's grants (NORC, 2014). NSF Graduate Research Fellows have a higher rate of PhD completion, report greater flexibility in choosing their research project, and have better career outcomes in terms of future research contributions such as publication and reviews (NORC, 2014). NIH postdoctoral fellowships increase five-year publication rates for recipients by 20%, and increase the probability that recipients will continue a career in research (Jacob & Lefgren, 2011). While funding at the master's level is complicated by disciplinary and jurisdictional differences and the extent to which programs are research based, findings related to PhD scholarships may apply to research-focused master's programs that last two or more years.

However, designing effective and equitable fellowship programs can be challenging. It can be difficult to assess the research potential of scholarship applicants, since bibliometric indicators cannot be used to evaluate researchers at the beginning of their careers (Académie des sciences, 2011). Some evidence suggests that peer review is superior to alternative methods for awarding scholarships. Recipients of São Paulo Research Foundation (FAPESP) PhD scholarships in NSE disciplines — which are awarded through peer review — had higher publication rates during and immediately after their PhDs than those receiving scholarships awarded using non-standardized institutional criteria (Bin *et al.*, 2015). Award amounts that do not cover cost of living also create challenges for trainees from lower socioeconomic backgrounds. In a recent Canadian survey, approximately two-thirds of respondents in NSE disciplines[18] indicated that they required other income while holding a federal graduate or postdoctoral award, with many relying on savings or family support (SPE, 2019). This is unsurprising given that the values of Canada's federal graduate awards (the Canada Graduate Scholarships for master's and doctoral students, NSERC doctoral awards, and Vanier awards) have not increased since 2008 (CCA, 2021). The value of postdoctoral fellowships was increased in 2014 to its current value (NSERC, 2015a, 2020f), but is still below what was recommended by fellows and their supervisors in 2013 (Ekos Research Associates, 2013). In the United States, approximately 40% of NSE doctorate recipients reported using personal savings as a source of financial support during their graduate studies, and approximately 30% reported using family earnings or savings (NSF, 2019b).[19] Research careers are less accessible for students unable to draw on supplementary sources of income.

Training for PhD students and postdoctoral fellows that develops links to industry and transferable skills supports the integration of researchers into the workforce (CCA, 2021). International funding agencies increasingly support programs incorporating entrepreneurship and research translation into research training. The Centres for Doctoral Training program in the United Kingdom funds cohort-based doctoral programs that include training in transferable skills and responsible research and innovation, and the formation of links with industry (EPSRC, 2018b, 2020b). At the postdoctoral level, the UK Research and Innovation (UKRI) Future Leaders Fellowship is designed to support researchers in the process of becoming independent, particularly as they move between sectors or undertake projects that create links between academia and business (UKRI, 2018). The NSERC Collaborative Research and Training Experience Program (CREATE) has similar goals, but directs funding to senior researchers rather than institutions or fellows (NSERC, 2020h). In addition, the NSF I-Corps program (Section 5.2) is designed such that graduate students and postdoctoral scholars typically serve as entrepreneurial leads on projects (NSF, 2020b); over 1,400 entrepreneurial leads have been trained under this program since 2011 (NSF, 2019a). The Panel also observes increasing efforts to train young scientists to do outreach. For example, the Stephen Hawking Fellowships for postdoctoral researchers in theoretical physics have a particular focus on scientific communication and outreach (UKRI, 2020c).

18 That is, 66% of respondents in life sciences and 65% of respondents in the physical sciences, mathematics, and engineering.

19 Rates were variable by discipline and gender.

A variety of grant programs are now designed to support the transition of researchers from the graduate or postdoctoral level to independent careers. For example, the NIH Early Independence Award is available to recent doctoral graduates who have spent no more than 12 months in a postdoctoral position and have an offer of an independent position from a host institution (NIH, 2020a). A similar requirement that the host institution offer an independent research position at the end of an award is included in the Dutch Research Council (NWO) Talent Scheme (specifying a tenure-track position for Vidi grant recipients), the UKRI Future Leaders Fellowship, and the FRQS Chercheurs-boursiers Senior Award (NWO, 2017a; FRQS, 2018; UKRI, 2020a).

Dedicated funding envelopes and segmenting awards by career stage provide ECRs with autonomy to develop their own research programs.

ECRs often struggle to compete with more senior researchers, having had less time to build their CVs, and often having less support and experience in preparing lengthy grant applications (Flood & Schuett, 2017). High success rates are particularly important for allowing ECRs to establish research programs (Naylor *et al.*, 2017). The funding of research teams has been shown to result in established researchers sharing funding with junior researchers (who may not be able to compete for funds on their own) through the process of delegating sub-projects (Li *et al.*, 2017). Such funding structures may reduce the time that ECRs spend applying for funding, allowing more time for research. However, ECRs report that being listed as co-investigators on grant applications with more senior PIs is of limited benefit when it comes to career development and advancement (Naylor *et al.*, 2017). Further, challenges in assessing individual contributions to collaborative projects may adversely affect ECRs (ARISE, 2008). Bourguignon (2018) argues that individual funding, and preferably grant-based funding for investigator-led research, is key for ECRs to become independent.

Some funders choose to support ECRs within their main funding programs, perhaps with a mechanism for ensuring that ECRs achieve a minimum threshold of success, as is the case with NSERC's Discovery Grants program (NSERC, 2020j). However, others are employing dedicated funding programs for ECRs. For example, despite targeting 15% of its Discovery Award budget towards ECRs, the ARC observed low success rates for these investigators and an increase in the proportion of ECRs applying as part of a team with senior researchers, motivating the creation of a separate Discovery Early Career Researcher Award (ARC, 2010). Additional examples of programs are highlighted in Table 3.1, where they are categorized according to three main funding practices: salary support, project funding, and segmenting awards by career stage.

Table 3.1 Selected Practices for Supporting Researchers Throughout Their Careers

Practice	Examples	Evidence of Success
Salary support for ECRs	**Salary Programs** (CIHR, Canada) **Scholar Program** (Michael Smith Foundation for Health Research, Canada) **Discovery Early Career Researcher Award** (ARC, Australia)	Researchers with CIHR salary support awards publish more papers than non-awardees, and some evidence suggests ECRs have quicker career progression, though a significant difference in research time was not observed (77% for awardees versus 71% for non-awardees) (CIHR Evaluation Unit, 2012).
Dedicated project funding for ECRs	**Director's Early Independence and New Innovator Awards** (NIH, USA) **Discovery Early Career Researcher Award** (ARC, Australia)	New Innovator awardees see increases in impact measures compared to non-awardees and ECRs with traditional grants, but are similar on other professional indicators (NIH & STPI, 2016).
Awards segmented by career stage	**Chercheurs-boursiers: Junior 1, Junior 2, Senior** (FRQS, Canada) **Veni Vidi Vici** (NWO, Netherlands) **Starting, Consolidator, and Advanced Grants** (European Research Council)	Six years after application, NWO grant recipients are more likely to stay in academia and become full professors, but less likely to have a permanent position, possibly because unsuccessful applicants are motivated to obtain less desirable permanent positions, while successful applicants do not feel pressure to obtain such security (Gerritsen *et al.*, 2013).

Salary support allows newly independent researchers to dedicate most of their time to research, protecting their time from teaching or administrative responsibilities (MSFHR, 2020). Project funding supports ECRs' research more directly. Some programs, such as the NIH Director's New Innovator Award, involve larger funding amounts (up to US$1.5 million over five years) and allow ECRs to participate in highly competitive grant programs without being evaluated alongside established researchers (NIH, 2020b). The New Innovator Award is notable for enabling ECRs to participate in riskier research while providing career benefits similar to the traditional R01 grant program (NIH ACD, 2019). Some programs, such as ARC's Discovery Early Career Researcher Award and Future Fellowships, include both salary support and project operating funds (ARC, 2019).

Examples of awards that are segmented so that researchers compete with applicants at similar career stages include the Netherlands' Veni Vidi Vici awards (NWO, 2021) and the European Research Council's (ERC) Starting, Consolidator, and Advanced awards (ERC, 2020a). Based on Panel members' experience and discussions with research funders, these types of programs are particularly successful in supporting researchers at different career stages. NWO grant recipients are more likely to stay in academia and become full professors six years after application than unsuccessful applicants (Gerritsen *et al.*, 2013). A 2017 ERC evaluation found that 83% of projects receiving an Advanced grant, and 75% of those receiving a Starting grant, produced either a major scientific advance or a breakthrough, indicating that both ECRs and established researchers funded through these structures frequently generate high-impact work (ERC, 2018b). Notably, two-thirds of the ERC's grant support is directed to researchers under 40 (Didili, 2020). Both the NWO and ARC schemes provide awards that increase in value as the researcher's career stage advances, reflecting a possible change in optimal grant size at different stages. The Panel further notes that such programs give funders the opportunity to manage the labour force structure by providing targeted support to different segments. By calibrating the amount of support for each segment, funders can help promote a steady succession of researchers across different career stages.

In designing these types of awards, however, it is important to account for career-stage transitions. In Canada, for example, the two-tier Canada Research Chairs (CRC) program created gaps in support for early- and mid-career researchers. Tier 2 CRCs are only available for ECRs in tenure-track positions (GC, 2021b), which excludes an increasing number of young researchers as such positions become increasingly rare (Flood & Schuett, 2017). In contrast, the FRQS Chercheurs-boursiers program, which has similar researcher recruitment goals, provides segmented salary awards for early- and mid-career researchers who are not necessarily in tenure-track positions (FRQS, 2018). In addition, Naylor *et al.* (2017) note that the increasing age and experience of researchers supported by renewable Tier 1 CRC awards reveals a gap in support for mid-career researchers no longer eligible for Tier 2 awards. Limiting Tier 1 awards to one renewal (GC, 2017) helps address this concern, however these awards may also be inaccessible to mid-career researchers because of Tier 1 criteria such as international leadership. Flood and Schuett (2017) argue that this criterion can be difficult for researchers to demonstrate until roughly 5 to 10 years after they cease to be eligible for Tier 2 awards. Dedicated award programs for mid-career researchers can be introduced to provide support for NSE scientists at this stage; for example, the ARC's Future

Fellowships have had a positive impact on mid-career researchers (ARC, 2010). However, the Panel believes that the explicit inclusion of early- and mid-career researchers in a continuum of awards segmented by career stage is less likely to overlook career transitions than programs focused on one career stage in isolation.

3.2 Supporting Equity, Diversity, and Inclusion in the Research Community

Recent analyses of the OECD International Survey of Scientific Authors (OECD, 2020a) and staffing data for 15 globally competitive universities (Khan *et al.*, 2019) indicate persistent underrepresentation of women and racialized individuals in academia. Gender-based discrepancies are particularly pronounced in the physical sciences and engineering, as opposed to life sciences or social sciences (Institute of Medicine, 2007; CCA, 2012a).[20] According to a U.S. study that followed the academic careers of PhD recipients, scholars from underrepresented groups tended to produce more novel scientific findings, but these findings were less likely to be taken up by other scholars or result in successful careers (Hofstra *et al.*, 2020). Biases within the current grant review system negatively impact women (Institute of Medicine, 2007) and preliminary observations suggest that similar biases affect members of racialized groups (Gandy *et al.*, 2018). Poor success rates for women ECRs, compared to men, may contribute to these women leaving research (ARC, 2010). As noted in Chapter 2, COVID-19 is exacerbating some of the challenges faced by marginalized researchers, further disadvantaging groups that are already underrepresented (Kramer, 2020). While increasing funding dispersion is one approach for increasing the diversity of researchers (Katz & Matter, 2017), fully addressing these issues requires significant changes to evaluation criteria and research cultures (Institute of Medicine, 2007). Funding agencies are consequently exploring a variety of practices to enhance EDI in the research community.

Funding practices involving calls for applications and grant review can have equity implications through a variety of mechanisms.

Different funding outcomes can manifest through differences in application rates, success rates, or funding level. For example, inequities within NIH high-risk/high-reward grants such as the New Innovator Award are driven primarily by differences in application rates rather than in success rates (Lee & Tabak, 2019). Meanwhile, gender gaps in success rates have been reported in programs administered by CIHR (Witteman *et al.*, 2019) and the NWO (van der Lee &

20 In the Canadian context, women made up only 9% of full professors in physical sciences, computer sciences, engineering, and mathematics in 2008–2009, compared to 23% of full professors in the life sciences and 29% of full professors in the humanities, social sciences, and education (CCA, 2012a). Gender balance in the Canadian professoriate is further discussed in Section 6.3.

Ellemers, 2015). Gender differences in award amounts among successful recipients have been noted in the NSERC Discovery Grants program (Urquhart-Cronish *et al.*, 2019) as well as Wellcome Trust grants in the United Kingdom (Bedi *et al.*, 2012). Overall, based on analysis of first names,[21] out of the 10% of NSERC award recipients receiving the greatest total amounts in 2019–2020, approximately 76% were men, compared to 70% of all funded researchers (NSERC, 2020b); as these data did not include career stage, this finding could be due at least in part to the demographics of senior researchers (Section 6.3).

Increased outreach to members of underrepresented groups, through conference presentations that encourage them to apply for awards, for example, has been proposed as a mechanism for improving application rates (NIH, 2019b). However, greater attention may also be paid to gender-exclusive language (e.g., "man-hours") and gender stereotypical language (e.g., "independent" versus "thorough").[22] Such language has been observed in grant evaluation criteria, including applicant-directed materials (van der Lee & Ellemers, 2015). Gendered language in job advertisements can reduce their appeal to women by conveying that they do not belong in these jobs (Gaucher *et al.*, 2011), and language in grant application materials may contribute to a reported tendency for women to see themselves as less competitive for prestigious awards (Sheil, 2011).

Other equity concerns arise during peer review. "Person-based" awards that evaluate the achievements of individuals support independence and provide stable funding for flexible research (Section 4.3). However, women had lower success rates than men when applying for the CIHR Foundation Grant, which is attributed to the grant's focus on quality of the researcher as a criterion (Witteman *et al.*, 2019). The precise mechanism of this bias remains unclear, but strong possibilities include individual reviewer bias, systemic inequalities in access to CV-building opportunities, different prioritization of non-research activities such as mentoring, and differences in how women present their professional accomplishments (Witteman *et al.*, 2019). The Foundation Grant program has been discontinued because of these and other biases (CIHR, 2019b). Lower assessments of women on a "quality of researcher" criterion were also observed in the person-based Talent Scheme in the Netherlands (van der Lee & Ellemers, 2015).

21 Name analysis was performed using the R package "gender" as described by Blevins and Mullen (2015). This method relies on U.S. Census data. Thus, it cannot capture individual gender identities that differ from those recognized by the state, and the analysis may not accurately capture the gender of names from other cultural contexts, such as francophone names. Recipients of undergraduate awards were excluded from the analysis.

22 Van der Lee and Ellemers (2015) define gender stereotypical language based on work by Schmader *et al.* (2007) and Gaucher *et al.* (2011), who in turn draw on studies by Bem (1974), Spence *et al.* (1979), Trix and Psenka (2003), and Madera *et al.* (2009). Words are categorized as masculine or feminine stereotypical in part based observed differences in language used by reference letters to describe men and women. For example, adjectives categorized as *standout* (e.g., "outstanding") or *agentic* (e.g., "independent" or "objective") are more associated with men, while *grindstone* (e.g., "thorough") or *communal* (e.g., "understanding" or "helpful") terms are more associated with women.

To counter biases in grant review, NIH has recently announced a plan to anonymize or "blind" peer reviews for its Transformative Research Awards (Lauer, 2020). This move builds on previous changes to its Pioneer Award and New Investigator Award, which delay the assessment of the researcher biosketch until the second phase of review (NIH, 2019b). Similarly, the São Paulo Research Foundation (FAPESP) structures its peer review around a set of questions (Osório de Almeida, 2011), and the Panel heard during interviews that questions about the research are prioritized before those about the researcher. However, blind reviews can be problematic. In some cases, reviewers may be able to identify the author from the described research, introducing a new inequality to the process. Moreover, evaluative criteria can perpetuate bias when developed without the input of researchers from underrepresented groups (Acker, 1990). Adjustments to how certain types of research activities are valued may improve the prospects of marginalized researchers in peer review. For example, a Danish study suggests women are overrepresented in interdisciplinary (compared to within-discipline) collaborations (Nielsen, 2017), so efforts to support interdisciplinary research (Section 4.1) may also improve funding access for women.

Standardizing aspects of evaluation based on transparent, clearly defined metrics may be one strategy to mitigate bias (Ioannidis, 2011). However, biases at the review stage can be exacerbated by reliance on bibliometrics. For example, a bibliometric performance indicator used to assign funding to universities in Denmark has been shown to widen the gender gap in research performance from 14 to 20% as compared to assessments based solely on the number of published articles. This could result from the greater participation of men in large and international research collaborations, or from the underrepresentation of women on the committees determining which publications are considered more impactful for the purpose of this metric (Nielsen, 2017). Despite the fact that this Danish metric is intended to evaluate institutions rather than individuals, there is evidence of departments using it to assess the performance of researchers, which could potentially disadvantage women in promotion decisions (Aagaard *et al.*, 2014; Nielsen, 2017). While it is not always inappropriate to use bibliometrics to evaluate researchers, due to biases and other inadequacies, the use of such metrics in individual grant selection must be approached with a high degree of caution, and they should always be subordinate to the judgment of expert reviewers (Académie des sciences, 2011; CCA, 2012b; Hicks *et al.*, 2015).

Equality charters have succeeded in advancing EDI, though the benefit of linking their adoption to funding eligibility is uncertain.

With equality charters, institutions commit to a set of principles and develop and carry out equality action plans (AAAS – SEA Change, 2020). Progress on these plans is measured through a review process in which institutions are granted non-monetary awards (e.g., bronze, silver, and gold ratings) (Athena SWAN Charter Review Independent Steering Group, 2020). These charters originated with the Athena SWAN program in the United Kingdom, but the same framework is currently used in Australia under the SAGE program (SAGE, 2020), and in the United States under SEA Change (AAAS – SEA Change, 2020). In the United Kingdom, a separate Race Equality Charter has recently been developed (Advance HE, 2020a), while the SEA Change charter addresses gender and racial equity simultaneously and intersectionally (AAAS – SEA Change, 2020). NSERC, along with SSHRC and CIHR, is also piloting a charter program called Dimensions: Equity, Diversity and Inclusion Canada, which includes a variety of underrepresented groups in its mandate (GC, 2019d).

The original Athena SWAN program has been evaluated repeatedly and positively. Athena SWAN award-holding departments have more women staff and higher career satisfaction among women (Graves *et al.*, 2019). Case studies indicate positive impact, and departments that have submitted award applications show positive trends in some gender-balance indicators (Graves *et al.*, 2019). However, some concerns have been raised about the current implementation of Athena SWAN, particularly the administrative burden of the application process, the consistency of evaluation, and whether the application format accurately captures progress for all institutions (Athena SWAN Charter Review Independent Steering Group, 2020). The United Kingdom's Race Equality Charter has not yet been formally evaluated.

The impact of equality charters can be increased through the development and dissemination of successful practices. A Good Practices Database has recently been introduced to share insights from the Athena SWAN and Race Equality Charter (Advance HE, 2020b), and Canada's Dimensions EDI charter includes a commitment to "institutional collaboration, transparency, and the sharing of challenges, successes and promising practices" (GC, 2019d). In addition, providing funding to assist institutions in undertaking improvements related to equality charters could make the work more sustainable and less dependent on volunteers, most of whom are women (Rosser *et al.*, 2019). In this respect, NSF's ADVANCE program is an interesting example, which provides Institutional Transformation grants that fund both institutional changes to improve gender balance in STEM (such as better data collection related to gender gaps) as well as research into gender equity (such as methods for reducing bias) (Rosser *et al.*, 2019). Institutions receiving ADVANCE grants reported better gains than non-recipients in women faculty, new hires, and leadership roles (Case Western Reserve University, 2018 as cited in Rosser *et al.*, 2019).

Funding agencies could also incentivize participation in equality charter programs by linking ratings to eligibility criteria. For example, a silver Athena SWAN award is required to receive U.K. National Institute for Health Research funding (Donald *et al.*, 2011). Interviews and surveys targeting staff in medical science departments at the University of Oxford indicate that, while linking the Athena SWAN program to funding eligibility encouraged departments to participate, there are concerns that external mandates to implement the program could lead to administrative box-checking rather than genuine change (Ovseiko *et al.*, 2017). Achieving the full benefits associated with equality charters may require some level of intrinsic motivation on the part of participating institutions.

It is also possible to recognize applicants' individual EDI efforts. This approach has been taken by NSF through its Broader Impacts criterion, and by Fonds de recherche du Québec – Nature et technologies (FRQNT, 2019; NSF, 2020c). The adoption of EDI criteria for grant applications requires funders and reviewers to determine how EDI efforts will be evaluated, and places the responsibility of advancing equity on the applicant, rather than on the department.

Diversity targets and support for collaboration can be used to counteract systemic inequalities.

Diversity targets may be effective in some cases. They have, for example, been used in Canada with CRC appointments, which by 2019 had (despite inconsistent progress) met representation targets for women, racialized individuals, Indigenous researchers, and researchers with disabilities (GC, 2019b). Programs specifically targeted to researchers from disadvantaged groups can have significant impacts. Examples of these include the Rosalind Franklin Fellowship at University of Groningen, Netherlands, which is awarded to women (Gov. of the Netherlands, 2014), and the Georgina Sweet Fellowship, granted as an additional award to the top woman applying for the ARC Laureate Fellowship in a field of science & technology (Sheil, 2011). Such targets, however, may do little to address the underlying drivers of underrepresentation.

Women may need additional funding support related to international collaboration, where men are overrepresented (Uhly *et al.*, 2017). The geographic mobility of scientists during and after their training correlates with participation in international collaborations (Scellato *et al.*, 2015). Women's participation in international research visits decreases in later career stages compared to men's, which may contribute to diminished international networks (Jöns, 2011). This creates barriers for women in extracting maximal benefits from collaborations. Ferreira and Klutsch (2018) argue that barriers related to family commitments can be reduced by funding spousal support or moving expenses. However, such policies should be carefully evaluated to ensure that they provide the intended benefit to women. For example, some gender-neutral policies allow new parents to extend the amount of time before their tenure evaluation, with the intent of accommodating caregiving responsibilities. However, a study of economics departments found that men are disproportionately able to use this extra time to publish additional papers, widening the gender gap in tenure rates (Antecol *et al.*, 2016).

Underrepresented groups benefit from guidance in obtaining funding, but caution must be exercised to ensure that service workloads do not unduly impede these researchers.

Time constraints related to greater teaching burdens and service loads may contribute to lower application rates among women to prestigious grants (Easterly & Pemberton, 2008; Leberman *et al.*, 2016), as noted above with respect to the NIH New Investigator Award (Lee & Tabak, 2019). Empirical evidence that women have higher teaching burdens is mixed.[23] However, there is stronger evidence that women, racialized faculty, and other marginalized groups have disproportionate service workloads (e.g., serving on departmental committees or diversity task forces),[24] which might limit grant-writing and research time. Women indicate that long application processes and lack of feedback on some grants (e.g., the Marsden Fund; see Section 5.1) can contribute to the perception that the application time was not well spent (Leberman *et al.*, 2016). Thus, providing feedback while improving the efficiency of the application process may increase application rates for researchers under time constraints.

Marginalized researchers also often lack access to mentoring (CCA, 2012a; McCoy *et al.*, 2015), which may contribute to lower success rates in grant applications (Leberman *et al.*, 2016). Funding agencies can address this issue by providing targeted grant-writing support, and by giving marginalized researchers avenues for mentoring outside their institutions. The Georgina Sweet Fellowship provides an interesting example of mentoring support. The award includes, in addition to

23 Park (1996) synthesizes evidence from multiple sources demonstrating significant gender-based historical differences in teaching and service responsibilities among university faculty, and O'Meara *et al.* (2017) find similar discrepancies in more recent studies, controlling for rank. However, the Social Sciences Feminist Network Research Interest Group (SSFNRIG) (2017) finds no significant differences in teaching responsibilities when controlling for rank, and Meyer and Xu (2009) find that women have a lighter teaching load both within research-focused and community (teaching-focused) colleges.

24 Misra *et al.* (2012) found that women at associate professor rank reported an extra two hours of mentoring and five hours on other service activities every week, compared to men, while the Social Sciences Feminist Network Research Interest Group (SSFNRIG) (2017) finds differences at assistant professor rank in service work for women and faculty from marginalized groups (defined as "faculty of color, queer faculty, and faculty from working-class backgrounds"). Regardless of rank, Guarino and Borden (2017) report heavier service loads for women, and Misra *et al.* (2012) report heavier service loads for racialized faculty.

research funding, AU$20,000 per year for five years to be used for mentoring and promoting women in research. Georgina Sweet Fellows have initiated a variety of equity initiatives, including the introduction of the SAGE equality charter in Australia (ARC, 2018a). However, Adkins and Dever (2015) have expressed concerns that including an extra mentoring focus in these types of fellowships risks assigning the work of addressing EDI issues disproportionately to women.

Similar dynamics might be observed in NSERC's Chairs for Women in Science and Engineering (CWSE) program. The CWSE program was previously recognized in an international review of "exemplary and promising practices" for gender equity in engineering (Mody & Brainard, 2005). These Chairs undertake various outreach and mentoring activities for women, including engaging in efforts focused on Indigenous women (Croft *et al.*, 2012), and stakeholders generally perceive a "significant" return on investment for this program (Whynot *et al.*, 2019). However, the Chairs commit half their time to program activities, and previous Chairs reported challenges in maintaining research activities and their professional reputations (Williams *et al.*, 2002). Current requirements that Chairs be released from part of their teaching and administrative load and provided with additional funding for postdoctoral fellows may have mitigated these burdens (NSERC, 2020g).

Including service activities or public outreach in funding criteria (Section 3.1) could level the playing field for researchers from underrepresented groups who find themselves spending relatively large amounts of time engaging in mentoring or other diversity initiatives to address structural barriers. Outreach and mentoring programs for members of underrepresented groups are likely to be more effective if combined with other strategies for improving EDI, as discussed throughout this section.

3.3 Supporting Indigenous Researchers and Research

Indigenous research and researchers merit unique considerations in some regions. Such research is of particular significance to Canada due to its colonial legacy and its focus on reconciliation (GC, 2019a); other countries, such as Australia, Denmark, Finland, New Zealand, Norway, Sweden, and the United States, share similar considerations in supporting Indigenous research (Juutilainen & Heikkilä, 2016; Ríos *et al.*, 2020). This section thus considers the separate but interrelated issues of individual pressures on Indigenous researchers (whether or not they are engaged in Indigenous research) and funding considerations for Indigenous research (Box 3.1) regardless of whether Indigenous researchers are the primary investigators. While the Panel summarizes key challenges and promising approaches based on recent initiatives, it notes this kind of review cannot substitute for close, ongoing collaboration with Indigenous communities and researchers on how funding practices can be adjusted to better serve these communities.

Box 3.1 What Is Indigenous Research?

Tuhiwai Smith (2018) describes Indigenous research as "research carried out by Indigenous researchers, for Indigenous researchers, and with Indigenous communities" and "particularly research that draws on Indigenous Knowledge, uses Indigenous methodologies, and seeks to improve the lives of Indigenous peoples." Indigenous research centres on Indigenous perspectives and communities, but can involve non-Indigenous scholars collaborating with Indigenous communities (Pidgeon, 2019). While much of the discussion on Indigenous research concerns social sciences or health research, Indigenous research also occurs within NSE fields such as ecology and environmental change (Sjöberg *et al.*, 2018).

Longer timeframes, changes to allowable expenses, and greater community input in review processes can improve support for Indigenous research.

Indigenous research is typically characterized by relationship building and community engagement. These require longer timeframes and more preliminary work than assumed by standard grant-funding length and milestone expectations (Weston *et al.*, 2009; Gittelsohn *et al.*, 2020). Building the expected publication record can be challenging for researchers who spend the time to engage Indigenous communities and who respect Indigenous data sovereignty (Gewin, 2021). Community engagement also requires funding expenses often excluded from standard funding packages, such as salaries for community research staff (Gittelsohn *et al.*, 2020; Williams *et al.*, 2020), food for meetings with Indigenous community members in accordance with cultural expectations (Gittelsohn *et al.*, 2020), and thorough research dissemination (Wong *et al.*, 2020).

Proposed Indigenous research projects can be challenging to evaluate based on standard ways of assessing research methods, ethics, and impacts. Indigenous methodologies and concepts can be difficult to convey to peer reviewers using English rather than Indigenous languages (Gifford & Boulton, 2007). Australia, Canada, New Zealand, and the United States have developed ethical guidelines for Indigenous research, and this appears to have created greater understanding compared to Nordic countries where such guidelines are not well established (Juutilainen & Heikkilä, 2016; Sjöberg *et al.*, 2018). Indigenous nations have in some cases developed their own research guidelines, such as the National Inuit Strategy on Research (ITK, 2018). However, these ethical practices (e.g., return or destruction of data) can be incompatible with funding requirements (e.g., data sharing) (Gittelsohn *et al.*, 2020), and assessing ethical suitability requires community input that is not present in conventional review boards (Gifford & Boulton, 2007). Further, Indigenous research often values impacts on local communities rather than the wider public (Gifford & Boulton, 2007). Its importance may not be well captured by traditional metrics as a result, with adverse consequences for funding (Tuhiwai Smith, 2018). Interviews with associates of an Australian Indigenous research funding organization indicate that, while peer review can be useful for feedback purposes, competitive grant funding is contrary to the particularly collaborative nature of Indigenous research (Street *et al.*, 2009).

Within standard programs, timeframes or allowable expenses policy could be adjusted to better accommodate the requirements of Indigenous research (Moore *et al.*, 2017). Dedicated committees may be necessary to properly evaluate Indigenous research, such as those used in Australia's National Health and Medical Research Council (Knight *et al.*, 2009; NHMRC, 2018). Participation in research advisory committees can improve funders' understanding of the research timeframes involved (Adams & Faulkhead, 2012). Indigenous community participation in grant review or research advisory boards is also beneficial, but can be difficult to implement due to questions about which perspectives to include, the problem of ensuring that researchers do not create dysfunctional advisory boards merely to satisfy funding requirements, and challenges around avoiding conflict of interest when dealing with a small pool of expertise (Street *et al.*, 2009; Adams & Faulkhead, 2012; Gittelsohn *et al.*, 2020).

Indigenous researchers and research are most effectively supported with dedicated funding.

Support is sometimes directed to Indigenous researchers through targeted funding programs, such as those discussed in Section 3.2. The ARC's Discovery Indigenous program funds projects led by Indigenous researchers, and has received generally positive evaluations (ARC, 2018b). Similarly, the RCN SAMISK program is focused on Sámi-related questions such as climate and environmental research, and recruits Sámi researchers as one of its objectives (Forskningsradet, n.d.). However, superficial requirements for Indigenous involvement in funding applications may encourage tokenism. It is important that Indigenous research projects involve Indigenous perspectives and researchers during all stages from project development to data analysis and publication (Gewin, 2021).

Indigenous researchers also benefit from tailored support. They may, for example, need to balance funding agency expectations and community responsibilities (Gewin, 2021). Failing to meet funder expectations could lead to Indigenous researchers leaving academia, while failing to meet community expectations could prevent them from engaging these communities in research (Gifford & Boulton, 2007). Mentoring programs such as the Native Investigator Development Program (Box 3.2) are likely to be particularly beneficial for Indigenous trainees (Manson *et al*., 2006). Providing support for networking among Indigenous researchers and communities would also be beneficial (Sjöberg *et al*., 2018); for example, the trainee and ECR networking group NorrSam has facilitated relationships among Indigenous researchers and Sámi communities, positively contributing to the field of Indigenous research in Sweden (Drugge, 2016). More broadly, support for ECRs helps to retain Indigenous researchers as they begin their careers (Gewin, 2021).

Community research groups are important contributors to Indigenous research, but they have difficulty competing for funding with large universities (Gifford & Boulton, 2007). Expanded support for research at rural universities in Indigenous communities improves access as a whole and supports Indigenous researchers who wish to build local research capacity rather than take faculty positions in universities elsewhere (Gittelsohn *et al*., 2020). In the United States, this is promoted through the Tribal Colleges and Universities (Box 3.2). In addition, programs dedicated to supporting community-based research, with specially designed criteria and a focus on promoting wide participation, may be better equipped to support Indigenous research than standard funding programs (Gifford & Boulton, 2007). Overall, Indigenous research benefits from sustained funding of community-based Indigenous research teams and research centres that provide feedback on Indigenous research and act as hubs for international networking (Tuhiwai Smith, 2018; Gittelsohn *et al*., 2020).

Box 3.2 Native American Research Centers for Health (NARCH) and the Native Investigator Development Program

NARCH is an example of a program providing dedicated research funding to Indigenous organizations, communities, and researchers. The program, administered by NIH and the Indian Health Service, provides funding to Native American tribes, tribal organizations, and academic partners with the goal of not only directly funding research to the benefit of these communities, but also increasing research capacity, improving collaborations, and supporting Indigenous researchers. NARCH funding is directed in part to the Tribal Colleges and Universities, which serve Indigenous students on reservations that are otherwise geographically isolated (Gittelsohn *et al.*, 2020).

NARCH also administers the Native Investigator Development Program, which provides professional development for Indigenous postdoctoral researchers. The program combines instruction in quantitative and qualitative research methods, with mentoring from established Indigenous researchers and researchers involved in cross-cultural research. Participants receive 35% salary support to ensure they can participate in program activities. An evaluation indicated that the program increased participant skill levels; over the first 6 years, 10 graduates wrote 57 publications and won 12 NIH grants (Manson *et al.*, 2006).

4

Supporting Interdisciplinary, High-Risk, and Responsive Research

Chapter Findings

- Traditional grant application and review processes are perceived by the scientific community to work well for research undertaken within standard disciplinary boundaries, but such processes are often insufficient for interdisciplinary and high-risk research due to the difficulty of organizing the appropriate expertise in an interactive way.
- Multi- and interdisciplinary research benefits from changes to standard funding practices at several stages. These include support for networking and collaboration, carefully tailored calls for proposals, adaptations to existing organizational structures and review processes, overarching frameworks such as "Grand Challenges," and ongoing support for meetings and collaboration.
- High-risk projects hinge on the creativity of researchers. Long-term, flexible grants encourage risk-taking while allowing for greater responsiveness to external developments. Funders can also organize long-term strategic initiatives to provide support for high-risk proposals on specific themes. Experimental approaches in competition design, including shortened proposals and double-blind reviews, have also shown promising results in encouraging creativity and risk-taking.
- To build more flexibility and responsiveness into their portfolios, funding agencies can reserve resources to provide timely support or use continuous application cycles. Funding instruments for transdisciplinary research can also increase social responsiveness by requiring teams to specify the intended beneficiaries of the research program, and by recognizing outputs other than high-impact publications.

Research funding agencies support a wide variety of scientific work, reflecting both the diverse research interests of their applicants and wider social pressures and trends in their communities. Basic research, which tends to take place within single disciplines, forms the bedrock of the NSE environment and remains a central priority for funding agencies; however, some questions cannot be answered using the tools and knowledge of one discipline (Mazzocchi, 2019). Research is now expected to interface with the broader innovation and technological environment and to address societal needs in addition to investigating fundamental questions in science (Mejlgaard & Aagaard, 2017). Technological advances have made the scientific workforce increasingly connected, drawing researchers closer together and leading to new fields of study. While researchers continue to become ever more specialized, they are also often turning to questions that lie adjacent to or beyond their immediate expertise. Scientific problems and research questions emerging in response to these trends are often too complex to be addressed by a single researcher from a single discipline (Mazzocchi, 2019).

The scientific community generally agrees that traditional grant application and review processes work well for research undertaken within a single discipline. However, for some other types of research, such processes are often perceived as insufficient, in part due to the difficulty of organizing appropriate expertise in an interactive way. Interdisciplinary and multidisciplinary research often requires departures from standard processes or dedicated funding mechanisms, in order to accommodate multiple research communities involving different practices, cultures, and needs. High-risk research may also require agencies to adopt specific measures to overcome an inherent bias towards conservatism in standard funding programs — a bias that is amplified when applicant success rates are low. Finally, unexpected developments — a global event such as a pandemic, or a significant research breakthrough — often require a flexibility on the part of funders that transcends their normal operations and programs. This chapter therefore explores the types of strategies and practices that funding agencies are adopting in areas of research where standard practices have proved inadequate.

4.1 Supporting Multidisciplinary and Interdisciplinary Research

The combination of multiple researchers and multiple disciplines poses difficulties at several points along the funding lifecycle for NSE funders.[25] Research partners need to first leave their disciplinary siloes and come together to consider projects that combine or integrate their respective disciplines. The resulting proposals must then be assessed and compared to one another in a competition, but reviewers in one area are often ill-equipped to judge the quality of proposals or applicants from outside their disciplines. Multi- and interdisciplinary research partnerships may require additional forms of support to ensure their success. Finally, evaluating the output of this research may also frustrate processes designed for single-discipline projects, such as the normalization of citation data according to research field (Mazzocchi, 2019).

25 The observations in this section generally pertain to both multidisciplinary and interdisciplinary research. *Multidisciplinary* research draws on techniques or knowledge from multiple disciplines to answer a specific question, but does not necessarily go so far as to integrate these disciplines. *Interdisciplinary* research is understood to offer a holistic understanding of complex research problems, based on integrative approaches for combining knowledge of methods from different disciplines (Wagner *et al.*, 2011).

Funders can stimulate partnerships among multiple disciplines by supporting networking.

The development and effectiveness of collaborations are facilitated by proximity, with conferences and meetings providing opportunities for researchers within disciplines to exchange ideas and form new connections (Hall *et al.*, 2018). Promoting networking is particularly relevant for interdisciplinary work, which often lacks an organized research community (Bridle *et al.*, 2013; Bammer, 2016). By fostering greater connectivity in the research network, NSE funders can help to stimulate novel partnerships and research questions. At large scales, the Kavli institutes represent examples of multi- and interdisciplinary capacity building, occurring through institutional support from a funding agency to create new networks. Research centres are oriented according to broad themes that span multiple disciplines (e.g., nanoscience) and combine researchers of disparate disciplinary backgrounds; such centres are distributed across the world within post-secondary education institutions (Kavli Foundation, 2020a). The Kavli Foundation also organizes a series of meetings and conferences to stimulate additional network-building (Kavli Foundation, 2020b).

At smaller scales, agencies in some jurisdictions support network-building by developing venues or institutes designed specifically for hosting scientific workshops and summer schools. The Telluride Science Research Center (United States), Centro de Ciencias de Benasque Pedro Pascual (Spain), and Lorentz Center (Netherlands) represent three examples that make use of long-term support agreements with NSE funders to host events dedicated to research activities throughout the year (CCBPP, 2020; Lorentz Center, 2020b; TSRC, 2020). These events are supported through externally submitted proposals, or initiated by funders in the context of strategic initiatives (CCBPP, n.d.; Lorentz Center, n.d.; TSRC, n.d.). An "overwhelmingly positive" 2020 external evaluation of the Lorentz Center — whose core mission is the initiation of new collaborations — found its model of hosting small workshops (up to 55 attendees) facilitated by professional, non-scientific staff to be effective in building bridges among disciplines (Lorentz Center, 2020a).

Alternatively, funders can integrate networking directly into their competitions. One example of this is the Research Council of Norway's (RCN) Idélab program, which was launched in 2014 to bring researchers from different fields together under an overarching research challenge (Maxwell & Benneworth, 2018). In this program, 30 successful applicants from a variety of backgrounds participated in a week-long sandpit exercise as "delegates" of their fields. Delegates were combined into teams, participated in brainstorming exercises, and wrote proposals. The RCN provided financial support and staff to facilitate the process (Maxwell & Benneworth, 2018). While the number of participants and funded proposals was small, the program was found to change the behaviour of participating researchers, making them more receptive towards research questions outside their immediate areas of expertise, and preparing them to address such questions together with partners from other disciplines. In this sense, the program succeeded in building capacity for multidisciplinary research.

Avoiding disciplinary terminology, soliciting details about collaboration, and clarifying objectives in calls for proposals can improve research outcomes.

Many research questions are not suited to a multidisciplinary or interdisciplinary approach. For those that are, thoughtfully structuring calls for proposals increases the chance of applicants targeting the right program. It is helpful, in funding programs dedicated to such research, to prioritize proposals where collaboration within and across disciplines is indispensable, rather than merely advantageous (National Research Council, 2015). Requiring applicants to justify the suitability of their proposals on this basis can discourage the submission of proposals better suited to other programs, or where disciplines are combined as a box-checking exercise (Shahin *et al.*, 2014).

Call formulation can also help to clarify whether different disciplinary perspectives should be combined in an additive (multidisciplinary) versus integrative (interdisciplinary) manner.[26] Along similar lines, NSE funders could design proposals to solicit clarification from applicants on the details of their collaboration (National Research Council, 2015). This can consist of defining roles for participants, potential outputs, or even levels of disciplinary integration throughout the project's lifecycle (National Research Council, 2015). The appropriateness of a multi- or interdisciplinary approach should be reflected in the research question proposed by applicants. This criterion could then be assessed during peer review, alongside the suitability of the proposed partners (Bammer, 2016).

European Research Council (ERC) Synergy grants exploit this strategy (ERC, 2020b). They provide guidelines for applicants prior to the publication of the call for proposals instructing them to identify partners, justify their presence in the application, and begin crafting a suitably integrative research question. Successful applications are assessed on the inherent synergistic potential of a team as well as on excellence, and awardees receive funds to relocate PIs as part of the start-up costs (ERC, 2020b).

26 See additional discussions of methods for measuring multi- and interdisciplinarity in Wagner *et al.* (2011), Campbell *et al.* (2015), and Adams *et al.* (2016).

Grand Challenges can be used as top-down frameworks for generating novel partnerships tasked with tackling far-reaching problems.

In addition to drawing on the creativity of collaborators who are proposing new areas of research in curiosity-driven funding programs, funders may also define strategic initiatives with overarching themes to guide potential applicants (European Commission, 2012a; PCAST, 2014). The European Commission's Horizon 2020 Framework identified societal challenges corresponding to six areas of research that promise to impact society (European Commission, 2011). Similarly, Grand Challenge frameworks have also been adopted by philanthropic funders for cross-cutting initiatives potentially spanning multiple disciplines and sectors (Global Grand Challenges, 2020; Grand Challenges Canada, n.d.). These programs differ in their scope and objectives. However, for the National Nanotechnology Initiative in the United States, the President's Council of Advisors on Science and Technology proposed the following parameters: the framing should anchor the initiative in a compelling story, "[presenting] outward facing effort, with a specific measurable goal" to attract actors from multiple disciplines and sectors. These problems must possess designated endpoints and therefore have an implicit lifetime, while also committing to measurable milestones; the resources to solve these challenges, meanwhile, may be unknown at the outset and too large to be carried out by a small number of researchers or institutions (PCAST, 2014).

Broad frameworks such as Grand Challenges, and the funding competitions associated with them, aim to support correspondingly multifaceted projects co-designed by multiple applicants. As such, the call for proposals should also be co-designed, and avoid using language anchored to a single dominant discipline (Shahin *et al.*, 2014). In a European Commission study on interactions among multiple disciplines in the Horizon 2020 Digital Agenda for Europe program, Shahin *et al.* (2014) argue that involving social sciences and humanities researchers in the formulation of calls encourages contributions from these disciplines in particular. For example, Horizon 2020 was criticized for superficially integrating social science and humanities research in some projects, by framing the role of these disciplines "as understanding human responses to new technological interventions," and therefore as subordinate to NSE research (Maxwell & Benneworth, 2018). In contrast, the aforementioned Idélab overcame this issue by allowing for mutual engagement among research partners early on as a result of the workshop-like model of that competition. Shahin *et al.* (2014) provide other examples of early opportunities for engagement in more conventional competitions, such as opening exercises or support for research stays during the design stages of projects.

Funding agencies are adjusting standard practices to accommodate multi- and interdisciplinary research in different ways, depending on the local context.

Once a funding agency succeeds in cultivating a strong collaborative environment across disciplines, and has designed programs to stimulate novel partnerships, it must subsequently assess proposals against one another in competitions. Proposals that combine disciplines challenge traditional peer review due to the logistics of arranging panels with suitable compositions (National Research Council, 2015). The extent to which interdisciplinary research proposals are disadvantaged by standard peer review has not been conclusively determined (Bromham *et al.*, 2016; Guthrie *et al.*, 2018). It may depend on specific disciplinary combinations, and the "distance" between disciplines within partnerships (Bromham *et al.*, 2016). Evidence is also limited, however, to support the conclusion that any resulting advantages or disadvantages facing collaborations involving specific pairs of disciplines are systematic (DFG, 2018).[27] Some instead argue that panels composed of many disciplines can in fact be advantageous, as the different perspectives among panelists allow them to more easily assess the value of novel research, lessening the risk of groupthink (van Arensbergen *et al.*, 2014; Wang *et al.*, 2017).

There is significant diversity in the approaches adopted by funding agencies to support multidisciplinary research. Agencies in some jurisdictions have opted for a pluralistic approach, implementing dedicated programs for research proposals involving more than one discipline; others have taken the opposite approach and focused on streamlining their portfolio and modifying existing programs (Janger *et al.*, 2019). This observation was echoed during the Panel's conversation with outside experts, which highlighted how the local context and funding landscape played a significant role in defining the approach to handling and reviewing proposals. In 2009, NSERC adapted its proposal peer-review system for increased multidisciplinary and interdisciplinary collaboration by introducing a "conference model" (NSERC, 2014). Review committees were re-organized to form 12 evaluation groups with broader topical expertise than the more focused Grant Selection Committees which preceded them. Members of these panels supported this revised approach for handling multidisciplinary proposals (NSERC, 2014). When a proposal's content is too broad for a given evaluation group, other groups

27 The German Research Foundation (DFG) draws on a pool of 600 researchers elected by their peers to four-year terms to review grant applications; an analysis of over 30,000 proposals submitted to the DFG revealed no strong evidence of correlation between success rate and the interdisciplinarity of review panel composition (DFG, 2018). This analysis found that at the level of individual competitions, some pairs of disciplines resulted in higher success rates and some lower, but that these trends were inconsistently reproduced in subsequent years, suggesting that the riskiness of interdisciplinary panels may be exaggerated (DFG, 2018).

can be called upon to conduct a joint review; experiences found that this has been seldom necessary, however, in the new format (NSERC, 2014).[28]

Frequent meetings and support for relationship building are hallmarks of successful programs that support research projects combining multiple disciplines.

Though collaborators within an interdisciplinary team need not all be based in the same geographical location, providing opportunities for researchers to network or be temporarily co-located helps in forming the relationships needed to sustain productive collaborations (Bridle *et al.*, 2013; Shahin *et al.*, 2014). A recent review on collaboration in science underscored the importance of relationship and trust building for successful teams, even within the same discipline (Hall *et al.*, 2018). In interdisciplinary work, there is an additional cultural barrier: different disciplinary communities have their own terminology, methodologies, and publication practices (Shahin *et al.*, 2014).

NSE funders have explored various formats for building relationships and overcoming barriers among potential collaborators from diverse disciplines. The U.S. Defence Advanced Research Projects Agency (DARPA) is an active supporter of multi- and interdisciplinary research. An important element of its funding model is an emphasis on program meetings, which allow participants to maintain and build new relationships with researchers outside their disciplines (Piore *et al.*, 2019). The DARPA model is successful, but has been challenging to replicate elsewhere due in part to the agency's generous resources: each three- to five-year-long program enjoys a budget on the order of tens of millions of U.S. dollars (Windham & Van Atta, 2019; Editorial, 2020). On smaller scales, the provision of resources in the form of "floating budgets" for unstructured (as well as structured) engagement opportunities was recommended as a promising practice for supporting multi- and interdisciplinary partnerships funded through the Horizon 2020 Digital Agenda for Europe program (Shahin *et al.*, 2014). CIFAR in Canada, meanwhile, uses an approach based on a virtual rather than physical co-location model (ISED, 2017b). Individual researchers remain at their home institutions; however, programs are accompanied by multiple in-person meetings and opportunities for networking. A majority of CIFAR program members responding to a survey agreed that the program meetings and collaborative activities were instrumental in enabling major research achievements (Meier & Santiago, 2015).

28 Between 2010 and 2013, only 2.7% of reviewers in Discovery Grant applications for the physical sciences came from other evaluation groups (NSERC, 2014).

Funding agencies can take advantage of new techniques and data sources to design interventions for creating and supporting novel collaborations.

Partnerships emerge most easily from existing departmental, institutional, or disciplinary networks, and the NSE landscape shows a tendency towards the reinforcement of existing collaborations (Dahlander & McFarland, 2013; Sciabolazza *et al*., 2020). For example, in the proposal assessment process, the quality of a team can potentially be inferred by the fact that they have already published together, providing an advantage for established collaborations (Bammer, 2016). This leads to risks of path-dependency, whereby researchers eschew new partnerships, and pursue familiar research questions with known partners (Dahlander & McFarland, 2013; Sciabolazza *et al*., 2020). Supporting long-term multi- and interdisciplinary collaborations that have proven successful is important given the barriers that need to be overcome. But funding avenues that encourage new and unproven multi- and interdisciplinary partnerships are also valuable.

Some programs, such as Research Grants in the portfolio of the International Human Frontier Science Program Organization (HFSPO), require novel collaborations in their calls, though this practice is sometimes seen as being overly stringent (Campbell, 2018). Funding agencies possess additional tools to facilitate the creation of new ties, besides altering program requirements. Network analysis of publication and grant data can provide snapshots of a given research landscape to predict areas for potential collaboration. In a pilot program funded by the University of Florida, network analysis of data on publications or funded grants was used to identify research communities, and subsequently potential partners, for the creation of new collaborative links unlikely to form naturally (Sciabolazza *et al*., 2020).[29] The selected pairs were invited to meet and submit a letter of intent describing the nature of their collaboration. These letters were then assessed through peer review, and the authors of the top-ranked letters were invited to submit full proposals for expedited review (Sciabolazza *et al*., 2020). Similarly, the Research Corporation for Science Advancement has organized Science Dialogue (Scialog) meetings since 2010, in collaboration with other agencies acting as partners (Michelson, 2020). After determining a broad theme for the meeting, 50 ECRs are selected to participate in a workshop process where new multidisciplinary partnerships are created, in part, through formal networking exercises driven by data analytics (Wiener & Ronco, 2019). At the conclusion of the meeting, the resulting partners write proposals on-site, with successful applications receiving seed funding for projects conceived during the workshop (Wiener & Ronco, 2019).

29 In recognition of the fact that the algorithm employed might identify partnerships that could be inherently unfeasible, the study authors targeted pairs of researchers who shared common collaborators in the past (Sciabolazza *et al*., 2020).

In these approaches, the funding agency intervenes in the research network to promote the production of proposals on novel topics from new combinations of researchers. Some philanthropic funders have explored other novel network interventions, defining new research areas on which to base strategic frameworks (Michelson, 2020). For example, the Rockefeller Foundation developed the Searchlight Network (2009 to 2014) as a forecasting exercise, with participating organizations providing regular reports to the Foundation on local developments and trends. This information, which drew on diverse expertise and points of view, was analyzed to determine trends that could inform the Foundation's funding activities and guide it towards promising challenge areas of international and interdisciplinary scope (Michelson, 2020).

Co-funding requirements can facilitate partnerships across disciplines and sectors, but also risk increasing inefficiency and inequity.

Projects combining multiple disciplines sometimes target topics that lie on the border between the scientific mandates of more than one agency. This is also true for other forms of collaborative research involving, for example, multiple international funding agencies, large multi-user facilities, or industrial partners. Co-funding or cost-sharing requirements are a common practice for meeting this challenge (OECD, 2018d). For example, the themes of Scialog meetings relate to overarching topics that may be broadly defined and relevant to several agencies. As a result, philanthropies have sometimes co-sponsored meetings based on shared topical interest, co-funding many of the resulting projects (Michelson, 2020). Agreements to share costs can be effective for thematically constrained competitions, but cost-sharing for bottom-up research can suffer from challenges in determining how partners in multilateral agreements should fund research prior to holding competitions (Degelsegger-Marquéz *et al.*, 2017). Alternatively, the responsibility to define co-funding can be left to applicants in individual calls, leaving researchers to secure commitments for matching funds from institutional or external partners. This approach offers a means to leverage scarce public funds, build new partnerships, and provide incentives for industry to participate in research (Institute of Medicine, 2004; Mervis, 2007; NSB, 2009).

However, there are also risks and drawbacks with co-funding requirements. NSF revised its cost-sharing policies twice during the 2000s (first abolishing it entirely in 2004), following concerns that the practice was problematic from the standpoint of equity (Mervis, 2007; NSB, 2009; NSF, 2020c). Well-resourced institutions and well-networked researchers benefit from these requirements (Tyers *et al.*, 2005; Mervis, 2007), but ECRs and researchers from underrepresented groups may be disadvantaged due to their limited networks. Similarly, in funding programs supporting industrial collaborations, small businesses and start-ups may not benefit or participate to the same degree as larger ones given their more limited resources. NSF now restricts the practice of requiring cost-sharing commitments in the eligibility requirements of funding applications to a minority of specific programs according to a set of guidelines, for example where the practice is instrumental to the program objectives (NSB, 2009; NSF, 2020c). Similarly, variable cost-sharing requirements have emerged in research partnerships supported by the NSERC Alliance program, to account for the fact that the size and type of external industry partners play a role in their ability to match funds (NSERC, 2020i). In the Panel's view, co-funding requirements can be a promising practice when employed carefully; however, mandatory co-funding is better reserved as "the exception and not the rule" to avoid imposing prohibitive barriers on researchers, and steering them away from promising ideas due to limited financial leverage in their networks (Feller, 2000; NSB, 2009).

4.2 Supporting High-Risk/High-Reward Research

A central aim of NSE funding agencies is to support research that could lead to ground-breaking new discoveries or technologies. Research outcomes are unknown *a priori*, and the competitive processes used to select proposals must both accept — and try to limit — risk in multiple forms. From the perspective of the funding agency, the potential impact of a proposal and the probability of its realization are two often competing factors contributing to risk. Meanwhile, researchers may feel compelled to propose incremental research with a very high probability for success in the hopes of improving their chances of receiving funding (Sinkjær, 2018). Proposals with unknown but transformative potential may go unfunded, or unwritten, because of the desire to mitigate risks by both funders and applicants. The issue is further complicated by the long delays associated with the impacts of truly groundbreaking work (Wang *et al.*, 2017). Funding agencies consider such risks in their allocation of research funds, and risk levels can be adjusted through various aspects of program structure, for example by removing requirements for the submission of preliminary data alongside applications to demonstrate likelihood of success (Gewin, 2012). Increased competition is also sometimes perceived to reduce risk, as the ranking process for applications and applicants should (in principle) allow funders to support only the most promising proposals.

Funding agencies' need for risk mitigation is understandable as they are required to demonstrate accountability and responsible stewardship of public money (Mejlgaard & Aagaard, 2017). However, issues such as hyper-competition in grant applications, and the perceived conservatism of review panels, have contributed to increasing concerns that researchers are discouraged from taking risks (ARISE, 2008; OECD, 2018d). The 2011 Physics Nobel co-laureate Saul Perlmutter described this risk aversion from the standpoint of researchers, whom he argues are asked: "What is it that you are planning to research? When will you finish it? And what day will your discovery be made?" (THE, 2017). Instead of pursuing lines of investigation that have the potential to yield transformative discoveries, some researchers lament they must write proposals for projects they do not find interesting but which have a higher probability of being funded (Sinkjær, 2018).

Specific funding instruments and strategies have emerged for supporting high-risk/high-reward research ventures, which aim to produce results that are transformative, or "[lead] to discoveries which would be otherwise impossible" (ARISE, 2008). There is an inherent tension for funders that adopt these approaches, however, as the opportunity cost for funding such research as opposed to more feasible projects is unknown (Piore *et al.*, 2019). This has led to experimentation by NSE funders to determine how to solicit, assess, and evaluate risky research. The evidence is mixed as to whether specific competitive funding programs need to be created to support these initiatives, or whether NSE funders can rely on adapting their existing portfolios (OECD, 2018d). This section identifies challenges or tensions accompanying support for high-risk/high-reward research programs, as well as common and emerging practices used to promote their success.

Past approaches to assessing risk and novelty in program calls, and during peer review, have often proved unreliable.

Peer-review panels are typically asked to evaluate and rank proposals based on several considerations, including methodology, feasibility, and preliminary data (Gallo *et al.*, 2018). Individual reviewers subsequently assign each proposal a score, which can be used to establish a ranking and determine the order according to which projects will be funded (Barnett *et al.*, 2018). It can be challenging to assess high-risk research based on standard review criteria given uncertainties around feasibility and the absence of preliminary data. Though it would seem intuitive to directly include an assessment of project risk in review criteria, the subjectivity of these judgements often makes this problematic. For example, a survey by the American Institute of Biological Sciences revealed that evaluations based on risk and novelty can be subjective and distorted by bias in peer review, with investigator track records carrying significant weight in the assessments (Gallo *et al.*, 2018).

The degree to which a proposal polarizes a panel (in its scoring) has also been taken as a quantitative proxy for risk (Barnett *et al.*, 2018). Some programs have experimented with "golden tickets" as a way of protecting polarizing projects, where reviewers can nominate a proposal irrespective of poor scores assigned by other reviewers (Sinkjær, 2018). Some evidence exists to counter the notion that proposals with significant variance in their score have higher impact (as reflected in citations) than proposals with high mean scores, but is limited to a small dataset (Barnett *et al.*, 2018). Whether golden tickets result in a meaningful change in funding outcomes is currently under evaluation and remains to be determined (QSSLab, 2020).

Investigator-led high-risk/high-reward programs benefit from clear language in funding calls and short proposals.

Programs for supporting high-risk research led by individual PIs may unlock the creativity of researchers who may otherwise feel pressured to explore safer or more conservative avenues. Practices have emerged to encourage proposals that harness this creativity and capture the intent of high-risk programs, mitigating risk aversion described previously. In Canadian programs that support high-risk/high-reward research, such as those offered through the New Frontiers in Research Fund (NFRF) (launched in 2018) or the Fonds de recherche du Québec – Société et culture (FRQSC) Audace program (launched in 2017), calls for proposals and review criteria stress the importance of submitting applications that would not be suitable or appropriate for existing competitions (GC, 2019c, 2021a; FRQSC, 2020). Separate strategies, some experimental and not yet widespread, have also been employed in other high-risk high-reward programs to avoid the danger that these (often substantial) research awards serve merely as rewards for previous accomplishments (Philogene, 2010).

NIH in the United States introduced the Pioneer Award program in 2004 as a first attempt at providing a specific instrument for high-risk research (ARISE, 2008). The grant's first years of operation saw multiple changes to the review structure to avoid issues surrounding subjectivity (Philogene, 2010). Following the initial competition, the call language was modified to include clarifications regarding definitions for *pioneering, innovative,* and *award*, and candidates would no longer be assessed for leadership qualities due to concerns about bias. Evaluators noted that pioneers can be defined in two possible ways: researchers who take risks, accept failures, and challenge orthodoxy, or researchers who have led their fields by producing the most impactful research at the most prestigious institutions (Philogene, 2010). It was found that the program was primarily attracting and funding the second category of candidate, and efforts continue to seek broader representation of underserved groups and institutions (Philogene, 2010; NIH ACD, 2019).

Proposals submitted to dedicated high-risk/high-reward competitions are assessed according to different criteria, with less emphasis on initial data and greater focus on creativity or vision (Gewin, 2012). This is the case for the Pioneer Award program as well as similar instruments offered by NIH, which have no requirements to submit preliminary data (NIH ACD, 2019). In addition to not requiring preliminary data, high-risk programs offered by the NIH as well as other agencies restrict application length requirements (Philogene, 2010; Volkswagen Foundation, 2020d; Villum Fonden, n.d.). This practice places restrictions on research statement lengths to promote short but innovative proposals. At the conclusion of the workshop accompanying the Scialog program, participants must rapidly compose and submit proposals as short as two pages, a format intended to avoid over-editing (Wiener & Ronco, 2019). Evaluations have confirmed that, despite restrictions on the amount of application material submitted, these programs attract and fund the types of proposals they are seeking (Campbell, 2018; NIH ACD, 2019). These bottom-up, high-risk initiatives also distinguish themselves through their increased impact with respect to comparable programs, or control groups consisting of unsuccessful applicants (Campbell, 2018; NIH ACD, 2019).

Finally, experimental approaches continue to be suggested and tested to stimulate unique proposals. In Canada, the NFRF Exploration program for high-risk/high-reward interdisciplinary research has a mandate to test novel review practices. In the 2020 competition, applications were reviewed using a double-blind process (GC, 2020b). Ideally, this practice aims to decouple the assessment of the candidate from that of the proposal, and is already being experimented with in other jurisdictions in high-risk/high-reward programs. The Volkswagen Foundation and the Villum Fonden in Germany and Denmark, respectively, have explored double-blind applications for their programs (Villum Fonden, 2019; Volkswagen Foundation, 2020c), with limited but encouraging evidence of success. Candidates in the Villum Fonden program stated that anonymity empowered them to propose certain ideas that they would not have felt comfortable proposing otherwise due to, for example, concerns they had an insufficient track record (Sinkjær, 2018). Reviewers, in turn, also viewed this feature positively. So far, a third of awardees have been under the age of 40 (Sinkjær, 2018). Though evaluations of those programs are ongoing, the Economic and Social Research Council (ESRC) in the United Kingdom has also made use of anonymous peer review and short proposals in its high-risk research program for the social sciences, with one evaluation concluding that this methodology is successful in attracting and identifying transformative research (Kolarz *et al.*, 2016).

Longer grants and long-term strategic initiatives can provide stability to empower researchers to take greater risks.

Funding length has long been identified as an important lever for agencies that encourage high-risk research, either in the form of long grants or through the provision of grant renewal opportunities allowing for up to 11 years of support (ARISE, 2008). The ERC's Starting and Advanced grants are of five-year duration, and have been demonstrated to succeed in promoting risk-taking by applicants: *ex post* evaluations of projects funded under these schemes confirm that the majority can retrospectively be designated as high-risk/high-reward, and resulted in major advances or breakthrough discoveries (ERC, 2018b, 2020a). The NIH high-risk/high-reward programs, meanwhile, also provide support for five years (NIH ACD, 2019). Recently, some philanthropic funders have tended towards even longer durations: the Howard Hughes Medical Institute has, as of 2017, increased its Investigator grants from 5 to 7 years of funding, and has adopted 15-year research cycles at its Janelia Research Campus in order to "enable Janelia to stay at the frontier of science" (HHMI, 2017). The Novo Nordisk Foundation in Denmark recently launched the New Exploratory Research and Discovery (NERD) program targeting researchers in NSE disciplines and offering seven years of support; it also uses a blind review stage as part of its peer-review process (Novo Nordisk Foundation, 2020).

Challenge-based approaches, both for short- and long-term projects, have also been embraced for this purpose, particularly by philanthropies. The Scialog program is organized along a specific topical focus (e.g., improvement of solar energy technologies) to determine the allocation of one-year grants. The Open Philanthropy Project, meanwhile, has focused on "global catastrophic risks" as the framework for some calls, and the Audacious Project initiative directs support from multiple philanthropies and non-profits towards high-risk research following open calls for ideas to address "big, bold solutions to the world's most urgent problems" (Michelson, 2020; The Audacious Project, 2020; Open Philanthropy, n.d.). Here, agencies provide stability through a commitment to research goals with distant horizons. In this way, even short-term grants within Grand Challenges can promote risky research — these can potentially allow researchers to test risky ideas before subsequently proposing a larger project within the scope of the challenge (Gibson *et al.*, 2019).

Outside of philanthropies, the Japanese Council for Science, Technology and Innovation together with the Japan Science and Technology Agency (JST) launched the Moonshot initiative, which looks ahead to 2050 for the projects under its umbrella. Up to 10 years of funding will be made available for proposals selected within individual Moonshot projects (JST, 2020a, 2020b). The initiatives are overseen by project directors recruited from academia and industry through a competitive proposal-based process. Project directors are tasked with adopting a portfolio approach from the standpoint of balancing risk (JST, 2020b). This strategy, while uniquely long-term, is not dissimilar to that of DARPA's — perhaps the canonical example of an organization fostering high-risk research and transformative technologies. At DARPA, following the definition of a technological problem, proposals are collected and managed by program managers, who operate with great autonomy (Piore *et al.*, 2019). Industry involvement is high in both the DARPA and Moonshot programs, given the technological implications of the targeted challenges (Windham & Van Atta, 2019; JST, 2020a). Contextual factors may be critical in determining whether such programs succeed in any given environment. However, evidence suggests that Grand Challenges or other long-term strategic initiatives can provide useful frameworks for contributions from industry in high-risk R&D, with successes in the semiconductor industry and promising ongoing initiatives in quantum computing and artificial intelligence (Windham & Van Atta, 2019; JST, 2020a).

4.3 Maintaining Flexibility in Research Funding

Previous sections in this chapter provided examples of how NSE funding agencies have adapted traditional practices, or implemented new ones, to better support some types of research. For multi-, interdisciplinary, and high-risk/high-reward research, conventional funding programs often require adjustments that consider the presence of partners from other disciplines, or the scope and novelty of the question. In these cases, funders can make deliberate choices based on the goals of the program. However, researchers may sometimes require additional flexibility from funding agencies to respond to emerging discoveries and to other external developments. The value of flexibility in the NSE research community was brought to the forefront by the COVID-19 pandemic. Agencies rapidly introduced new responsive mechanisms for providing support during the pandemic, directing resources to basic and applied science initiatives (OECD, 2020d). Flexibility and responsiveness in funding can also play a role in avoiding wasted resources and promoting effective partnerships with the private sector or policy-makers.

Funders can build flexibility into project-based funding instruments through long commitments and timely injections of additional funding.

Research projects can be shaped by unexpected breakthroughs or alterations in trajectories. In certain cases, researchers may be compelled to abandon proposed approaches in favour of new ones with greater promise. Funding agencies have numerous tools at their disposal for providing the flexibility needed to accommodate changes to research plans. The provision of long-term grants allows for an initial level of flexibility, allowing researchers to not only take long-term risks but also short-term strategic shifts. Another approach to providing such flexibility is the use of "people-based" awards, which provide funding that researchers can put towards one or more projects of their choice (OECD, 2018d); these awards, however, have in some cases been associated with increased bias against researchers from underrepresented groups (Witteman *et al.*, 2019) (Section 3.2). Alternatively, it may be possible to capture the same benefits by increasing the flexibility of project-based grants. For example, according to interviews conducted by the Panel, National Research Foundation Singapore allows researchers to request a change in direction for a project grant in communication with program administrators. Flexibility has also been identified as a strong point for the NSERC Discovery Grants, where support for programs (rather than projects) for up to five years allows researchers to execute strategic shifts in priorities (NSERC, 2014). During interviews, the Panel also heard that long-term partnerships of up to 10 years offered by FAPESP in Brazil were instrumental in facilitating successful partnerships with the private sector (FAPESP, 2018).

Responsiveness can also be achieved through the provision of additional resources by program administrators within existing projects (ARISE, 2008). Different agencies approach this in varying ways. Responsiveness by philanthropies follows from their relative autonomy compared to public funders, allowing them to offer seed or other timely funding, as in the case of the Scialog program discussed earlier (Grant, 2017; Michelson, 2020). Certain public funders have built in similar approaches; during interviews with outside experts, the Panel heard of a national funder setting aside a portion of its annual budget to provide additional support for ongoing projects at its discretion, recognizing the unpredictability of discovery research and the need for timely support. This approach, however, requires funders to justify holding a portion of their budget in reserve and places additional responsibility on program officers, who are tasked with providing or withholding additional support. It also underscores the need for clear communication between researchers and funders regarding changes to projects in order to manage expectations and avoid redundancies.

Rapid-response funds and rolling funding calls allow funders to quickly explore new research directions as they emerge.

Funding competitions generally run according to strict schedules on a periodic (generally annual) basis; this facilitates, for example, the logistics of gathering panels to assess proposals (OECD, 2018d). This structure is not designed to accommodate time-sensitive ideas in response to sudden developments. Dedicated rapid-response programs provide opportunities for researchers to apply for supplemental funding to address a sudden or time-sensitive need. The NSF Rapid Response Research (RAPID) proposal asks that researchers contact program officers with subject matter expertise to first judge whether the basis of their proposal is appropriate (NSF, 2020c). Proposals are assessed internally whenever possible and on a case-by-case basis. NSF advised its research community in 2020 to consider applications to the RAPID program for projects related to COVID-19 research (NSF, 2020a).

Importantly, dedicated rapid-response calls might not feature application deadlines. Such calls, as well as other rolling funding calls, offer the possibility for researchers to quickly act on a new source of inspiration by allowing proposals to be submitted at any time. This practice can be applied to both top-down and bottom-up approaches and is currently being employed in the UKRI pandemic response (UKRI, 2020b). The Australian Research Council (ARC) has also introduced this approach for their program to drive collaborations between academia and industry, enabling timely joint projects between researchers and non-academic stakeholders (Commonwealth of Australia, 2015).

For transdisciplinary research, program descriptions should be flexible and clear on the intended beneficiaries of the research and the nature of the expected outcomes.

Transdisciplinary research initiatives tackle challenges with direct and immediate relevance to society, through the "integration of knowledge from different science disciplines and (non-academic) stakeholder communities" (OECD, 2020c). Research of this type aims to identify and achieve goals that are common to many partners across society and, in contrast to inter- and multidisciplinary research, regularly involves individuals from non-academic sectors (Wright Morton *et al.*, 2015). The potentially large and diverse number of stakeholders in societally relevant research raises a central question: Which element(s) of society should the research be relevant to? (Schikowitz, 2019).

Relevance for academia or researchers is generally confined to the production of scientific knowledge, and is not necessarily consistent with the expectations of society. Society-driven research also risks being perceived negatively by scientists, who may view it as a form of "contract" research that offers no value for the affiliated researchers (Schikowitz, 2019). Efforts to provide greater recognition of this type of scholarship are required; from a career standpoint, it is generally safest for many researchers, particularly early in their careers, to instead pursue traditional scientific publications (OECD, 2018d; Schikowitz, 2019).

Programs where research questions are less strictly defined have sometimes led to problematic outcomes. A case study of the Austrian proVISION program, which "aim(ed) to foster the production of societally relevant knowledge by integrating locally affected actors," revealed that projects attempting to simultaneously produce knowledge with scientific, policy, and practical (or local) relevance often failed (Schikowitz, 2019). Issues encountered in other forms of collaborative research emerged, namely mismatches in expectations for the timescales of knowledge production, imbalances between societal and scientific relevance, and difficulties in evaluating research output using typical bibliometric criteria (Buswell *et al.*, 2017; Schikowitz, 2019). Research partners frequently differ in the methodologies they employ and the outputs they produce, and the intensity of participation of each partner and their required resources (e.g., human, financial) may vary over the course of the project (Shahin *et al.*, 2014; Hicks *et al.*, 2015; Buswell *et al.*, 2017). This challenge already occurs in collaborations between NSE and social sciences or humanities disciplines due to the different forms and rates of data collection (Buswell *et al.*, 2017), and is amplified for transdisciplinary research, where participants operate in multiple sectors, complicating the task of coordinating their efforts and maintaining engagement with non-academic stakeholders (OECD, 2020c).

Avoiding misalignment among stakeholder priorities in transdisciplinary research is an area where funding models can improve. For example, where a research project involves specific societal actors, funding programs can strive to clarify whether these actors should be beneficiaries of the produced knowledge, or contributors to it (Schikowitz, 2019). The Panel heard of ongoing efforts in New Zealand in this respect, with strategies by the Royal Society Te Apārangi focusing on the co-development of research programs with Māori contributors. In this way, the two distinct epistemologies in that country (European and Indigenous) are brought together in the earliest stages of conceptualizing a project, in hopes of reaching agreement with respect to the goals of the research. Clarifying expectations at the outset of programs, combined with evaluation approaches that recognize research output separate from publications, are promising practices to support transdisciplinary research (Whitley *et al.*, 2018; OECD, 2020c). Evaluations should additionally be sensitive to the potential for conflicts of interest, given that participants in the research may also be beneficiaries (OECD, 2020c). The provision of additional resources for project management may also be particularly useful in transdisciplinary programs as compared to conventional academic research initiatives, to account for the challenges described above (OECD, 2020c). If support for these projects fails to account for these and other considerations unique to multi-, inter-, and transdisciplinary research, funded projects may not achieve integrative or societally relevant discoveries.

5

Improving Administrative Efficiency and Enhancing Research Impact

Chapter Findings

- The exclusive reliance on traditional peer review to assess grant applications is being increasingly scrutinized, as the NSE funding environment becomes more competitive. Greater experimentation with alternative approaches such as distributed-review, pre-screening, multi-step applications, and partial lotteries, and more rigorous data collection on experiments, will allow NSE funders to better assess the costs and benefits of different approaches.
- Many funding agencies are working to support the adoption of open-access principles and practices. This trend has accelerated during the pandemic, and evidence suggests that support for infrastructure, such as repositories for articles and data at the level of institutions or disciplines, can improve open-access compliance.
- Both priority-driven and investigator-led approaches can support research that addresses societal needs. Small-scale programs can link researchers to targeted groups, and agencies have begun to make use of large-scale public consultations and engagement exercises to define thematic priorities or challenge areas. Investigator-led strategies for encouraging societally impactful research benefit from broad definitions of impact, and can be bolstered through training initiatives.
- Evaluation criteria are adapting to changing expectations in research outcomes, practices, and norms. Expanding evaluation into broad frameworks beyond traditional bibliometric indicators allows funding agencies to better capture non-academic outcomes, and to regulate research culture by signalling secondary objectives to research communities.
- Agencies can define new indicators, and help link practices to outcomes, by more fully operationalizing their data on the research environment. Challenges related to data heterogeneity and incompleteness can be partially mitigated by pooling data with other agencies (using third parties to improve interoperability if needed), thereby establishing platforms for more rigorous testing of funding practices and increased experimentation.

It is essential that funding agencies be able to assess the quality and potential impact of research proposals. Similarly, funders must have the means to measure research impacts — which can occur over long timescales — to evaluate the effectiveness of their own programs and the quality of the supported research. These assessment and evaluation processes often require significant resources. For example, while peer review provides the granular analysis needed to rank proposals in a competitive funding call, it can lead to high administrative burdens and opportunity costs, particularly as funding environments become more competitive due to growing numbers of proposals and shrinking budgets (Guthrie *et al.*, 2018). Agencies are also increasingly making efforts to enhance the impact of their funded research, by ensuring that scientific results are disseminated within the relevant professional communities, by expanding public access to research findings, and by promoting greater public outreach and engagement. To fund research more efficiently, effectively, and transparently, agencies are experimenting with alternative approaches in all of these domains. This chapter reviews examples of novel practices for reducing administrative burdens and operational waste, fostering tighter links between research and society, and more effectively evaluating the programs offered by NSE funders in their aims to support research excellence.

5.1 Improving Efficiency and Reducing Administrative Burdens

NSE funding allocation processes demand considerable resources, both human and financial. Supporting strategic priority areas requires determining appropriate funding levels to avoid waste and diminishing returns on investment, while grant competitions are notoriously labour-intensive for researchers and reviewers. There are many sources of administrative burden surrounding grant allocation — some unavoidable — that impact applicants, reviewers, and program officers differently. Large application packages with longer proposals require more time to assemble by researchers, with the resulting volume of proposals contributing to reviewer fatigue and long turnarounds. However, large comprehensive proposals can assist agencies in making informed funding decisions. Within a given competition, these various sources of burden represent a form of overhead. Moreover, as success rates in competitive programs fall, the costs of running a competition are spread out over a smaller number of projects (OECD, 2018d). Time requirements for unfunded grant applications are often substantial. An analysis of a competitive call by the National Health and Medical Research Council (NHMRC) of Australia estimated that the amount of time spent by researchers who had submitted unsuccessful proposals in 2012 exceeded 400 years in total (Herbert *et al.*, 2013).

Funding agencies are altering programs and assessment strategies in attempts to identify the most promising proposals efficiently and reduce burdens on researchers. The time and resources dedicated to traditional peer review within the grant assessment process are central to this discussion, and reliance on peer review in the evaluation of grant applications is under increased scrutiny due to the burdens placed on applicants and reviewers (Wilsdon *et al.*, 2015; Guthrie *et al.*, 2018). Peer review is a trusted process in the scientific community, perceived as a legitimate and nuanced method for assessing research (Wilsdon *et al.*, 2015). Peer-review panels also offer opportunities for scientific exchange and stimulating discussions among communities of researchers, and researchers can obtain valuable feedback on their unsuccessful proposals. However, it has also been criticized for suffering from bias, groupthink, and an inability to predict future success (van Arensbergen *et al.*, 2014; Guthrie *et al.*, 2018). Quantifying the true cost of peer review versus its value in each competition is also difficult (OECD, 2018d). For this reason, some funding agencies are modifying their review protocols and introducing new practices for research assessment to lessen the burden on research communities (Bendiscioli, 2019; Curry *et al.*, 2020).

Reducing the quantity of proposals through application restrictions allows funders to reduce review burdens, and can encourage higher-quality proposals.

In the Australian study mentioned above, the 400 years of lost research time was calculated based on the success rate of the call, the total number of proposals, and the self-reported average number of working days required to prepare a full proposal (approximately 30) (Herbert *et al.*, 2013). This significant amount of time is not unusual, and consists of two components: the time required for researchers to apply their knowledge and creativity towards defining a suitable research question, and the time required to fulfill the administrative requirements of a grant application. The former investment of time is scientifically productive, while the latter represents an opportunity cost and can be a source of operational waste as success rates fall (Roorda, 2009; Herbert *et al.*, 2013).

Efforts to reduce time spent on unsuccessful applications have explored adjustments to success rates in a variety of ways. The Dutch Research Council (NWO) defined a 25% success rate target for their programs, and will postpone calls if they expect that funding levels will be insufficient to meet demand at this rate (NWO, 2017a). Supply-side approaches, such as limiting proposal volumes, can also be used to adjust success rates. Rather than employing strict caps, the National Science Foundation (NSF) requested in 2015 that scientists respect a "voluntary cap" on the number of submissions for which they are listed as PI or co-PI (Mervis, 2014). Additional measures based on past performance in competitions have been used at UK Research and Innovation (UKRI) for several years, to curb the initial volume of proposals in competitions (EPSRC, 2009). Investigators are only permitted to participate in one Engineering and Physical Sciences Research Council (EPSRC) competition for a 12-month period if their overall personal success rate is below 25%, and if three or more of their proposals landed below a quality threshold (EPSRC, 2009). Similarly, unsuccessful applicants to the European Research Council's (ERC) annual frontier grants have been restricted from participating in the following year's call if their proposal scored below a certain level (ERC, 2020a).

These practices are usually successful in controlling the number of proposals in a competition and discouraging researchers from excessive submissions. They also may increase the overall quality of submissions. For example, an analysis of granting results from the Economic and Social Research Council (ESRC)[30] found that the share of highly rated proposals has increased since the demand management policy was introduced (ESRC, 2016). However, such approaches have also been controversial. Application restrictions have been criticized for promoting conservatism in proposals and discouraging collaborations (Sattary, 2012; Mervis, 2014). When EPSRC used this demand management policy to raise success rates to a more "appropriate" number of 40%, the agency was criticized for giving the impression of a reduced demand for funding (Sattary, 2012).

Multi-step applications lower burdens for applicants and potentially reviewers, but reduce opportunities for constructive feedback and risk introducing new sources of bias.

Instead of restricting the number of applicants at the outset of a competition, several highly competitive funding programs have made use of application processes involving multiple steps to eliminate inappropriate proposals or candidates at early stages in a competition. These programs make use of a combination of practices, including nomination processes, candidate pre-screening, short pre-proposals, and interviews (Philogene, 2010; Kolarz *et al.*, 2016; Gush *et al.*, 2018). In the case of the National Institutes of Health (NIH) Pioneer Award for high-risk/high-reward research, the first two years of the competition saw close to 1,000 nominees invited to submit proposals. A first stage "yes/no" choice by external evaluators (based on the candidates) was used to reduce the number of applicants to approximately 250 (Philogene, 2010). These applicants' short proposals were scored by a separate set of evaluators, resulting in approximately 20 interviewees (Philogene, 2010). The ERC also employs interviews in the final step of its three-stage assessment process for its Synergy Grants, which support small teams "address[ing] a research problem so ambitious, that [it] cannot be dealt with by you and your team alone" (ERC, 2020b). A similar approach is employed in the ESRC high-risk/high-reward program; in this case, however, applicants give presentations to the panel and their co-applicants (Kolarz *et al.*, 2016). The first stage of the Marsden Fund competition

30 The former U.K. funding agency for economic and social science research.

in New Zealand, meanwhile, instructs reviewers to screen one-page initial proposals, which eliminates up to 84% of the applicants (Gush *et al.*, 2018).

Carefully implemented, these approaches can help researchers avoid unnecessarily wasting time and effort on unsuccessful applications. Applicants feel that the process remains legitimate; most applicants to the NIH Pioneer Award program report that the process allowed them sufficient opportunity to make their case for funding (Philogene, 2010). The burden on peer reviewers may also be reduced, but this depends heavily on program design, as reviewers may be called upon on several occasions. There are problematic tradeoffs to this practice, however: they displace burden onto funding agency staff due to their increased logistical complexity, and may also eliminate the opportunity for constructive feedback on rejected proposals, offsetting any benefit in reduced time investment for unsuccessful applicants (Guthrie *et al.*, 2018). Multiple assessment steps, nominations (by institutions or peers), and interviews can create additional opportunities for the introduction of explicit or implicit biases, which may contribute to the underrepresentation of certain researchers and institutions among the beneficiaries of these programs (Kolarz *et al.*, 2016; NIH ACD, 2019; Yen, 2019).

Distributed peer-review can be used for small competitions, or for programs centred on a specific facility or topic.

For smaller competitions, reviewer fatigue could be addressed by having applicants review proposals themselves. This practice, known as distributed peer review or self-review, involves asking candidates to review other applications in the same funding call. It has shown promise and is employed in the Scialog program, as well as the U.K. Biotechnology and Biological Research Council and the NSF Ideas Lab, for example by having participants write and review their own proposals iteratively over the course of short conferences (Wiener & Ronco, 2019; NSF, 2020c). NWO first tested this practice in its Open Competition Domain Science – XS program, a bottom-up scheme that invites applicants to submit proposals for small projects; it concluded that "first experiences were positive" (NWO, 2020a, 2020b). The practice continues to be used in that program, and is also being applied to other NWO calls, such as the Dutch Research Agenda's Idea Generator. This program involves limited funding amounts, and encourages transdisciplinary projects carried out by researchers in collaboration with societal stakeholders. Distributed peer review ensures fast turnaround times on these applications (NWO, 2020a, 2020b).

Distributed peer review has also been applied to competitions that award access to major international facilities. For example, the Gemini Observatory employs this process to allocate observing time for outside researchers, while the European Southern Observatory has recently completed a pilot that combines distributed peer review with machine learning to assign reviewers to proposals (Andersen, 2020; Kerzendorf *et al.*, 2020). Both practices were viewed favourably by participants, particularly due to their faster turnaround times (Andersen, 2020; Kerzendorf *et al.*, 2020). Reviewers may feel more invested in distributed peer review (Andersen, 2020), and automated processes reduce the burden of determining how to distribute proposals among researchers for review (Kerzendorf *et al.*, 2020). Nevertheless, certain drawbacks remain, such as a possible lack of reviewer experience with subject matter and a risk that reviewers may be unreasonably critical of other applicants to improve their own odds of being funded (Andersen, 2020; Kerzendorf *et al.*, 2020). Program design employing peer review in this way will require mechanisms to avoid and mitigate potential conflicts of interest, as is done in the algorithmic approach used in the European Southern Observatory pilot program (Kerzendorf *et al.*, 2020).

Experimental alternatives to peer review are being proposed and piloted, though their appropriateness may be program-dependent.

Peer review may be well equipped to identify which proposals should be funded; however, when many proposals are scored highly, its efficacy in determining which projects to fund can come into question (OECD, 2018d). In situations where several closely ranked proposals are competing, small differences in score may not correspond to meaningful differences in the quality or potential of the ranked proposals. Final funding decisions therefore take on an element of chance (OECD, 2018d). Moreover, though the peer-review process accounts for the potential of research and its feasibility, evidence has emerged in some disciplines that the rankings produced from peer-review scores correlate unreliably with subsequent research impact (Fang *et al.*, 2016). In the above-mentioned Marsden Fund competition, for example, rankings from peer review were not predictive of subsequent success (Gush *et al.*, 2018). Despite its ubiquitous presence in scientific research, peer review has until recently not been extensively tested against alternative approaches for selecting and ranking proposals (Guthrie *et al.*, 2018).

Numerous experimental grant assessment strategies have been proposed to address weaknesses in traditional peer review (Bendiscioli, 2019). Among these, partial lotteries have drawn particular attention. Though the term "lottery" implies a complete lack of competition, these approaches typically make use of randomized selection only at a specific point in the process (Roumbanis, 2019). Proponents of partial lotteries argue that, while departures from meritocratic assessments risk being seen as illegitimate, their potential to reduce biases and increase efficiency in research funding allocation warrants testing and evaluation. Some funders are starting to experiment with this alternative to traditional review processes as a result (Roumbanis, 2019). The Health Research Council of New Zealand implemented a lottery system for a program supporting high-risk/high-reward research (Liu *et al.*, 2020). Their reviewers first screened short applications for eligibility, and those that showed promise were entered into a random lottery to select which proposals obtained funding. Participating researchers who were polled felt that the program lent itself well to a lottery, likely due to its smaller grant size and high-risk nature (Liu *et al.*, 2020).

Partial lotteries are also being tested by philanthropic funders in Germany, as a means for supporting "bold research ideas" (Volkswagen Foundation, 2020c). The Experiment! initiative at the Volkswagen Foundation first selects the 15 to 20 top applications using an external jury. Then, the same number of applications is drawn from a pool of 80 to 100 eligible proposals (including those that have already been selected) in a random draw, resulting in between 30 to 40 approved projects (Volkswagen Foundation, 2020b). Though such programs are still awaiting evaluation, uptake from researchers is growing (Volkswagen Foundation, 2020c). Similar to feedback about the New Zealand program, a survey of Experiment! participants found that a majority of researchers felt the scheme encouraged them to submit high-risk grant proposals that would not fit in other competitions, and that this approach could potentially improve the thematic and methodological diversity of the ensuing research (Röbbecke & Simon, 2020; Volkswagen Foundation, 2020a). In a preliminary evaluation of the program, Röbbecke and Simon (2020) concluded, based on initial results, that partial lotteries will not displace peer review entirely, but may be suitable for programs of short duration or for smaller funding amounts.

Other proposals to improve efficiency and reduce waste focus on using basic grants to replace costly competitions.

Many efforts for streamlining competitions focus on aspects such as controlling proposal volumes and modifying peer-review workflows. Others, however, have proposed more radical steps to lower administrative burdens by eschewing competition in grant allocation entirely. A recent study explored this proposition in the Netherlands, United Kingdom, and United States. The authors assessed funding levels for researchers if funds currently allocated through competition were distributed based solely on the cost of research in different disciplines. Without factoring in additional savings made by eliminating peer review, the resulting estimates suggest that concerns about the dilution of resources in an egalitarian system are unjustified in these jurisdictions (Vaesen & Katzav, 2017). Researchers funded by NSERC have sometimes made similar estimations to argue that a share of the Discovery Grants budget should be distributed non-competitively in the form of basic grants, by considering the time spent preparing and reviewing applications for the program (Gordon & Poulin, 2009a, 2009b). Such estimates have, however, been criticized as not appropriately valuing the benefits of peer review (Roorda, 2009).

Bollen *et al.* (2019) propose a more meritocratic but similarly radical approach to basic grants: in their self-organized funding allocation (SOFA) system, researchers would be provided with basic grants of a fixed value but required to redistribute a percentage of these funds to colleagues on an anonymous basis. The allocation proceeds iteratively such that researchers who received a greater amount of funding from colleagues after the first round have a greater amount of funding to share during the subsequent round. Architects of SOFA acknowledge that there are tradeoffs, benefits, and risks in this approach. Conflicts of interest and abuses of the system need to be monitored (Bollen *et al.*, 2019). Before implementing this system, NWO proposed studying it further to identify the disciplines or sub-disciplines and specific circumstances where a SOFA pilot would be most appropriate (NWO, 2017a). By allowing the scientific community to decide who receives the most funding, research to address societal needs may be de-prioritized. Nevertheless, SOFA and other basic grant systems offer an alternative funding allocation process that could aid in reducing overhead and pressure on the research community — ECRs in particular (Bollen *et al.*, 2019).

5.2 Enhancing Research Access and Impacts in Society

As noted in Chapter 2, funding agencies are increasingly supporting initiatives that encourage closer interactions between the scientific community and society. Supporting these interactions often requires the creation of links among stakeholders. These links can be made or strengthened by providing easier access to scientific results through adherence to open-science principles. Links can also be multiplied by encouraging researchers to directly consider the potential impacts of their scientific interests outside of academia. Funding agencies, meanwhile, are seeking reliable methodologies for measuring and monitoring a broad range of research impacts, taking into account the tension between incentivizing research with more immediate impacts on society and protecting support for fundamental, curiosity-driven research.

Supporting article repositories can promote open access, as high and volatile article processing fees can pose a barrier to open-access policies.

The open-access publishing model emerged in the early 2000s, seeking to make the results of research widely available to society at no cost to readers (MPG, 2003). Researchers following this principle can publish their findings in open-access journals, or in traditional subscription-based journals offering an open-access option (i.e., hybrid journals) (Piwowar *et al.*, 2018). Alternatively, they can upload articles to repositories managed by institutions or other organizations. Some disciplines also make extensive use of pre-print servers, which experienced increased uptake during the pandemic in disciplines that previously made little use of them (Callaway, 2020). These servers allow researchers to solicit feedback prior to peer review and can help establish priority in discovery given the delays associated with journal publication (Vale & Hyman, 2016; Sarabipour *et al.*, 2019). Funder policies on pre-prints vary, though many agencies allow them to be used in grant applications, and several popular journals now permit researchers to upload pre-prints to repositories prior to publication (Bourne *et al.*, 2017; Nature Editorial, 2019). Though popular in some disciplines, servers can be loosely regulated compared to journals, and researchers in certain fields may wish to avoid using them due to extreme competition or impacts on the patentability of research findings (Van Noorden, 2013; Kwon, 2020; ASAPbio, n.d.).

A researcher's choice of open-access venue defines the type of open access, subject to various conditions such as licensing. Taking all types together, data-driven attempts to define the state of open access have quantified the degree of uptake to almost half of available publications, with strong growth in the past decade (Piwowar *et al.*, 2018; Robinson-Garcia *et al.*, 2020). This trend of increased adoption, combined with other factors such as changing policies towards open access among funders and institutions, and shifts in the publishing industry — with Springer Nature announcing its model for open access in late 2020 — have led open-access authors and advocates to suggest that COVID-19 may have provided "the final push" towards widespread adoption of open-access practices (Piwowar *et al.*, 2018; Callaway, 2020; Nature, 2020a).

Funding agencies, through the practices they employ, play a role in determining how this push might proceed, but their policies have had varying success. An analysis of 1.3 million publications resulting from research funded by 12 different agencies found that one-third of researchers were noncompliant with the open-access policies underlying that financial support (Larivière & Sugimoto, 2018). The study found significant differences in compliance among funders, but also across disciplines supported by the same agencies (Larivière & Sugimoto, 2018).[31] To accelerate the widespread adoption of open-access publishing, a group of funders came together to form cOAlition S, which defined open-access principles known as Plan S (cOAlition S, 2019). This group includes several national funding agencies (primarily in the European Union) and the Bill & Melinda Gates Foundation (cOAlition S, n.d.). Plan S proposes several principles, such as requiring participating agencies to provide support for article processing fees and infrastructure. It also calls for funders to recognize that open-access publishers operate according to a wide range of business models (cOAlition S, 2019). The diversity of open-access journals is reflected by highly variable article processing fees; while the majority of journals do not charge fees, for those that do, fees vary over three orders of magnitude (Morrison *et al.*, 2015).

Plan S also proposes strict penalties for non-compliance, threatening the withdrawal of funding, the non-recognition of future publications in subscription-based journals, and the outright exclusion of applicants from funding calls (cOAlition S, 2019). The rigidity of these and other elements of the plan have sometimes drawn criticism. Some argue it is insensitive to the needs of researchers, and that obtained funding will play an undue influence on their decision about where to submit their work. While funders are responsible for paying article processing fees according to Plan S, researchers who are not supported by cOAlition S grants need to pay fees themselves, or risk exclusion from future calls (Global Young Academy, 2018; Perianes-Rodríguez & Olmeda-Gómez, 2019). Other criticisms centre on the plan's stance on hybrid journals,[32] with several professional societies in physics — a discipline historically enthusiastic about open-access principles — arguing that the option to publish in hybrid journals is valuable to their members (OSA, 2020). In this case, the issue is not the principles of Plan S but rather its abrupt adoption timeline. Frantsvåg and Strømme (2019) echo this argument in support of a longer transition period, noting that a large proportion of journals already considered open-access would in fact not be compliant under the plan's current requirements, particularly those from small publishers.

Discussions surrounding Plan S continue, but an approach balancing enforcement, financial support, and provision of infrastructure could ease the transition to open access without widening gaps between haves and have-nots (Larivière & Sugimoto, 2018). Larivière and Sugimoto (2018) notably found that higher levels of open-access

31 Below average open-access compliance has been observed for research supported by Canadian funding agencies at disciplinary and institutional levels (Larivière & Sugimoto, 2018; Robinson-Garcia *et al.*, 2020). Federal initiatives to drive adoption of open-science principles are underway in the form of a pan-Canadian open-science strategy, but few details are publicly available and stakeholder consultations are ongoing (GC, 2020c).

32 Analyses of trends in open-access publishing have found that publication in hybrid journals correlates with higher citation impact, but is also linked with high article processing fees, resulting from the legacy position and market power of established large publishers, and not from high production costs (Piwowar *et al.*, 2018; Schönfelder, 2019; Zhang *et al.*, 2020).

compliance were observed among funders who provide infrastructure for hosting article repositories, such as PubMed Central. This observation was mirrored in a separate study on institutional uptake for open access, which found that U.K. institutions are global leaders; their success is largely driven by open access through self-archiving of pre- or post-prints in institutional repositories and others (Robinson-Garcia *et al.*, 2020). This would indicate a promising avenue for other funders. Supporting the creation of repositories or incentivizing the use of existing databases can ease the burden for researchers who struggle to pay high article processing fees in a shifting publishing environment.

Agencies can employ both priority-driven and investigator-led approaches for enhancing research impact.

Granting programs increasingly count societal relevance among their objectives for research projects (OECD, 2018a). However, the societal impact of research is unpredictable, and societal needs are diverse. Agencies employ a corresponding diversity of practices to support research impacts on society. During interviews with external experts, the Panel heard conflicting viewpoints on the value of asking researchers to predict the societal impacts of their research upfront in proposals. Some argued that this practice encouraged conservatism by asking researchers to only conceptualize predictable or realizable research outcomes, and that research discoveries producing the most meaningful societal impacts were often unforeseen and unanticipated. Others pointed to the benefits of grounding researchers in their societal and economic contexts, and that encouraging researchers to consider societal impact could drive them to make new partnerships with other stakeholders in their local scientific community.

To provide guidance for researchers, some funders have turned to extensive public consultations and engagement processes to define societally relevant themes for their strategic initiatives. The European Commission, in designing its 2018–2020 work program of Science with and for Society, used an online questionnaire to solicit input from the public (European Commission, 2016). Building on this approach, the Dutch National Research Agenda performed an exercise inviting the general public to openly submit questions about science. The 11,700 entries were synthesized into a set of 140 questions by a multidisciplinary panel. These questions were explored through stakeholder meetings, and an online platform was built to enable ongoing conversations between researchers and members of the public, connecting the supply side of research to the demand side (NWA, 2016b). The resulting portfolio of activities is organized according to a roadmap of thematic priorities with accompanying funding programs, such as the Idea Generator (Section 5.1). Organizers argue that the co-design process for this research initiative has resulted in increased interactions between science and society through engagement and media coverage (NWA, 2016a, 2016b).

At the other end of the spectrum, NSF introduced the bottom-up Broader Impacts to its proposal assessment criteria in 1997, as a means of capturing the promise of proposals beyond intellectual merit. The criteria or targets for broader impacts are not strictly defined and allow for "innovation from the field" (NSF, 2014). Solving a problem that addresses a direct societal need represents one type of impact, as does training, public outreach, and capacity or infrastructure building (Kamenetzky, 2013). These activities can also be more or less prominent in the direct subject matter of the research proposal (NSF, 2014). An analysis evaluating the proposed broader impacts in funded NSF proposals found disciplinary differences in the types of initiatives funded, and that overall the most common form of impact was training, and the least common public outreach (Kamenetzky, 2013).

This diversity of broader impacts criteria lets researchers be creative in how they might produce outputs that benefit wider society, but it continues to challenge formal evaluation (Bozeman & Youtie, 2017). At the institutional level, professional incentive structures and the absence of training or infrastructure impede "broader impacts work" (Kamenetzky, 2013), which in turn reveals opportunities for funders to provide targeted support (Nagy, 2016). For example, in the context of education, some programs benefit from more specificity. PromoScience, offered by NSERC, aims to provide informal STEM education opportunities to youth. The specific need to generate broader interest in STEM has been found to be well addressed in the program's format. A recent evaluation indicated that the program could be made more effective, however, by being even more targeted, defining its desired outcomes as well as its desired audience (NSERC, 2016).

Advantages and disadvantages exist for top-down versus bottom-up strategies for encouraging societally impactful research through grant programs. Co-design approaches relying on consultations or other stakeholder input can help strategically orient research directions prior to announcing calls. Meanwhile, targeted approaches through standalone programs can address specific needs in more predictable ways. Bottom-up approaches, however, can promote shifts in research culture. The UKRI has eliminated the Pathways to Impact statement in proposals, for example, to reduce administrative burden. The agency concluded that 10 years of employing this practice changed the research culture in its community such that researchers now routinely consider public benefit in their proposed research (EPSRC, 2020a). Kamenetzky (2013) also argues that including criteria related to societal impact can attract a more diverse workforce, based on previous findings that women are more likely to engage in outreach and place a higher value on socially relevant work. Care must be taken, however, to avoid placing disproportionate burdens on underrepresented researcher groups (Section 3.2); this work still risks being professionally perceived as service work and considered supplementary to scholarly research (Kamenetzky, 2013; Wang, 2019).

Alternative indicators should be developed to monitor societal impact, and funders can support research that determines which indicators are appropriate to their context.

The societal impacts of NSE research take on numerous forms. Social and economic benefits manifest themselves differently, demanding separate methodologies for their assessment (Bozeman & Youtie, 2017). This makes the task of communicating NSE research funding accountability to the public challenging (Robinson-Garcia *et al.*, 2018). Traditional indicators for monitoring bibliometric performance are inappropriate, as societal impact is not necessarily synchronized with scholarly output, and because biases towards English-language publications mean that research with high relevance in a local context may lack prominence in the NSE literature (Hicks *et al.*, 2015). Alternative metrics or altmetrics have gained prominence as a tool for capturing societal engagement, for example through the monitoring of various social media interactions linked to scientific discoveries (Robinson-Garcia *et al.*, 2018). The use of altmetrics can borrow from methodologies developed in traditional bibliometrics, but is susceptible to similar pitfalls, and risks being exploited for marketing purposes by publishers (Robinson-Garcia *et al.*, 2018). Altmetrics, when reduced to a standalone statistic, can on their own offer limited insight on societal reach, with Twitter-based altmetrics having been found to more accurately reflect impact of a scholarly rather than societal nature (Robinson-Garcia *et al.*, 2018; Haustein, 2019).

Example methodologies that assess societal impact apply analytical frameworks to case studies in order to examine the interactions between researchers and stakeholders (Spaapen & van Drooge, 2011; Joly *et al.*, 2015). Some have proposed using altmetric indicators together with these existing approaches (Wilsdon *et al.*, 2015). Altmetrics could complement case studies — which can be laborious to undertake — by also identifying pathways or types of interactions that drive engagement through network analyses (Robinson-Garcia *et al.*, 2018). Wilsdon *et al.* (2015) propose that impact case studies from the U.K. Research Excellence Framework be used to provide guidelines for the development of additional indicators tailored toward specific contexts. In this way, further research on indicators (including altmetrics) supported by NSE funders could identify links between data and specific types of impacts, and could help develop more useful sets of quantitative or qualitative indicators (Wilsdon *et al.*, 2015).

Training initiatives built into fellowships or grant programs help researchers identify opportunities for research with societal impacts, and build capacity for entrepreneurship.

Encouraging researchers to explore societally impactful research can be accomplished through program design and greater recognition and monitoring of relevant research outputs. However, a lack of relevant training or instruction in pursuing goals unrelated to academic research presents an additional barrier. A study of activities pursued under the NSF Broader Impacts initiative suggested that the training and prior experience of researchers are strong predictors for the type of activities they pursue (Nagy, 2016). The Advancing Research Impact in Society (ARIS) initiative, supported by NSF, was developed to increase the societal impact of discoveries through research, training, and partnership creation (ARIS, 2020). Surveys employed in the context of this initiative have pinpointed specific needs and knowledge gaps in the research community, such as identifying audiences or stakeholders for these research activities. This allows ARIS to implement training sessions, webinars, and workshops targeting these needs. Participating researchers view these training opportunities positively, reporting improvements in their abilities to integrate Broader Impacts into their proposals and research plans (ARIS, 2020).

Programs for young researchers are also implementing measures to increase awareness of opportunities to derive economic impacts from research through commercialization. The UKRI Future Leaders Fellowship, for example, allows award holders to be hosted by businesses and asks applicants to propose plans for professional development and training associated with the focus of their fellowships (UKRI, 2020a). At institutional levels, the EPSRC Centres for Doctoral Training focus on topics aligned with societally relevant priorities, and act as linkage points between higher education and industry with a mandate to provide research training for specialized skills (EPSRC, 2018a). Host institutions are responsible for designing and implementing training environments for cohorts of 10 doctoral students per year. In addition to pursuing conventional research activities, students participate in professional development activities to build practical understanding of pathways towards research commercialization.

The NSF Innovation Corps (I-Corps) program offers an even more targeted approach for building capacity in entrepreneurship — specifically, teaching researchers to identify translation opportunities in ongoing research programs (NSF, 2019a). This accelerated experiential learning program takes place over the course of seven weeks (NSF, 2019a), forcing participants to quickly apply the knowledge they have obtained (Duval-Couetil *et al.*, 2020). I-Corps is open to PIs, postdoctoral researchers, research scientists, and graduate students. Participants apply in three-person teams, where one team member is an experienced entrepreneur, who provides mentorship and networking opportunities to their teammates. In addition to educating researchers about business development, the program requires researchers to engage with potential customers and stakeholders. An evaluation of the program found that it is popular among participants, and succeeds in promoting entrepreneurial knowledge and inducing behavioural changes in research. Researchers reported that the program allowed them to adopt a market-driven rather than technology-driven perspective, and led them to adapt mentorship approaches to better support trainees interested in translational research (Duval-Couetil *et al.*, 2020). Though these types of training programs vary widely in their implementation and aims, grouping researchers in cohorts and connecting them to stakeholders allows funding agencies to bolster the capacity for societally impactful research among interested researchers.

5.3 Improving the Evaluation of NSE Funding Practices

The ability of research funders to continually improve is partly dependent on their ability to evaluate their programs and practices. Program evaluation provides opportunities to inform policies by linking funding practices to research outcomes, and demonstrate public accountability and transparency regarding expenditures (ESF, 2009). However, *ex post* evaluations of funding programs inevitably face conceptual and methodological challenges, especially when broader social and economic impacts of research are considered.[33] The OECD (2018d) notes that challenges encountered at this level of evaluation include ambiguity about what social and economic objectives should be included; long and uncertain time lags between research investment and impact; complex chains of causality involving many variables; and the difficulty of identifying counterfactuals against which to compare observed outcomes. The attribution of outcomes to specific funding practices is also problematic, as researchers often receive funding from multiple sources and contextual factors influence research outcomes. However, new opportunities are emerging for NSE funders to improve evaluation efforts.

Funding agencies can benefit from acknowledged best practices and lessons learned from research assessment in other contexts.

Approaches for evaluating research vary widely among funding agencies, but commonly include bibliometric indicators (e.g., publications, citations), prizes, qualitative assessments of impacts (either self-reported or externally assessed), attraction of additional funding, and qualitative assessments of other aspects of the research process or outcomes, such as the degree of interdisciplinarity or the

33 This section focuses on evaluation initiatives and practices related to assessing the impacts of funded research and funding programs either during or *after* that research has been carried out. The focus is also on program evaluation practices relevant to competitive, grant-based funding.

achievement of transformative breakthroughs (OECD, 2018d). Input from successful and unsuccessful applicants can provide important insight on the strengths and weaknesses of program design (NSERC, 2014; Campbell, 2018).

While the context of any specific evaluation will determine which indicators and approaches are most important, funding agencies can benefit from existing guidance on these methods and indicators stemming from their applications in other assessment contexts. Bibliometric indicators are used to track publication and citation data and are appealing as a means of analyzing complex issues concisely and quantitatively (Wilsdon *et al.*, 2015; Stephan *et al.*, 2017). Some bibliometric indicators, however, are widely criticized or misused. Journal impact factors (JIFs), for example, have been critiqued as providing a poor proxy for both the quality of journals and of researchers (DORA, 2012; Wouters *et al.*, 2019).[34] An analysis of scientific publications over a 15-year period found that publications with high novelty have frequently appeared in journals with lower JIFs, and took several years to obtain the necessary citations for their high impact to be reflected in conventional indicators (Wang *et al.*, 2017). Some NSE funders have attempted to address this issue by providing specific instructions to avoid problematic indicators. For example, the U.K. Research Excellence Framework (REF) prohibited the use of JIFs and most bibliometric indicators in its evaluation of institutional performance (Arnold *et al.*, 2018). The 2021–2027 Evaluation Strategy Protocol applied to research in the Netherlands likewise restricts the use of bibliometrics (VSNU *et al.*, 2020).

Initiatives such as the San Francisco Declaration on Research Assessment (DORA) and the Leiden Manifesto also provide guidelines on appropriate uses of indicators (DORA, 2012; Hicks *et al.*, 2015). Reliability issues for single indicators can be overcome by considering multiple data sources together: for instance, a proxy for leadership within a team effort can be determined through analysis of co-authorship networks (Hicks *et al.*, 2015; Kelly *et al.*, 2020). The creation of new collaborative networks can also be used as an indicator given the growing importance of collaboration in research (Bromham *et al.*, 2016; Kelly *et al.*, 2020). Using multiple indicators also reduces one's ability to game a given metric (Wouters *et al.*, 2019). Through its support and hosting of the Research on Research Institute (RoRI), the Wellcome Trust provides an example of how an NSE funder can drive research on evaluation strategies, such that quantitative indicators can complement qualitative assessments and provide funders with mechanisms for transparently measuring impact (Hicks *et al.*, 2015; Michelson, 2020). Such

34 The JIF is a journal-based indicator, and citation analyses of journal outputs reveal that a minority of articles contributed to the majority of the JIF value (Schmid, 2017), making it a poor proxy for the impact of individual publications.

practices reinforce earlier guidance that quantitative indicators are still best used to complement, rather than substitute, expert judgment when it comes to assessment and funding allocation (CCA, 2012b).

The choice of evaluation criteria can also help steer research communities towards secondary objectives such as compliance with DORA and RRI principles. For example, in addition to banning problematic indicators, the REF is considering only open-access publications in its next round of assessments (REF2021, 2020). The REF also encourages quality over volume by restricting the number of publications that can be submitted.[35] Open science, PhD training, academic culture, and human resources policy are topics assessed for each research unit in the Dutch scheme (VSNU *et al.*, 2020). Critics sometimes contend that these expanding sets of criteria are a form of "mission-creep" (Bishop, 2020). However, incorporating such elements into evaluation approaches and frameworks is one means whereby funding agencies can signal support for supplementary objectives related to publication practices and norms.

Inclusive evaluation frameworks, coupled with appropriate assessment techniques, can help measure progress towards defined social and economic objectives.

One approach for assessing a broader range of research impacts involves developing inclusive evaluation frameworks linked to the agency's stated objectives or the applicant's predicted impacts. Such approaches can be used to observe aggregated outcomes to determine whether programs recruited the correct individuals or provided the desired research portfolio based on final reports (ESF, 2012). Alternatively, in the ERC's Science Behind the Projects initiative, a database was created for the scientific content of all research proposals supported by the agency. Those data could be used to compare how the activities of funded researchers align with overarching thematic objectives (ERC, 2014), while tailored reporting requirements for the database could be used to measure progress (ERC, 2018a). An extensive set of indicators could then be selected and applied based on their relevance to the objectives of a given program (ERC, 2018a). Indicators could be defined for core objectives (e.g., lists of prizes won by grantees) with complementary non-core indicators (e.g., the percentage of grantees who experienced upward career mobility during or after the project) (ERC, 2018a). The ERC's approach illustrates how extensive data collection, combined with experimentation with different analytical approaches, can better capture information on different types of research objectives and impacts.

35 While this practice counterbalances some of the risks of relying on quantitative metrics, the accompanying practice of rating research outputs submitted to the REF has been criticized in its current implementation as being biased against ECRs, and penalizing less prestigious research such as replication research or research with negative results (Torrance, 2019).

The OECD (2018d) also highlights the efforts of Science Foundation Ireland (SFI) in this regard. SFI's efforts are built around impact statements provided by applicants. Following the publication of a new strategy (SFI, 2013), SFI refined and expanded efforts to monitor research impact, assessing this aspect as "an integral part of the post-award review process" (OECD, 2018d). Many SFI awards are now subject to mid-term reviews where international experts in relevant areas (i.e., research translation and commercialization, industrial applications) evaluate progress made based on the information provided in the original impact statement. All SFI awardees also face annual reporting requirements, where they must identify which of 11 impact declarations best reflect the impacts arising from their work. These statements are used by SFI staff to characterize the range and types of impacts. They also provide the basis for impact case studies, and help convey to the public the impacts emerging from research investments in a detailed, structured way.

Digital tools and extensive data collection may aid in linking funding practices to research outcomes, informing future experimentation.

In addition to more extensive data collection, datasets combining information from multiple agencies or funding programs could be critical in addressing two major barriers to improved funding evaluations (OECD, 2018d). First, addressing some evaluation questions (especially regarding the efficiency of funding practices) often requires a comparative approach, measuring changes in outcomes against any differences in the funding processes used. Comparative experiments, however, may be politically and operationally difficult for agencies to set up given the need to maintain two parallel mechanisms. Second, sample sizes based on single programs may be small, especially if they are based on small-scale pilot projects. Pooling data across multiple funding agencies and systems can potentially address both challenges, yielding datasets large enough to support valid, statistical inferences about the differences in outcomes associated with different funding practices. While truly global datasets are likely unfeasible, even partial compilations of anonymized data from multiple agencies would improve understanding about the effects of different choices in how funding programs are configured.

The OECD (2018c) cautions, however, that data quality and interoperability remain significant challenges, and that the creation, maintenance, and use of large databases require significant resources and expertise. Design considerations in their implementation can also not be overlooked. In the Canadian context, one rationale for the introduction of the Canadian Common CV (CCV) was improved data comparability and resulting datasets that could support evaluation and analysis. However, this effort has been regarded as problematic by many in the research community it serves (Glauser, 2019). Many criticisms have been levelled at the system's design and capabilities, but most importantly, it is viewed as imposing a large administrative burden on researchers, contrary to its original intended purpose to simplify the application and reporting processes for grants (Glauser, 2017, 2019).

Canada's three federal research funders are reportedly exploring third-party organizations as alternatives to the CCV, examples of which are already in use in other jurisdictions to bridge interoperability issues among data sources (Glauser, 2017). The New Zealand ORCID[36] Hub exists to consolidate information on researchers, grants, and projects, such that unique identifiers can be assigned to people, grants, and institutions in that funding environment (Royal Society of New Zealand, 2017). It has also been used to monitor and provide recognition for peer-review contributions (ORCID, 2018). Chevalier *et al.* (2020) argue that these data systems allow quick implementation of low-cost, scalable solutions for evaluating funding programs, providing an example based on ORCID and the Dimensions Digital Science database to compare program outcomes across multiple agencies that support cancer research.

Such approaches can also in general be complemented by greater experimentation on the part of NSE funders. The OECD (2018d) notes that there are opportunities for greater use of counterfactual studies, assessing impacts from funded proposals in a competition versus unfunded proposals that later received funding from an alternative source. Ioannidis (2011) similarly notes that the deficit of an experimental perspective in research funding is problematic, arguing that controlled trials that involve randomizing consenting scientists to different funding schemes, and comparing their research outcomes and impacts, could provide an important role in informing future funding efforts. In a review of major research funding programs in six countries (Austria, Germany, Netherlands, Switzerland, United Kingdom, United States), Janger *et al.* (2019) conclude that "robust causal evidence for the impact of differences in research funding on research outcomes is rare." Ioannidis (2011) argues "it is a scandal that billions of dollars are spent on research without knowing the best way to distribute that money." Adopting a more experimental and rigorous approach to evaluation, combined with taking advantage of new opportunities in data collection and pooling, will be critical to better inform comparative assessments of NSE funding practices in the future.

36 Researchers registered to ORCID are assigned unique identifiers which can be used to unambiguously link to their activities and affiliations (ORCID, n.d.).

6

Applying Successful Funding Practices in Canada

Chapter Findings

- Changes or additions to funding programs must consider how they interface with other aspects of the funding system, including the availability of industrial and philanthropic research funding; how higher education institutions, research infrastructure, and equipment are supported; and the current configuration of research strengths and weaknesses.
- Canada's NSE funding landscape features multiple funding agencies, including both federal and provincial/territorial bodies. The number and diversity of funding organizations contribute to the flexibility of the Canadian system for supporting research, but increases the potential for fragmentation, sometimes making the system difficult to navigate.
- Many aspects of the research environment are outside of funders' direct control. However, agencies such as NSERC can play important supporting roles in reducing demographic and institutional barriers for early-career researchers, increasing diversity in the professoriate, attracting and retaining research talent, and mitigating the negative impacts of unequal funding distributions.
- Funding agencies often face competing priorities such as balancing support for priority-driven versus investigator-led research, and disciplinary versus interdisciplinary research. Evidence from abroad can only partly guide funders' actions given differences among jurisdictions. When it comes to balancing funding levels and success rates, however, most evidence supports distributions that prioritize greater equality and higher success rates.

Context is critical when considering the relevance of international research funding practices for Canada. Differences in the national composition and characteristics of research funding can alter the effects of funding programs as few researchers receive support exclusively from one source. Size and scale also matter; countries with smaller populations and economies are not simply scaled-down versions of large countries. Research funders operate as one component within a larger system of support, and strategies and actions are designed with consideration of their roles relative to other funders and institutions. With that in mind, this chapter discusses the Canadian NSE funding context, noting strengths and challenges that could affect how the approaches discussed in previous chapters are applied in Canada. The chapter concludes by revisiting key tensions among funding objectives touched upon in previous chapters, and by discussing how funding agencies such as NSERC can balance those tensions.

6.1 Reviewing the Options

Chapters 3, 4, and 5 reviewed funding practices that agencies have used to achieve specific goals. Table 6.1 presents a selection of promising and successful practices identified by the Panel, along with the Panel's assessment. As described in Chapter 1, *successful* practices were those where there was strong evidence (typically based on program evaluations and peer-reviewed studies) that they were effective in achieving their stated goals. *Promising* practices were those deemed by the Panel as likely to meet one or more of their intended goals, but where the evidence of success to date is limited. Problematic practices are not identified in this table, though they are commented on in the preceding chapters.

It is important to recognize that funding objectives are not always in alignment; a practice can be successful at meeting one goal, and problematic with respect to others. The Panel judging a practice to be successful does not indicate that the success of this practice is unconditional, or without drawbacks. As discussed in Sections 3.2 and 4.3, for example, "people-based awards" are attractive in offering researchers the flexibility to pursue the most meaningful research, and in particular empowering early-career researchers (ECRs), but biases in their review processes have sometimes had adverse impacts on equity (Witteman *et al.*, 2019). Increasing the equity of funding with more numerous, smaller grants can benefit ECRs, but also increases workloads as researchers must submit more applications to achieve the same level of funding. In other cases, practices have supplementary benefits. Reducing administrative burdens benefits researchers (particularly ECRs and those from underrepresented groups) by making grant applications easier and quicker, while also improving funding efficiency. Increasing diversity also enhances scientific productivity and impact, as a more diverse research community is better able to correct for bias, to consider a broader range of scientific hypotheses, and to make use of diverse types of evidence (Intemann, 2009).

Table 6.1 Selected Funding Practices Relevant to the Canadian Context

Goal	Practice	Example(s)
Supporting Researchers Throughout Their Careers	Segmenting awards by career stage	• Starting, Consolidator, Advanced (ERC) • Veni Vidi Vici (NWO)
	Dedicated funding for researchers from less-competitive institutions and regions	• EPSCoR RII Track-1 Program (NSF) • Strength in Places Fund (U.K.)
	Evaluative criteria recognizing a variety of scholarly contributions	• Biographical sketches (NSF) • ROPE (ARC)
	Bridge funding	• High Priority, Short-Term Project Award (NIH)
	Funding for staff scientist positions	• R50 Award (National Cancer Institute)
Supporting Equity, Diversity, and Inclusion (EDI) in the Research Community	Targeted funding opportunities and fellowships	• Rosalind Franklin Fellowship (University of Groningen) • Georgina Sweet Fellowship (ARC)
	Diversity targets	• Implementation in Canada Research Chairs
	Funding to research/share EDI practices	• ADVANCE (NSF)
	Assessment of EDI efforts as a project grant review criterion	• Broader Impacts Criterion (NSF) • FRQ – Nature et technologies (Canada)
	Equality charters	• Athena SWAN (U.K.)
	Equality charters linked to funding eligibility	• National Institute for Health Research (U.K.)
Supporting Indigenous Research and Researchers	Dedicated project funding	• Discovery Indigenous (ARC) • SAMISK (RCN)
	Dedicated grant review committees	• National Health and Medical Research Council (Australia)
	Ethical guidelines on Indigenous research	• Tri-Council Policy Statement 2 (Canada)
	Funding Indigenous-led research organizations	• Native American Research Centers for Health (NARCH)

Successful

Promising

Continued on the next page

Goal	Practice	Example(s)
Supporting Interdisciplinary Research	Requirements for new partnerships in collaborative programs	• Research Grants (HFSPO)
	Requirements to justify interdisciplinary approach	• Synergy Grant (ERC) • Exploration (NFRF)
	Interdisciplinary thematic workshops culminating in proposal submissions	• Scialog (RCSA) • Idélab (RCN)
Supporting High-Risk Research	Long-duration grants (5 years or longer)	• Advanced Grant (ERC) • New Exploratory Research and Discovery (Novo Nordisk Foundation)
	Double-blind applications	• Experiment! (Volkswagen Foundation) • Transformative Research Scheme (ESRC)
	Problem-oriented initiatives with long-term funding	• Societal Challenges (EC) • National Nanotechnology Initiative (U.S.)
Maintaining Funding Flexibility	Rolling funding calls	• Linkage Projects (ARC) • COVID-19 Rapid Response Rolling Call (NIHR)
	Provision of seed/timely funding	• Scialog (RCSA)
Improving Efficiency and Reducing Administrative Burdens	Pre-screening to reduce applicant pools	• Director's Pioneer Award (NIH) • Exploration (NFRF)
	Restrictions on resubmission	• Demand Management (UKRI) • Frontier Grants (ERC)
	Distributed peer review	• Open Competition Domain Science – XS (NWO)
	Partial lotteries	• Explorer Grant (NZHRC)
Enhancing Research Access and Impact	Infrastructure for open-access articles	• PubMed Central (NIH)
	Assessing non-academic outputs	• Broader Impacts Criteria (NSF)
	Consultations to inform strategic directions	• Societal Challenges (EC) • Dutch National Research Agenda (NWO)
Evaluation of Funding Practices	Broad frameworks to account for diverse outputs	• Monitoring and Evaluation Strategy 2018 (ERC)
	Controlled funding experiments	• Experiment! (Volkswagen Foundation)
	Data pooling across funders	(none identified)

Successful

Promising

Many practices in this table are already employed by NSERC and other Canadian research funders in various forms. Others could be adopted, either through the creation of new programs or the expansion of existing ones. For example, NSERC's Discovery Grants program is representative of several positive research practices identified by the Panel. Though the funding amounts are relatively low (with the 2020 competition results averaging $145,000 over five years for ECRs and $205,000 over five years for established researchers), success rates have been consistently above 50% since 2016, with some categories of applicants enjoying rates upwards of 90% (NSERC, 2020c). High success rates are beneficial for ECRs and for building research capacity. Because these grants are tied to a researcher rather than a specific project, and cover a longer than average duration of five years, they provide a combination of flexibility with relative stability (NSERC, 2014; OECD, 2018d). NSERC's Discovery Development program also provides researchers from smaller institutions with a form of bridge funding (Section 3.1), a short-term award to applicants who narrowly miss the funding cut-off for a Discovery Grant (NSERC, 2020e); opening this program to all researchers may improve access to stable funding. While it is unclear whether Discovery Grants are particularly effective in supporting high-risk research, their combination of duration, flexibility, and high success rates arguably permits researchers to take certain risks (NSERC, 2014, 2020d).

In other cases, improvements to current practices may be called for. The Canadian Common CV (CCV), for example, represents a case where efforts to introduce greater efficiency have instead increased administrative burdens for many researchers (Glauser, 2017, 2019), without necessarily producing a more robust data source for evaluation. Canadian research funders have also recently introduced new initiatives in a variety of areas, such as enhancing EDI, better supporting Indigenous research, or supporting high-risk, interdisciplinary research. It is not yet possible to evaluate the success of these efforts, though Canada can still benefit from lessons learned abroad as these programs are refined over time.

6.2 Understanding Canada's NSE Funding Context

As NSERC and other Canadian funders expand or adapt their portfolios, they can take advantage of evidence drawn from similar efforts undertaken elsewhere. Any changes or additions to existing programs, however, should factor in how they would interface with existing features of the funding system, including how Canadian higher education institutions are funded; how infrastructure and equipment are funded (including the indirect and operating costs of research); and how the NSE landscape in Canada is evolving.

Canada's R&D landscape stands out among OECD countries due to a large share of research carried out in the higher education sector and low levels of business R&D.

Approximately $32 billion was spent in Canada on NSE research in 2019 (StatCan, 2020a). The federal government contributed approximately 18% of these expenditures, about half of which ($2.8 billion) went to support R&D carried out by researchers in the higher education sector (i.e., universities and colleges). These institutions play a prominent role in Canada's research system. In 2017, universities and colleges performed 40% of all R&D in Canada. In comparison, these institutions performed only 13% of R&D in the United States and an average of 17% across OECD countries (Table 6.2) (OECD, 2020b). Conversely, relatively less R&D in Canada is performed by businesses and not-for-profit organizations. Among OECD countries, Norway has a similar distribution of R&D. However, Canada's total R&D expenditures relative to the size of its economy are lower. On this measure, Canada is now well below the OECD average and less than half that of leading countries such as South Korea.

Table 6.2 R&D Performance by Sector, 2017

	Business		Higher Education		Government		Private Non-Profit	Total R&D
	% of total R&D	% of GDP	% of total R&D	% of GDP	% of total R&D	% of GDP	% of total R&D	% of GDP
South Korea	79	3.41	8	0.36	11	0.46	1.4	4.29
United States	73	2.05	13	0.37	10	0.28	4.3	2.81
OECD Avg.	70	1.65	17	0.41	10	0.23	2.4	2.34
France	65	1.44	21	0.46	12	0.28	1.6	2.20
Norway	53	1.10	34	0.71	14	0.29	–	2.10
Canada	52	0.87	40	0.67	7	0.12	0.5	1.67

Data Source: OECD (2020b)

The table above shows the distribution of Gross Expenditures on R&D (GERD) by *performing sector* (i.e., where the R&D takes place), and R&D as a share of GDP. Countries are listed in descending order by the share of R&D conducted by the business sector. Note: Data on the *source* of funding reveal a similar pattern. In Canada in 2017, 42% of R&D was funded by the business sector compared to an average of 62% in the OECD.

While this pattern is partially driven by high levels of R&D in higher education relative to gross domestic product (GDP) (Canada currently ranks 6th among OECD countries on this measure), a more significant factor is persistently low R&D in the business sector. Low and declining business R&D has eroded Canada's overall research competitiveness in recent decades; Canada's total R&D investment is below the OECD average when measured as a percentage of GDP, and is the second-lowest among G7 countries (OECD, 2020e). Employed researchers as a percentage of the total working population decreased between 2011 and 2017, compared with an overall increase in OECD countries (OECD, 2021a), while the number of R&D personnel working outside higher education declined between 2008 and 2017 (StatCan, 2019b).

Many explanations have been suggested for why Canadian businesses underinvest in R&D, including a lack of competitive pressures and protective regulatory regimes, the integrated position of Canadian firms in North American value chains, poor commercialization of university research, and a more risk-averse business culture (CCA, 2009, 2013, 2018). While there is no definitive answer as to the cause of this pattern, higher education institutions play a relatively larger role in Canadian research activity as a result, and opportunities for R&D collaboration with industry are comparatively less common.

Canada's colleges and polytechnics, however, play a significant role in supporting such collaborations. While the majority of academic NSE research in Canada is conducted in research-intensive universities (the largest 15 universities in Canada account for nearly 80% of all competitively allocated research funding) (NSERC, 2020c; U15, 2020), researchers based at colleges and polytechnics are increasingly undertaking small-scale R&D projects with industry. According to Polytechnics Canada, over 3,000 applied research projects were carried out by its members between 2019 and 2020, involving over 2,000 industry partners (Polytechnics Canada, 2020), and in 2018 Canadian colleges and institutes were involved in over 7,300 research partnerships (Amyot, 2019). The College and Community Innovation (CCI) program administered by NSERC is a key source of support for this research, and funding from both the federal government and other sources for research carried out in these institutions is growing (RE$EARCH MONEY & Colleges and Institutes Canada, 2019).

Canada's research output in many NSE fields is modest, and growth has stalled in recent years due to fewer publications from government and industry.

Canada continues to be a leading contributor to global research in many fields of research judging from citation-based indicators (CCA, 2018). Canada's publication output in some fields of NSE research (including Chemistry, Enabling and Strategic Technologies,[37] Engineering, Mathematics and Statistics, and Physics and Astronomy) is low, however, compared to that in other countries. The CCA (2018) notes that this "comparatively low research output in core areas of the NSE is concerning, and could prevent research institutions and researchers from being able to pivot to tomorrow's emerging research areas". Even in emerging areas where Canadian researchers and institutions played a key developmental role, Canada is falling behind countries that now are rapidly increasing their efforts, judging by bibliometric indicators and patent data (Naylor *et al.*, 2017; CCA, 2018). Canada's growth in research publications also stalled in recent years, driven by fewer publications from researchers based in industry and government facilities (NSERC, 2020c). Publication output from the National Research Council of Canada (NRC), for example, declined by more than 50% between 2009 and 2014 (CCA, 2018).

The Canadian NSE research environment features multiple funders, including those at both federal and provincial/territorial levels.

NSERC is far from the only source of competitive NSE funding in Canada. At the national level, other agencies and organizations involved in supporting research include the Canada Foundation for Innovation (CFI), Genome Canada, Mitacs, CIFAR, Compute Canada, and the Perimeter Institute, among others. The division of funding roles and responsibilities across these organizations is correspondingly complex. Some (e.g., Genome Canada) focus on a particular domain. Others, such as Mitacs and CFI, perform specific roles. Mitacs supports researcher development and training and fosters collaborations with industry, while CFI is the federal government's primary means of investing in major research infrastructure. Relying on a dedicated, third-party organization for funding infrastructure helps ensure that funding decisions are partially shielded from political influences (Naylor *et al.*, 2017). However, the separation of funding for infrastructure from funding covering its operation adds complexity and administrative burdens for researchers.

The presence of provincial/territorial funding bodies, each with their own goals, programs, and funding structures, amplifies this complexity. Provinces and territories have their own means of funding NSE research, either through

37 This category includes several emerging sub-fields such as Bioinformatics, Energy, Nanotechnology, and Photonics (CCA, 2018).

dedicated agencies (such as Fonds de recherche du Québec), or through programs in government departments. Provincial/territorial governments collectively contributed $1.5 billion in NSE research funding in 2019 (StatCan, 2020a). Some provinces have mechanisms designed specifically to take advantage of CFI funding, which requires matching funding from provinces or industry, making it easier for researchers in those provinces to access CFI support (Naylor *et al.*, 2017). Regional agencies, such as the network organized under Genome Canada, offer opportunities to build local research capacity and respond to regionally specific needs, but add another layer of complexity. Canada's private not-for-profit sector is not a major source of funding in most areas, though Canadian researchers can and do benefit from support from philanthropies based in other countries.

Recent evaluations have been positive about the contributions of many of these independent, third-party funding organizations to Canada's research landscape. CFI has contributed significantly to building world-class research capacity in Canada (Halliwell, n.d.); 60% of highly cited researchers worldwide believe Canada has world-class research infrastructure or programs in their field (CCA, 2018). CIFAR has positively impacted interdisciplinary and international collaboration, as well as outreach and support for ECRs (ISED, 2017b). Elsewhere, Mitacs has supported links between academia and industry and helped Canada retain ECRs (ISED, 2017c); Genome Canada has contributed to Canada's strengths in genomics research (ISED, 2020); and the Perimeter Institute has added to Canada's capability in foundational theoretical physics, helping position Canada as a world leader in the field (ISED, 2017a).

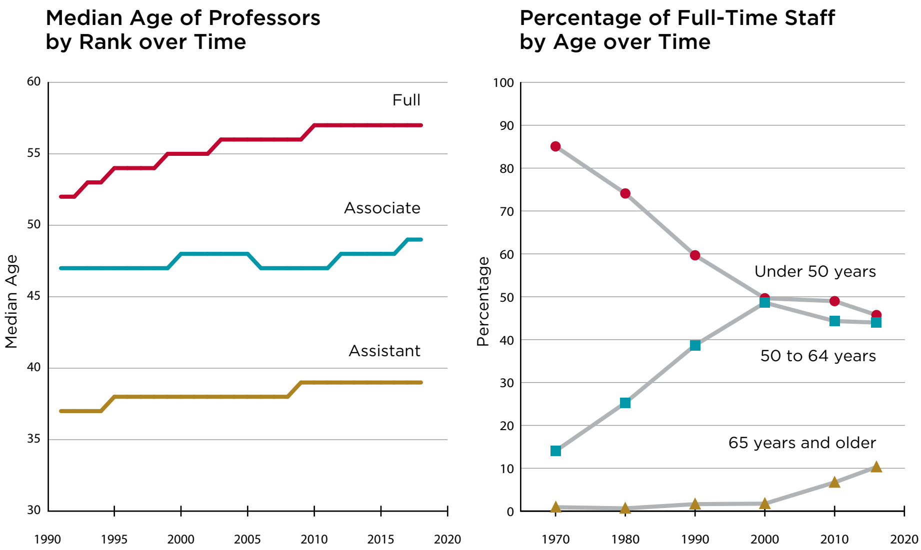
The number and diversity of Canadian research funders, however, can make this landscape difficult for researchers to navigate (Naylor *et al.*, 2017). Researchers may be required to seek funding from multiple organizations through multiple programs, each with their own eligibility and application requirements and timeframes. Among the federal granting councils, the Canada Research Coordinating Committee (CRCC) was recently created to address this challenge in the federal context, with a mandate to "achieve greater harmonization, integration and coordination of research-related programs and policies and to address issues of common concern to the granting agencies and the CFI" (GC, 2020d). This body may help harmonize the activities of Canada's research funders (or help researchers navigate this landscape), and now provides a directory of funding programs offered by the federal granting councils; however, its role in launching the New Frontiers in Research Fund (NFRF) and other funding calls suggest a function that is evolving beyond that of a coordinating body (CRCC, 2019).

6.3 Systemic Challenges and Potential Improvements

Canada's system for supporting NSE research has maintained an ability to contribute world-leading research in many fields (CCA, 2018). Several systemic challenges noted by the Panel, however, present opportunities for improvement if funding agencies can work effectively with other stakeholders.

Limited opportunities for advancement, and unequal access to education, contribute to equity, diversity, and inclusion challenges in Canadian research.

Demographic factors are impacting career progression for many researchers in Canada. The elimination of mandatory retirement has slowed the exit of faculty from Canadian universities (Worswick, 2005), with Naylor *et al.* (2017) arguing that this limits opportunities for ECRs to establish independent academic careers and slows the entry of underrepresented groups. Since 1991, the median age of full professors in Canada has increased from 52 to 57, the proportion of full-time academic teaching staff over the age of 65 has increased from 2 to 10%, and the proportion of professors younger than 50 has dropped from 50 to 46% (Figure 6.1) (StatCan, 2018, 2019a). Similar trends have been observed in the United States, where mandatory retirement at higher education institutions was also eliminated in 1994 (Ghaffarzadegan & Xu, 2018). There, the share of faculty members in science, engineering, and health disciplines above the age of 65 rose from 4 to 11% between 1995 and 2010, while the share of members below age 50 dropped from 55 to 46% (Ghaffarzadegan & Xu, 2018). Meanwhile in most European Union member states, the 35–49 age group represents the largest share of academic staff (Eurydice Report, 2017). Although variability exists across countries as to how such staff is defined, statistics from certain countries offer reasonable comparisons to the Canadian context. For example, in the Netherlands and the United Kingdom, the shares of full-time academic staff under the age of 50 are 61% and 72%, respectively (VSNU, 2019; Advance HE, 2020c).



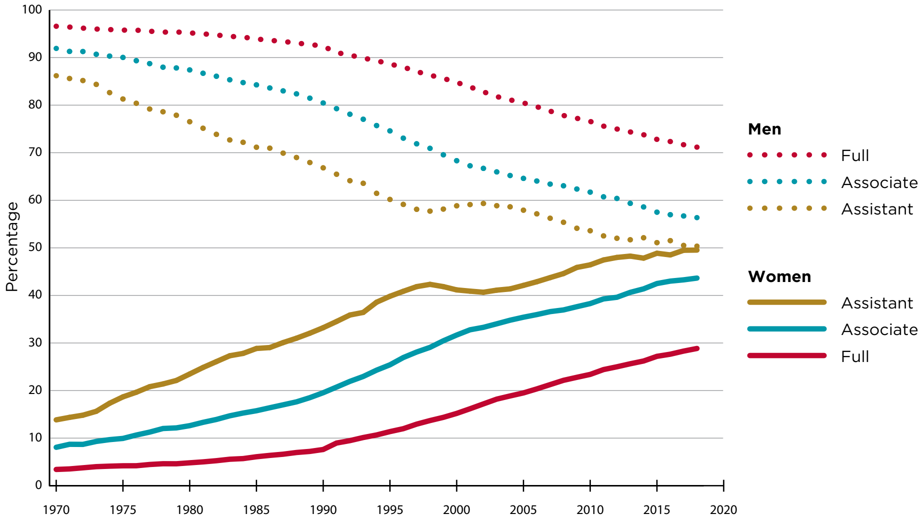
Data Source: StatCan (2018, 2019a)

Figure 6.1 The Aging Professoriate in Canada

Data for median age by rank is shown for all years from 1991-2018. Data for percentages of full-time staff by age is shown for the indicated years, from 1970-2016. Each year represents the beginning of a one-year reference period: for example, the 1970 data represents the reference period spanning 1970-1971.

The increasing number of faculty delaying retirement, combined with reduced hiring of new tenure-track faculty in favour of contract positions, slows the entry of younger researchers into the professoriate across North America (Faucher, 2014; Kezar *et al.*, 2016). This demographic inertia also slows progress on equity, diversity, and inclusion (EDI): while the gender gap in the professoriate is narrowing at all levels, it is currently largest among full professors (StatCan, 2019a) (Figure 6.2). However, various gender biases and societal pressures can contribute to a "leaky pipeline" (CCA, 2012a; Witteman *et al.*, 2019); despite having a younger professoriate, a majority of European Union countries have wider gender gaps at the full professor level than Canada does (European Commission, 2019). In 2016, in the European Union, on average 24% of top-ranked professors were women compared to 28% in Canada (European Commission, 2019). In the United States, the gap is slightly narrower, where 34% of full professors were women in 2018 (NCES, 2019).[38]

38 For a full comparison: In Canada in 2018, 49.5% of assistant professors, 43.6% of associate professors, and 28.8% of full professors were women (StatCan, 2019a). In the United States in 2018, 52.3% of assistant professors, 45.9% of associate professors, and 33.5% of full professors were women (NCES, 2019).



Data Source: StatCan (2019a)

Figure 6.2 Percentage of Researchers in the Canadian Professoriate by Rank and Gender

Data is shown for all years from 1970-2018. The 2018 data included 0.2% of professors with gender "unknown/other;" these were omitted from the figure. Each year represents the beginning of a one-year reference period: for example, the 1970 data represents the reference period spanning 1970-1971.

Targeted assistance for early- and mid-career researchers may alleviate some of the challenges for EDI caused by limited opportunities for advancement. The Dimensions EDI program (GC, 2019d) represents a significant step, and recently introduced bias training for reviewers and Gender-based Analysis Plus training for staff could reduce biases and barriers within funding programs described in Section 3.2 (CRCC, 2019). An opportunity exists to adapt the EDI Institutional Capacity-Building Grant, currently in pilot, to more strongly support innovation and evaluation of EDI practices, as seen in NSF's ADVANCE program (NSERC, 2020k; NSF, 2020f). In addition, the effects of increased service work among underrepresented groups should be considered as these programs are implemented.

However, some underrepresented groups are still far from equitably represented even at the assistant professor rank. Disparities in access to primary and secondary education limit the number of Indigenous students and students with disabilities entering research training (Parkin, 2015; CHRC, 2017). In 2016, Indigenous people in Canada were found to be less likely to have university degrees (including master's and doctoral degrees) than the general population, and were half as likely to have graduated from high school (StatCan, 2017). Improving EDI in the research community over the long term may consequently require intervening at earlier educational stages. In this regard, programs that provide paid undergraduate research experiences to Indigenous students, such as the Pathway to Graduate Studies program at University of Winnipeg (UWinnipeg, 2020), are promising. Research Experiences for Undergraduates, a similar program funded by NSF, provides research experiences to students from a variety of underrepresented groups, including those with disabilities (Beninson *et al.*, 2011; Davenport, 2014), and could provide a model for expanding the University of Winnipeg program or creating new Canadian programs.

More can be done to improve support for Indigenous research and researchers, including improving the recognition and funding of Indigenous higher education institutions.

Canada is making progress in better supporting Indigenous research and researchers. The Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans (TCPS2) has contributed to a shift towards equitable relationships between researchers and Indigenous communities (Moore *et al.*, 2017; Morton Ninomiya & Pollock, 2017). The CRCC has facilitated a variety of discussions with Indigenous organizations regarding their research needs (CRCC, 2019). In response to feedback that funding requirements for institutional affiliation can act as a barrier to Indigenous researchers, the Government of Canada committed to revising eligibility guidelines to ensure support for Indigenous research organizations (GC, 2019a); these organizations and their affiliated researchers are now eligible for CIHR's project grants (CIHR, 2020a). CIHR has also committed to mentoring and training Indigenous researchers starting at the undergraduate level, including $100.8 million in funding for building a network of centres for Indigenous-led health research (CIHR, 2019a; GC, 2020a). A tri-agency Reference Group for the Appropriate Review of Indigenous Research was announced in 2020 (CIHR, 2020c).

In addition to these and other ongoing initiatives, broader recognition of Indigenous-governed higher education institutions could help ensure that Indigenous research organizations are funded and discrepancies in pre-research education are remedied. New Zealand recognizes Indigenous-led higher education institutions with the same status and eligibility for funding as traditional universities (Durie, 2009). Ontario's *Indigenous Institutes Act*, passed in 2017, also gives Indigenous-governed institutions the ability to grant post-secondary degrees (Gov. of ON, 2017). However, conflicts between federal and provincial governments in Canada have contributed to leaving these institutions under-resourced (Ríos *et al.*, 2020). With multiple institutions and jurisdictions involved in Indigenous education and research, partnership models could be explored. As an example, the NARCH program represents a partnership between NIH and the Indian Health Service, with a demonstrated track record in funding Indigenous research projects and researcher development (Gittelsohn *et al.*, 2020). As such, it could be informative for NSERC in developing a similar partnership with organizations such as Indigenous Services Canada or provincial higher education bodies, especially if a cross-country recognition of Indigenous organizations like the U.S. Tribal Colleges and Universities could be implemented.

NSERC and other funders can continue to build on Canada's role as a destination for international students and an active participant in international research networks.

Canada serves as an important node in the movement of researchers internationally (Sugimoto *et al.*, 2017), possibly due to its attractiveness to international students. The share of international doctoral students in Canadian universities has grown steadily in recent years, reaching 35% in 2017 (StatCan, 2020b). In certain NSE disciplines, such as many fields in engineering, these students now make up the majority of the cohort (StatCan, 2020b).

Changing political realities in other countries can provide Canada with an opportunity to attract a greater share of international research talent (Redden, 2017; Sugimoto *et al.*, 2017). While developing Canada's overall research capacity can help make it an attractive destination for researchers and students (Cuntz, 2016), targeted funding for international recruitment and dedicated support programs can also make a difference (Naylor *et al.*, 2017; Ferreira & Klutsch, 2018). Career prospects for international researchers can be improved by providing support in relocation, immigration, and integration, as these processes currently act as barriers (Ferreira & Klutsch, 2018). Mobility support could include funding for moving expenses, or support or employment for a researcher's spouse. Currently such incentives are provided by universities, but Canadian funding agencies could play a role. For example, the Swedish Research Council provides family support in its international postdoctoral grant (Swedish Research Council, 2020).

Canada could also benefit from providing additional support for researchers training in other countries. Past concerns about the retention of leading researchers largely focused on a "brain drain" to the United States, which in 2011 hosted 70% of Canadian researchers from certain NSE disciplines who were working abroad (Franzoni *et al.*, 2012). However, researchers working abroad retain many connections to their country of origin (Sugimoto *et al.*, 2017). Survey evidence suggests Canadian researchers abroad frequently intend to return, depending on the availability of opportunities in Canada (Franzoni *et al.*, 2012). Scholarships allowing Canadians to train abroad are therefore likely to be beneficial in strengthening Canadian research capacity so long as sufficient opportunities exist for researchers to resume their careers in Canada.

While highly collaborative internationally (NSB, 2020b), Canada has a relatively low number of interprovincial collaborations (CCA, 2018). Programs that create interprovincial linkages may also provide an opportunity to increase collaboration and impact. Practices for creating international linkages in multi-jurisdictional contexts such as the European Union may be useful models for creating interprovincial linkages in the Canadian context. Virtual mobility programs, such as Sweden's Global Links for Strong Research and Finland's MOTIVE, can create research connections in cases where researchers are unable to physically relocate (Ferreira & Klutsch, 2018). Such programs may be particularly relevant after the constraints placed on travel in response to COVID-19.

Some aspects of Canada's research funding structure contribute to differences in institutional research capacity, along with regional disparities.

Researchers based at smaller institutions in smaller communities are often at a disadvantage when it comes to competing for research funding. This can limit the ability of these communities to capture the economic and social benefits of research to the same degree as large, urban centres. While not alone in facing this challenge, Canada's funding structure contributes to the concentration of research resources in several ways. First, an unusually large portion of NSE research in higher educational institutions in Canada is funded by the universities themselves, which contribute close to 50% of total higher education research expenditures (StatCan, 2020a). A university's ability to leverage funds from tuition, external scholarships, fees, and donors strongly impacts its research activities and supports a "rich-getting-richer" phenomenon. Because higher education falls under provincial jurisdiction, policies on institutional funding vary and there are disparities in fiscal capacity which can have significant impacts on research.

Federal funding programs in Canada also often inadvertently distribute funding unequally among institutions through peer-reviewed grant applications. As noted in Chapter 3, there is a success-rate gap in Discovery Grants awarded to researchers at small and large institutions, which given recent trends, is likely to widen over time (Murray *et al.*, 2016). NSERC's Discovery Development Grants (recently made permanent) may counteract this tendency (NSERC, 2020e). However, researchers from smaller institutions are also less likely to obtain Research Tools and Instruments supplements for Discovery Grants (NSERC, 2020d). The awards associated with the Canada Excellence Research Chairs and the Canada First Research Excellence Fund further concentrate funding at the level of specific institutions and individuals (Naylor *et al.*, 2017). Requirements for matching funds to access federal funding can widen gaps, as not all provinces and territories are equally able to provide such funds (Naylor *et al.*, 2017). Canadian research funders may be able to improve the overall performance of the system by continuing to reduce regional and institutional disparities in the distribution of funding.

6.4 Balancing Competing Priorities

Details matter when it comes to research funding practices. Using clear and appropriate terminology in a call for proposals, collecting only essential information in grant applications, being careful that required biographical information does not inadvertently introduce opportunities for bias — in all these cases, small decisions can have far-reaching consequences. Funding agencies, however, also face larger, overarching choices that involve weighing competing priorities and needs, such as assessing trade-offs between increasing funding levels and success rates or supporting interdisciplinary versus disciplinary research. For these issues, it is often a question of achieving the right balance, considering both the context and evidence from other jurisdictions.

A plurality of funding instruments allows funders to tailor support for different types of research, but at additional administrative costs.

When planning to expand support for new funding objectives, agencies must ask whether existing programs can be adapted or whether a new funding instrument is required. Funders have generally broadened their portfolios in response to the diversification of objectives (OECD, 2018a). This has the advantage of allowing for experimentation with a broad variety of funding characteristics, but must be balanced against the administrative inefficiency of running a large number of small programs, the potential difficulty for researchers to identify the appropriate funding opportunity, and the need for co-ordination among programs (Janger *et al.*, 2019).

Most objectives discussed in this report are supported by dedicated programs at NSERC. However, some may still benefit from expanded support. Naylor *et al.* (2017) argue that inconsistent approaches have been applied in certain specialized programs, noting an ad hoc approach to rapid-response research, and a dearth of programs that support high-risk/high-reward research and international collaborations — recently addressed by the addition of the NFRF.[39] That fund aims to support these research objectives (GC, 2019c), but it is too early to tell whether it will achieve these goals. Whether Canada will be best served in the future by the creation of additional programs, or the adaptation of existing ones, will depend on the distinctiveness of the research needs, the extent of complementarity among existing programs, and the balance of administrative costs versus benefits.

While international experience provides little guidance on balancing investigator-led and priority-driven research, the share of the former has been declining in Canada.

The tension between supporting priority-driven versus investigator-led research surfaced repeatedly in discussions among Panel members and external experts, but no conclusions could be drawn on the "correct" balance to be made. The entire funding landscape, including contributions from industry and philanthropy and the existence of specific research opportunities, influences how a federal granting agency prioritizes one over the other. In Canada, the share of granting council funding distributed to priority-driven research increased from 30% in 2000 to 42% in 2016, driven by decreased per-researcher funding for investigator-led research (Naylor *et al.*, 2017). While increases in federal funding for research may now be reversing this trend, the tendency to shift funding to targeted research in economically challenging times can cut off the pipeline of discoveries needed to feed innovation in the longer term. The recent development of novel mRNA vaccines

39 NSERC's Discovery Frontiers program is an exception; it periodically offers high-value awards to interdisciplinary, international teams on priority-driven topics.

for COVID-19 provides a useful reminder of how fundamental, investigator-led research can pave the way for breakthroughs critical to addressing societal challenges and priorities. These vaccines would not have been possible without decades of earlier fundamental research on mRNA and lipid nanoparticles (some of which was undertaken in Canada), the usefulness of which was often called into question (Verbeke *et al.*, 2019; Garde & Saltzman, 2020; Lowe, 2021).

Most evidence suggests that dispersing funding broadly, with modest grants and comparatively higher success rates, benefits capacity development and scientific output.

Achieving the right balance between grant size and application success rates is critical to many funding objectives. These objectives include recruiting leading researchers at an internationally competitive level, supporting ECR and workforce stability, achieving high-impact research, and obtaining a good return on the investment of public funds. As discussed in Section 5.1, the ability of reviewers to meaningfully assess differences in quality between multiple, closely ranked proposals in competitions that also have very low success rates (e.g., below 10%) is questionable. Conversely, increasing success rates without increasing total funding can spread funding too thinly among researchers, potentially leaving them with insufficient resources for meaningful work, and increasing the time they spend applying for grants.

In general, little empirical evidence supports higher levels of funding concentration. While NSE funding competitions rarely have success rates above 40%, there is no strong evidence that higher success rates compromise research quality (Janger *et al.*, 2019). Out of 19 studies included in a review of the correlation between grant size and research performance (measured by the number of articles, citations per article, and numbers of highly cited papers), 17 studies found that increasing grant size either has a negative effect on performance, or leads to diminishing returns after some threshold (Aagaard *et al.*, 2019). More dispersed funding may represent a diverse investment portfolio, increasing the chance that grants will pay off by producing high-impact research, especially with respect to basic science, which can have unpredictable long-term impacts (Peifer, 2017). For large group grants, such as funding for Centres of Excellence, the evidence is more mixed. Higher levels of funding concentration can provide stability, support the development of data and infrastructure resources, and aid in recruiting excellent researchers (Hellström *et al.*, 2018); results differ by field, however, and greater impacts are observed for research groups not already at the highest level of performance prior to the award (Ida & Fukuzawa, 2013; Langfeldt *et al.*, 2015). Moreover, one study found evidence of diminishing returns as the number of researchers involved in a research consortia increases (Breschi & Malerba, 2011).

Studies do indicate, however, that very low grant sizes can also be ineffective if they do not provide a minimum level of resources (Aagaard *et al.*, 2019). Optimal funding levels vary based on differences among jurisdictions and disciplines; different types of research require different types of resources. Together with the complexity of factors shaping the distribution of funds, this suggests that experimentation is necessary to determine how best to tune the distribution, or portfolio, of funding within a given system (Aagaard *et al.*, 2019; Azoulay & Li, 2020). When multiple funding organizations are operating with similar criteria and low coordination (which may be the case in Canada), the risk of unintended funding concentration increases (Aagaard *et al.*, 2019).

Funding agencies therefore have many factors to consider in finding an appropriate balance between funding levels and success rates. However, most empirical evidence supports broader distribution of funds and higher success rates — an orientation consistent with NSERC's provision of modest "grants-in-aid" with the Discovery Grants program. This approach has also been repeatedly validated in past evaluations, though it has been noted that inflationary pressures are gradually eroding the value of grants over time, threatening their effectiveness (NSERC, 2020d). In the Canadian context, the Panel notes that the success of the Discovery Grants program crucially depends on the existence of a supporting ecosystem of supplementary funding programs and opportunities that researchers can access.

7

Conclusion

NSE funding practices are evolving in response to both social and scientific trends. While the core practices of competitive research funding (e.g., peer review by discipline-based evaluation committees) are not likely to be replaced any time soon, funders increasingly recognize that supporting a robust, resilient, and diverse research community is central to fulfilling their mandates over the long term. They are also gradually diversifying their portfolios of funding programs, recognizing that different objectives are best served by different funding and review practices.

This report provides a review of international practices for funding NSE research. The unique context in which every funding agency operates prevents the identification of successful practices that could be readily deployed in all circumstances. Providing direct recommendations on how NSERC should apply this review to its portfolio was beyond the Panel's mandate. However, this chapter summarizes the Panel's key findings in relation to its charge, focusing first on questions about the research context, and then on what is known about successful funding practices and how these can be applied in Canada.

7.1 Responding to a Changing Research Context

What major trends in NSE research, nationally and globally, are most relevant to how NSE should be supported going forward?

Changing patterns in public R&D spending are altering the research landscape. Globally, the scientific landscape is shifting as China and other emerging economies rapidly expand their research efforts. Many OECD countries, however, have seen reduced government R&D spending in recent years amidst continued expansion of higher education systems and growing populations of researchers. The result has been increased competition for funding and positions. A more competitive research environment places further stresses on junior researchers and students trying to establish their careers, and amplifies concerns about conservatism in research funding — researchers feel compelled to propose safe projects and avoid more novel proposals. Industry and philanthropies are playing important supporting roles in some areas of research, providing investigators with more funding choices. Governments are also using a wider spectrum of funding mechanisms; having formerly relied either on institutional block transfers or competitive research grants, they now make use of a variety of hybrid mechanisms. A greater array of funding models contributes to the flexibility of the research system, but makes that system more difficult to coordinate and navigate.

Several additional factors are making the research landscape more complex. Inter-, multi-, and transdisciplinary research efforts bring new partners together across an increasingly interconnected research community, and new technologies bridge gaps in knowledge and offer novel tools for study. The nature and scale of questions that can be addressed through NSE research are growing and diversifying as a result, with corresponding changes in the types of participants and research outcomes. These developments also challenge how proposals are assessed and projects evaluated. It can be difficult to assemble the expertise needed to appropriately evaluate inter- and multidisciplinary proposals, and traditional metrics can be insufficient to capture the full range of research outputs. Some funders have responded to this trend by implementing new programs, while others have maintained the same portfolio but adapted their procedures. Agencies will need to continue exploring which approaches work best in their own context, being mindful of the potential for duplicate (or conflicting) efforts with other funders; the costs of introducing and monitoring new programs; and the need to support research within disciplinary boundaries while enabling opportunities for interdisciplinary connection, collaboration, and knowledge translation.

COVID-19 posed new challenges for research funders and resulted in an unprecedented mobilization and acceleration of research activity in many domains. Funders had to find ways to maintain existing programs despite the disruptions created by the crisis, while also rapidly implementing new funding mechanisms — and did so successfully in many cases. The stresses and disruptions caused by COVID-19 also exacerbated inequities in the research system, disproportionately affecting women, early-career researchers, and those with young children. Meanwhile, departures from standard practices for scientific publishing and research dissemination raised concerns about the erosion of traditional checks on research quality and rigour. While the long-term implications of this period for the research community remain uncertain, the pandemic illustrated how quickly the social and scientific landscape can change, underscoring the value of flexibility for NSE funders.

What role(s) do NSE funding agencies play in supporting research ecosystems, and how are these roles changing?

While public funding agencies maintain their traditional role as providers of competitive, grant-based funding, they are also increasingly active as arbiters or regulators of the research environment and culture. The central position funders occupy among research stakeholders provides them with unique leverage to improve the accessibility of research as well as the health and resiliency of the research workforce, so long as they accept the diversity of ways research is practiced.

Funders, for example, are becoming more engaged in research assessment practices, with many (including Canada's federal funding agencies) signing the San Francisco Declaration on Research Assessment (DORA). The development of the Responsible Research and Innovation paradigm and its adoption by the European Commission is another indication of how funders are gradually expanding their activities in areas such as research ethics. They are also helping to promote open-science principles and open access to research publications, and supporting public science engagement and science education. COVID-19 emphasized the role that funders can play in supporting scientists, science communicators, and policy-makers in their efforts to inform the public about the role of the research community in responding to a crisis.

Looking ahead, funders may be required to develop new ways of engaging with research communities, and with the public at large, to ensure that the practices and approaches they employ are consistent with the needs of their communities. Systemic issues, such as bias and underrepresentation, are attracting more attention among funders as they acknowledge their role in the long-term management and support of the research workforce. In addition to statements on infrastructure and scientific excellence, high-level strategy documents published by research funders increasingly feature plans to improve equity, diversity, and inclusion (EDI), and to curb cumulative advantage. Similarly, funders are supporting research networks in new ways to advance research goals — for example, through practices designed to stimulate novel collaborations or through support for international mobility.

7.2 Successful NSE Funding Practices

What is known about successful practices for funding NSE research internationally, and how could such practices be applied to funding for NSE research in Canada?

The Panel organized its review of successful and promising international research practices along three dimensions: supporting researchers; supporting interdisciplinary, high-risk, and responsive research; and improving funding efficiency and impact. Taken together, the practices reviewed by the Panel provide tools that can be used to build more effective and efficient approaches for funding NSE research. Their effectiveness, however, is often context-dependent; successfully adapting these practices in Canada will hinge on appropriately tailoring them to this country's research landscape and funding environment.

Practices for Supporting Researchers

Many funding practices can be adjusted to provide better support to researchers across their careers. Awards segmented by career stage, similar to those offered by the European Research Council and the Dutch Research Council, were deemed by the Panel to be particularly successful. These programs allow early-career researchers to develop into independent investigators, and continue to support those researchers through mid-career transitions. Researchers at different stages also benefit from award programs that provide flexibility and resources over extended periods; bridge funding programs can be used to mitigate the effects of funding gaps. Increased support for staff scientist positions — whether through project funding (in place of postdoctoral fellows) or independent grants — and for specialized fellowships including structured training and transition support are other practices funders are exploring to help support researchers early in their careers.

Funding agencies are also actively exploring a range of strategies for addressing long-standing inequities in the research community. Equality charters such as Athena SWAN have led to higher proportions of women researchers and staff (and greater career satisfaction); the U.K. National Institute for Health Research is experimenting with using participation in these charters as a criterion for eligibility. Changes to review and evaluation practices can also help address systemic disadvantages from implicit and explicit biases. Opportunities for researchers from underrepresented groups, diversity targets in program participation, and increased mentorship and training in grant-writing represent other successful or promising approaches to address EDI concerns. Given that service burdens can be higher for underrepresented groups, evaluations can also be made more equitable through recognition of more diverse scholarly work, including mentoring activities and engaging local stakeholders in research. For individual competitions and peer review, blind reviews may help mitigate bias, to the extent that application packages do not reveal the identities of its authors, as can judging the quality of the proposed research prior to considering the applicant's track record.

Indigenous research and researchers face unique challenges, which funders are attempting to address in a variety of ways. Dedicated funding programs and review committees for Indigenous researchers and research appear to be appropriate and effective in many circumstances, as is increased support for community-based research centres or researchers. Involving Indigenous communities and researchers early in the design of programs is critical. Building relationships and engaging in co-development of programs ensures that funding program designs and objectives are sensitive to the needs of these communities and researchers, who have often experienced negative interactions with the research establishment in the past.

Many of these practices are already employed in Canada, and others could be adapted to the Canadian context. Considering the challenges faced by researchers entering the professoriate, segmenting funding programs by career stage could provide an alternative to existing provisions for ECRs while also addressing potential career gaps. Lessons learned from equality charters such as Athena SWAN can continue to inform the development of the Dimensions program in Canada. At smaller scales, some Canadian funding programs have begun to ask applicants to define EDI-related objectives for their proposals and offer guides for evaluating EDI dimensions in projects or teams as a strategy to combat bias. Improved support for Indigenous research and researchers is needed in many countries, but the Canadian context offers considerations separate from those of Australia, New Zealand, the United States, or Nordic countries. That said, dedicated programs such as the Discovery Indigenous program in Australia, SAMISK in Norway, or the Native Investigator Development Program in the United States could potentially serve as models for Canadian funders, though any such programs must be co-developed with the Indigenous researchers and communities involved.

Practices for Supporting Interdisciplinary, High-Risk, and Responsive Research

Supporting interdisciplinary and high-risk research often requires changes to standard funding programs and practices, such as forming evaluation groups with a broader range of backgrounds and expertise. For interdisciplinary research, misalignment among partners, anchoring projects in a single, dominant discipline, or mismatches in expected research outcomes can prevent such efforts from meeting their potential. Some agencies encourage partners to resolve these issues early on by requiring statements outlining the extent of disciplinary integration, or collaboration plans to explain the expected contributions of each partner. Grand Challenges or problem-oriented calls can also provide an effective framework for partnerships across disciplines and sectors. Many funding practices with this aim focus on relationship-building and networking events at multiple stages in programs, such as workshops, or support for the temporary co-location of researchers.

The Panel also explored funding practices for supporting high-risk/high-reward research, which have multiplied in recent years in response to concerns that researchers have become risk-averse due to intense competition for funds. Many of these programs are also interdisciplinary in nature, so networking-based practices could encourage high-risk/high-reward research. Changes to funding duration can also be critical for this purpose. Funding agencies have begun to offer longer-duration grants for high-risk programs, sometimes greater than five years. Furthermore, procedural changes are being tested within dedicated high-risk/high-reward programs to combat risk aversion, distinguishing these from more conventional calls. These programs are using several novel assessment processes that both reduce burdens on applicants and encourage risk-taking. For example, some calls require shorter proposals — omitting requirements for preliminary results — and anonymize proposals during peer review to ease concerns among applicants that their track records (or other considerations) will put them at a disadvantage when proposing ideas that are not "safe."

The diversity of research needs and objectives underscores the value of funding flexibility. As is the case for high-risk research, funding duration is a key parameter that can help adapt programs to many specific purposes. Short-term funding schemes, operating on fast turnaround times or through rolling deadlines, have shown promise for supporting projects in partnership with the private sector, or in response to crises such as the COVID-19 pandemic. In general, flexibility is required to support research that addresses immediate societal or policy challenges. Such research initiatives place additional demands on funding agencies and researchers, due to differing priorities, timelines, and objectives for multiple non-academic stakeholders. Practices to successfully support such initiatives include the recognition of non-academic research outputs, and early involvement of external stakeholders in program design.

Several successful approaches to support research across multiple disciplines have been employed in Canada. CIFAR has been effective in supporting interdisciplinary research and networking across a range of research themes. Meanwhile, NSERC has adjusted the structure of its peer-review process to better accommodate bottom-up proposals combining multiple disciplines. In addition to existing approaches, greater support for workshops or other small, topic-oriented meetings can efficiently create ties across disciplines, regions, and institutions. The effectiveness of the New Frontiers in Research Fund (modelled on the FRQ Audace program), which provides five years of support for interdisciplinary, high-risk, and collaborative research, remains to be seen. Its use of double-blinded assessments, however, is a promising experiment. Building on this initiative with other targeted programs offering short, anonymized proposals with even modest funding could provide other avenues for risk-taking, outside of elite competitions.

Practices for Improving Efficiency, Evaluation, and Impact

As funding instruments multiply, so do the numbers of proposals and administrative requirements for reviewing them. With declining success rates due to increased competition, the resources allocated to reviewing unsuccessful proposals increase. Restrictions on resubmission, demand management, and staggered calls are examples of supply-side policies that can be used to reduce burdens on reviewers. However, agencies should take into account the value of providing feedback to unsuccessful applicants. In addition to variations on traditional review practices such as shortening proposals or blinding review panels, some funders are exploring more unconventional alternatives such as distributed review (i.e., having the pool of applicants serve as reviewers) and partial lotteries (where funding allocations are made in part by chance after initial screening). While evidence on the success of these practices is limited, applicants participating in a high-risk/high-reward competition using a partial lottery found the process fair, and some research facilities have used distributed peer review to allocate facility time, reporting lowered administrative burdens. These and other approaches aiming to reduce the peer-review time benefit both applicants and reviewers, but also risk introducing new sources of bias and can call into question the rigour and integrity of the funding process. More evidence is needed to define the costs and benefits of these alternative approaches as substitutions for traditional peer review.

In line with their expanding roles and activities, funding agencies are also experimenting with new approaches to strengthen links between science and society, and to enhance the impact of the research in their portfolio. Doing so effectively requires recognition of non-academic forms of research output (e.g., public outreach and engagement initiatives), improving the public's access to scientific research, and increasing the participation of societal actors in NSE research. Practices allowing researchers to be evaluated based on self-defined forms of societal impact provide flexible encouragement to engage with broader society; they have also been shown to result in capacity building in the United States. Measuring the impact of NSE research in society requires funders to define and test new indicators. These could be based on interactions between scientists and stakeholders, and on case studies to capture nuance. Open-access commitments such as Plan S are another means of supporting more widespread access to publicly funded research. In addition to mandating compliance with such policies, funders can encourage open-science principles by funding or hosting repositories for storing data and publications.

Practices for evaluation are also expanding to include new forms of data, as agencies recognize that the impacts of research occur over multiple timescales, and manifest themselves in multiple forms. Some lessons for funding agencies can be drawn from large-scale national evaluation exercises such as the Research Excellence Framework in the United Kingdom. These assessments prohibit the use of problematic indicators such as journal impact factors, and increasingly prioritize research quality and impact over quantity. Impact case studies combining quantitative and qualitative observations relating to research outputs are also a promising approach in the Panel's view. The European Research Council (ERC) serves as an example of what is possible with better data collection. Regularly collecting data on funded projects allows the ERC to analyze how the research it funds aligns with policy objectives, and where there may be gaps. Opportunities also exist to make use of pooled data across agencies, or open linked datasets through third parties, to further broaden the evidence base needed to experiment with new indicators, evaluation models, and funding practices. Bolstering reporting, monitoring, and evaluation standards and methods provides funders with more evidence to guide both their strategies and their reactions to the evolving scientific landscape.

Canadian research funders such as NSERC can learn from international experiences in all of these areas. When it comes to improving efficiency and lowering administrative burdens, demand management or resubmission restrictions could assist NSERC or other Canadian funders to exert control over success rates and discourage serial submissions. Reducing peer-review burden ultimately benefits funders and researchers alike. NSERC can learn from efforts in the United States and other countries that support broader public science outreach and engagement without being overly prescriptive or creating excessive burdens for researchers. When it comes to increasing impact, Canadian funding agencies struggle to ensure compliance with open-access policies, which could affect the eligibility of Canadian researchers in competitions offered by funders participating in Plan S. A pan-Canadian open-science strategy has been announced but not yet established; this could involve commitments to supporting open-access infrastructure. In the meantime, Canadian funding agencies need to continue accounting for article processing fees when encouraging researchers to publish in open-access journals.

Many aspects of NSE funding hinge on balancing competing priorities. When it comes to managing trade-offs between funding levels and applicants' success rates, empirical evidence tends to support the prioritization of more broadly dispersed funding, consistent with the approach NSERC has taken with the Discovery Grants program. Funders must also balance support for investigator-led and priority-driven research. Tailoring funding calls to immediate societal needs and priorities has an intuitive appeal, which is further amplified in the current environment dominated by a global health crisis and the resulting economic and social pressures. But, in the view of the Panel, NSE funders should remain cognizant that the investigator-led discovery research proposed today may be crucial to resolving tomorrow's challenges — a fact powerfully demonstrated by the recent development of novel COVID-19 vaccines building on decades-old science. NSERC and other NSE funders should consequently be wary of allowing the share of priority-driven funding to increase at the expense of fundamental, investigator-led research.

7.3 Final Reflections

The Panel's discussion of NSE funding practices was often constrained by the limited evidence available. Many practices are promising but not yet fully substantiated, either due to lack of publicly available evidence, or an absence of controlled studies. In the Panel's view, placing a greater priority on experimentation with alternative funding practices could help rectify this situation. New funding approaches could be tested, evidence of effectiveness collected, and links across agencies created to facilitate data sharing, making it possible to assess the relative performance of different approaches more accurately. Better data collection and data management in the funding environment provide opportunities to perform such experiments transparently, and to disentangle the effects of contextual factors from funding interventions. Experiments with blind reviews, partial lotteries, and other alternative funding approaches are promising in this regard; even in cases where new approaches are rejected, funders and the scientific community benefit from knowing more about how such practices influence research outcomes. Any efficiency gains stemming from these and similar experiments could ultimately allow funders to support more research while lessening burdens on researchers. If NSERC and other funders commit to supporting such experiments, the universe of funding practices and our collective knowledge about their outcomes will continue to improve and expand.

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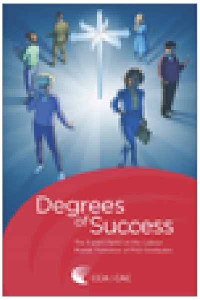
CCA Reports of Interest

The assessment reports listed below are available on the CCA's website (www.cca-reports.ca):



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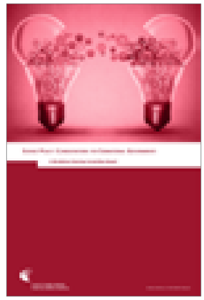
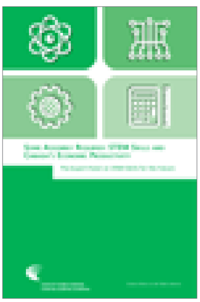
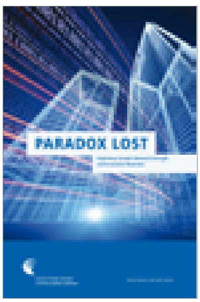


Science Policy: Considerations for Subnational Governments (2017)



Some Assembly Required: STEM Skills and Canada's Economic Productivity (2015)



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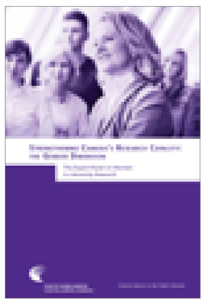

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