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Implementing the Innovation Agenda: A Study of Change at a Research Funding Agency

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Abstract With the rise of an innovation agenda in science policy, previous studies have identified a shift in how the state delegates responsibility to funding agencies in order to change the behaviour of the scientific community. This paper contributes to this literature through a micro-level study of how one of Canada's largest research funding agencies, the Natural Sciences and Engineering Research Council (NSERC), has changed resource allocation for research over 25 years. Our study foregrounds research funding agencies as key sites for examining the reconfiguration of the relationship between the state and science, as expressed in programmatic and resource allocation decisions. Through analysis of an original dataset compiled from NSERC's funding and documentary data, we demonstrate the relationship between the introduction of innovation objectives in funding instruments, the adoption of new delegation modes to guide resource allocation, and changes in funding among research fields over time. Our study empirically demonstrates the cumulative effect of programmatic and funding decisions in a major agency, going beyond previous accounts of more general trends at the national level.

Keywords Research policy · Research councils · Principal-agent theory · Delegation modes · Innovation · Canada

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Introduction

The reorientation of research policies towards technological innovation and commercial objectives in recent decades has sparked scrutiny of how this trend affects the organization and conduct of academic science (Godin and Gingras 2000; Larsen 2011; Martin 2012). In this context, scholars question whether basic and applied research activities serve as complements or substitutes for one another (Landry et al. 2010; Quaglione et al. 2015), and how the emphasis on commercial applications impacts funding for various fields (Ylijoki 2003). These issues have also been raised in Canada where the shifts toward a "commercial orientation" in science were instigated in the 1980s with successive science and technology (S&T) policies emphasizing innovation and the mobilization of science for economic growth (Doern et al. 2016; Sá and Litwin 2011; Fisher and Rubenson 2010). A long-standing rationale behind the push towards commercialization have been indicators showing Canada's poor performance in industrial innovation and lower business expenditures on research and development (R&D) relative to other countries perceived as competitors (Council of Canadian Academies 2018; Independent Panel on Federal Support to Research and Development 2011; Science, Technology and Innovation Council 2015). This paper focuses on the implications of these policy trends within research funding agencies, which are key actors in the implementation of government objectives related to innovation in the science policy domain.

To understand the role of funding agencies in this context, we frame their relationship with the state as involving a delegation of roles and responsibilities, employing the conceptual lens of the principal–agent theory as the main organizing framework. In science policy, the principal (the state) operates through its intermediary agencies (e.g. the research funding agencies) that incentivize agents (scientists) to carry out tasks (research) in exchange for financial support (Braun 1993, 2003; Gulbrandsen 2005; Guston 1996; van der Meulen 1998). Intermediaries effectively execute policy goals and objectives through the design of programs and the allocation of resources that are then pursued by agents. However, the intermediary role of funding agencies and the complexity of their mandates induce tensions in their relationships with the principal and the agents (Guston 2000). These tensions stem partly from ensuring that policy objectives from governments are addressed while maintaining scientific norms and adhering to institutionalized practices that guide the research enterprise. Arguably, the policy orientation of the principal will partly shape the mechanisms by which the intermediary apportions funds, especially in systems with tighter accountability mechanisms between intermediary and principal. This may involve a shift in the mode of delegation in place from state to funding agencies, whereby different actors and activities are involved in funding decisions to ensure state objectives are being addressed.

Indeed, studies have shown that the rise of the innovation agenda in science policy has led to a shift in control over the resource allocation process, which was gradually transferred from scientists to the state and its interests (Elzinga and

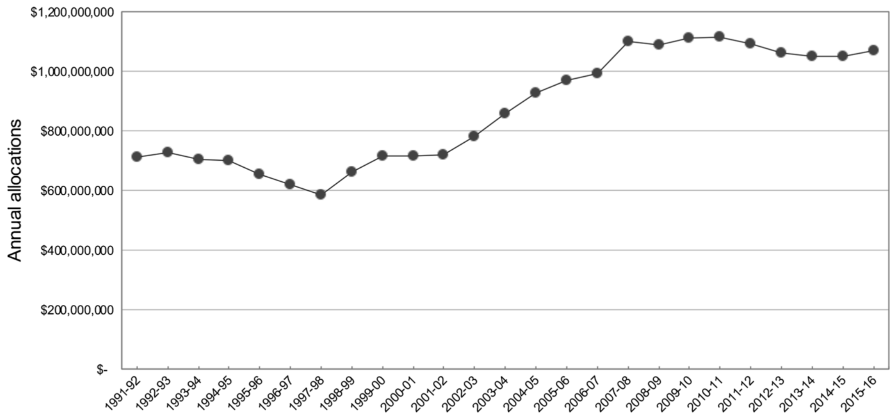

Fig. 1 Total budgetary allocations by the research council per fiscal year, in 2015 constant C$. *Source*: Authors' calculations based on total amounts given out each year and the number of grants recorded in NSERC's awards database

Jamison 1995; Braun 2003; Lepori et al. 2007; Potì and Reale 2007). Some country-level studies have provided evidence of "structural changes" in funding mixes that have sharpened the focus on contractual arrangements emphasizing state priorities and socioeconomic benefits in academic research (e.g. Lepori et al. 2018; OECD 2018; Wang and Hicks 2013). While these studies provide informative findings on the broader policy environment, the literature is relatively silent on how shifting policy agendas and modes of delegation interact to produce different outcomes within funding agencies.

In this context, we turned our gaze to one of Canada's largest research funding agencies: the Natural Sciences and Engineering Research Council of Canada (NSERC), the premier source of financial support for natural science and engineering researchers. Most of Canada's federal investments in R&D occur through arm's-length government agencies, including NSERC alongside two other research councils covering broad research areas.[1] NSERC's R&D budget has increased steadily over the past two decades to over C$1 billion per year (Fig. 1). However, with growing funding commitments come increasing political demands to demonstrate the relevance and impact of public investments in research, like their counterparts in countries such as the United States and the United Kingdom (Sá et al. 2013). As a result, NSERC has been tasked to foster industrial R&D and science-based innovation, as recognized in a national review of federal programs for business innovation: among the ten largest direct-investment programs for collaborative R&D between scientists and firms, two were housed at NSERC (Independent Panel on Federal Support to Research and Development 2011).

[1] The other two federal funding agencies are the Social Sciences and Humanities Research Council of Canada (SSHRC) and the Canadian Institutes of Health Research (CIHR). SSHRC supports research and training in the social sciences and humanities; CIHR provides support for health and medical research.

Thus, considering the saliency of NSERC as a research funding agency and a leading organization in the promotion of innovation within Canada's research community, the purpose of our study was to examine how the federal government's innovation agenda has affected NSERC's resource allocation over time. Specifically, we ask: how have the goals of NSERC's funding instruments shifted over the past 25 years? How have different delegation modes been deployed across programs? And to what extent have possible shifts in goals and delegation modes affected the distribution of resources across research fields?

We situate our work in the broader literature and discuss the theoretical foundation for our study in the section below. Next, we offer evidence of a growing concentration of use-and industry-driven research activities and changing delegation modes over time, substantiating that industry-driven projects in priority S&T areas have been increasingly emphasized. This pattern is associated with changes in delegation modes to support externally oriented projects. The final section considers implications for policy and practice.

Theoretical Background

This paper frames the relationship between government and science funding agencies principally through the conceptual lens of the principal–agent theory (Braun 1993; Gulbrandsen 2005; Guston 1996; van der Meulen 2003). The theory, rooted in neo-institutional economics, assumes that principals and agents are rational actors seeking to maximize their priority-ordered preferences. The priorities of the principal (the government) and the agents (researchers) may diverge, and the principal does not have full information to judge if the agents are following their end of the bargain (van der Meulen 1998). Agents may use discretion in performing the work they are funded for to pursue their own interests, which may or may not be aligned with the goals of the principal. Hence, principal–agent theory assumes that the design of institutions and contractual arrangements is important in mitigating the potential problems involved in the delegation relationship between principals and agents.

Traditionally in the science policy domain, a *blind delegation mode* entailed the transfer of control over resource allocation from the state to scientists who were left to govern their own affairs following disciplinary norms and standards. However, recent trends have ushered in new delegation models, including the *incentive delegation mode*, in which funding is targeted to reflect political objectives, and the *network delegation mode*, in which the state encourages the creation of networks of scientists, firms, and end-users to define and pursue their own objectives (Braun 2003). The *steady state delegation mode* is an additional category described by Braun (2003) as:

> a means—certainly not conceived as such but strategically used […] by funding policy-makers—for a fundamental re-orientation of scientific activities. (p. 314)….The 'steady state' manipulates the relative importance of

Table 1 Connections between delegation modes, funding instrument types, and commonly used committees. *Sources*: Potì and Reale (2007) and Braun (2003)

Delegation mode	Funding instrument types	Composition of evaluation committees
Blind delegation	Academic-oriented field-initiated projects and grants	Mainly academics
Steady state	Innovation-oriented field-initiated projects and grants	Mixed (academics, industry, government)
Incentive delegation	Programs	Mixed (academics, experts, economy)
Network delegation	Networks	Mixed (academics, experts)

global and directed funding, thereby reducing the options of scientists to engage themselves in investigator-initiated research (p. 319).

One can argue that the resource allocation modes of the intermediary (i.e. research council) may change over time to reflect the policy preference of the principal (i.e. government) toward one or more delegation modes (blind, incentive, network, or steady state). Moreover, to assess relations between policy preferences and changes in delegation modes in practice, we need constructs that connect the theoretical delegation modes to actual resource allocation instruments used by funding agencies. In our study, we build on the classifications of project funding proposed by Potì and Reale (2007: 420) and Braun (2003), who connected funding instruments to delegation modes. This offers a useful operational link between instruments observed in practice and theoretical delegation models prescribed by the principal–agent theory. Table 1 outlines their categorization.

Field-initiated projects and grants are instruments that allow scientists to define their own objectives and are linked to the blind delegation mode. Potì and Reale (2007) also distinguish between *field-initiated projects and grants* in pursuit of either *academic-oriented goals or innovation-oriented goals. Innovation-oriented field-initiated projects and grants* are arguably instantiations of the steady state delegation mode. *Programs* encompass instruments supporting research activities for state-prescribed priorities and are linked to the incentive delegation mode. *Networks* are instruments supporting networks of researchers and non-academic stakeholders and are mapped onto Braun's network delegation mode.

The distinction between the academic and innovation orientations is important because instruments driven by different goals and objectives are subjected to different criteria in the evaluation of potential projects. Shifts from one delegation mode to another are typically accompanied by differences in evaluation criteria and committees making decisions on proposed activities (Potì and Reale 2007). Focusing projects on innovation means that criteria centered on the usefulness and impact of the research become emphasized, necessitating related expertise during adjudication. Academic-oriented field-initiated projects and grants are assessed through the standard disciplinary peer review process, while innovation-oriented field-initiated projects and grants, thematic programs, and networks widen the scope of evaluation to include criteria and actors from other domains.

From the perspective of funding agencies and delegation, one can also distinguish between the goals of the funding instruments, which express broader policy and political objectives. While the delegation model helps us understand how the contractual arrangements between principals and agents are managed, a more nuanced approach is needed to evaluate instruments' goals, particularly those that discard the sharp separation between basic and applied research and support work that blurs fundamental investigations with utility. Stokes' (1997) influential work offers such a typology. His model of basic scientific and technological innovation includes a two-dimensional array that places scientific activities on a plot with "quest for fundamental understanding" as the vertical axis and "consideration of use" as the horizontal axis. The resulting plot situates research into one of three quadrants[2] (p. 73):

- pure basic research (*Bohr's Quadrant*) representing work that seeks fundamental insight into phenomena without consideration of use;
- pure applied research (*Edison's Quadrant*) that is driven by consideration of use without seeking fundamental insight into general phenomena; and
- use-inspired basic research (*Pasteur's Quadrant*), where the dichotomy between fundamental and applied sciences is blurred entirely.

Representing the seminal notion in Stokes' model, Pasteur's Quadrant casts basic and applied research as synergistic rather than oppositional activities, in which the quest for basic understanding can also bring useful applications, thus relaxing the long-standing notion of basic and applied research as two extremes on a one-dimensional spectrum.

Approached to date mainly from the perspective of scientists, Stokes' framework has been employed, for instance, to survey researchers on inspiration for knowledge production or entrepreneurial activities (e.g. Abreu and Grinevich 2013; Amara et al. 2019), to explore how corporate "Pasteur and Edison bridging scientists" in firms contribute to R&D partnerships with other firms and universities (Subramanian et al. 2013), and to investigate how R&D productivity of firms is affected by collaborations with "Pasteur scientists" in universities (Baba et al. 2009). Stokes' model has been challenged and developed further, albeit with the researcher still as the main unit of analysis (Tijssen 2018). In this paper, we apply the typology to categorize funding instruments. In addition to connecting the instruments to delegation modes, coding instruments using Stokes' framework allows for tracing how changing policy priorities have shaped resource allocation among different research goals.

[2] Stokes clarifies that there is, in fact, a fourth quadrant in which the answer to both "consideration of use?" and "quest for understanding?" is no. Such research "systematically explores *particular* phenomena without having in view either general exploratory objectives or any applied use to which the results will be put" (emphasis in original, Stokes 1997: 74).

Data and Methodology

We carried out a case study of resource allocation at NSERC between 1991 and 2016. Data sources include: (1) funding data since 1991 representing C$21.8 billion in investments and (2) program documentation including description of goals, objectives, requirements, and forms of evaluation. We extracted NSERC's publicly available dataset consisting of 505,708 funding records (NSERC 2017). Each record provides information about the amount disbursed to a researcher per fiscal year with the following data: principal investigator and co-researchers (if any), institution, department, province, competition year (the calendar year in which the competition was held), annual award amount, fiscal year in which the installment was disbursed, installment number, instrument name, selection committee, research subject and area of application for the work conducted, non-academic partners' names (if any), and the project summary (if available). As to the use of documentary sources, we drew from program descriptions to assess committee compositions used in the evaluation of proposed projects. While some applications may be assessed internally by the research councils or through a peer review process (i.e. disciplinary committees), others may use mixed committees consisting of researchers and government representatives, or members from all three main stakeholder communities (i.e. researchers, government, and industry). All committees engaging at least one non-academic representative during the evaluation are considered mixed committees. Although the nature of the committees can vary substantially depending on the number of non-academic members participating, program descriptions for the evaluation mechanisms were used to ascertain the inclusion of various members in evaluation panels.

Our analysis focused on instruments supporting research and development activities performed by individual or groups of researchers. Instruments for science outreach, science promotion, and academic and industrial scholarships for undergraduate or graduate students and postdoctoral fellowships were excluded, reducing the number of records for analysis from 505,708 to 298,616 and the number of funding instruments in the database from 209 to 154 in total. The reduced set used for analysis is equivalent to C$18.4 billion in investments, or 84% of the total database based on funding amounts. These funding instruments and abbreviated versions of their objectives are listed in the electronic supplementary material (Online Resource). They consist of a wide range of schemes issued over the past 25 years to support the natural science and engineering enterprise in Canada, from programs that support major and transformative institutional research initiatives (e.g. Discovery Frontiers program) on the order of C$1 million per year to the flagship "grants in aid of research" (e.g. Discovery Grant) that help Canadian researchers subsidize their core programs with an average C$35,000 per year (NSERC 2018).

The diversity of funding schemes also reflects the diversity of research needs in terms of scope, research tools, equipment, facilities, geographies of collaborations (local vs. international), and potential collaborators (other academics vs. external actors). Although not explicitly mentioned in the abridged objectives,

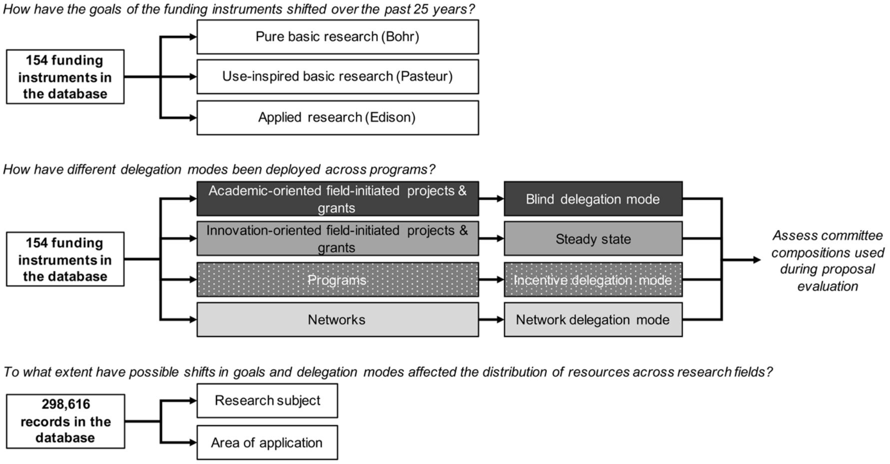

Fig. 2 Coding steps involved in analyzing the various funding instruments and records.

most programs within NSERC also have a training mandate to nurture the development of technical skills among young trainees. One of the challenges here was to distill the essence and critical feature of such a diverse range of programs—some that support small tools and equipment for an individual laboratory while others finance large-scale collaborations involving academic and other external partners.

Our overarching coding strategy is shown in Fig. 2. Using data on instrument goals and descriptions, the first step entailed coding all records to estimate the relative investment in pure basic research (Bohr), use-inspired basic research (Pasteur), and pure applied research (Edison) (Stokes 1997). Each instrument was assessed according to whether it pursues a "quest for fundamental understanding" (yes/no) and whether it is driven by "consideration of use" (yes/no). Based on that, each instrument was assigned to a particular quadrant. We chose to code the goals and objectives at the level of funding instruments rather than the actual work in the field (as eventually delivered by scientists) as this partially circumvents our lack of access to submitted grant applications, results on final project outcomes, and the motivations for the research driving each individual project record in the database. In addition, there is also a question as to which should take precedence: *ex ante* or *ex post* evaluation—an issue clarified by Stokes (1997):

> Although the historian of science will in due course be able to give far more assured judgements as to which research proved in fact to advance the general understanding of a field and which in fact led to significant use, only a framework that deals ex ante with the goals of research can serve the needs of science and technology policy (p. 78).

To understand how delegation modes had been deployed across programs, funding instruments were then classified according to the types proposed by Potì and Reale (2007), along with the added steady state delegation mode (refer to Table 1). Although this classification offers a useful starting point, funding instruments in practice may blend elements of one or more delegation types described earlier. For example, it is typically assumed that "programs" are automatically geared toward innovation outcomes, but themed research programs may seek to advance fundamental research. In other examples: a large-scale network undertaking research targeting state-prescribed areas could potentially be classified under both the network and incentive delegation modes; and researchers may pursue field-initiated projects in response to calls from networks supporting sub-projects by individual scientists.

In our analysis, the guiding principle was to identify the most prominent feature of the instrument in question: i.e. is the primary objective of the instrument to promote the network structure (making it the network delegation mode), or is thematic research in state-prescribed areas prioritized (making it the incentive delegation mode)? Or is the instrument's core feature to give scientists complete autonomy to define their research questions in pursuit of fundamental discovery (the mark of academic-oriented, field-initiated projects under blind delegation)?

The records also contained fields for research subjects and sub-areas of application that were analyzed and grouped using NSERC's tables for Research Subject Codes and Area of Application Codes (NSERC 2011).[3] In total, NSERC's code tables contained 396 research subjects grouped under 55 fields of research, and 78 sub-areas of application divided across 12 broader areas, which were used to categorize the records. A coding challenge here was that a notable fraction of the original records did not have entries available for research subjects and/or application areas. In our analysis of supported research fields and application areas, we only included records where available.[4] Data visualizations were carried out using Tableau Software. All amounts are expressed in 2015 constant Canadian dollars.

Results

Shifting Goals

All funding instruments NSERC deployed over the last 25 years were categorized according to their goals and objectives (see Online Resource). We distinguish between instruments that are oriented toward pure basic research (in the tradition of Bohr), use-inspired basic research (Pasteur), and pure applied research (Edison). The first set supports unfettered, researcher-defined work investigating phenomena without consideration of utility (21 instruments in the database). Instruments supporting use-inspired research seek both fundamental insight and relevance (73 instruments). Instruments emphasizing applied research seek shorter-term relevance without emphasis on fundamental insights; these are typically conducted jointly

[3] For example, research subjects "1101 Structural loads and safety" and "1102 Steel: materials and structures" could be grouped under the broader research field "1100 Structural Engineering". Application sub-areas "501 Processed food products and beverages" and "504 Human pharmaceuticals" could be grouped under "500 Manufacturing processes and products".

[4] Approximately 9% of investments of interest, or C$1.6 billion out of C$18.4 billion, did not have research categories available in the database. 18%, or C$3.4 billion, did not have entries available for application areas.

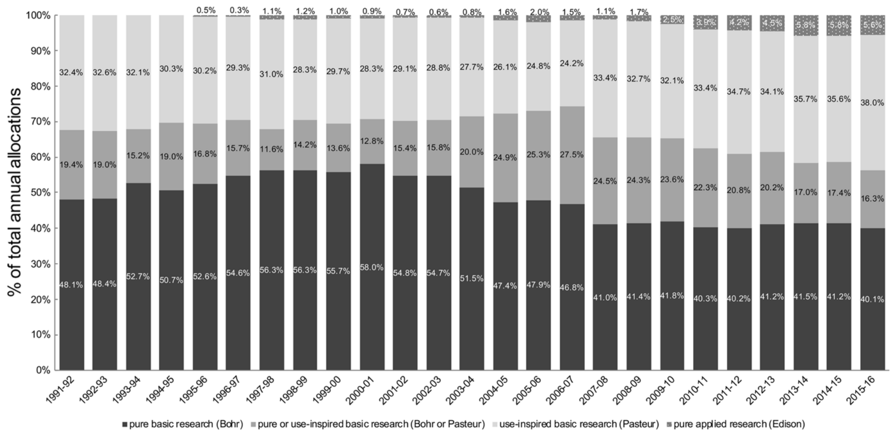

Fig. 3 Distribution of funds allocated through funding instruments that support each Stokes' quadrant (shown as percentages of annual totals). Some funding instruments support both pure and use-inspired basic research and are shown as an additional category. *Source*: Authors' calculations based on total amounts given out each year in NSERC's awards database

with an external partner (17 instruments). In Fig. 3, the allocations of the resources between the quadrants are shown as fractions of total annual outlays (see Online Resource for distribution of funds in absolute amounts). Some funding instruments were found to support both pure and use-inspired basic research and are shown as an additional category (43 instruments).

In the 1990s, instruments dedicated solely to pure basic research made up, on average, nearly 53% of the total funding. Since a peak 58% in 2000–01, the fraction dedicated to instruments exclusively supporting pure basic research has been on a downward trajectory, until it finally touched a new 40% share in 2015–16.

Although current budgetary allocations still appear to favour an orientation toward pure basic research, the absolute funds disbursed through instruments with a use or applied orientation have grown at a significantly faster pace (79% growth from 1991–92 for use-inspired work) relative to those for pure basic research (27% growth), to the point where the total disbursed amounts for pure and use-inspired basic research were almost on par in 2015–16.

A notable drop-off in the fraction for basic research occurred between the 2006–07 and 2007–08 fiscal years (from 47 to 41%). This mirrors an increased emphasis on innovation and associated funding at the policy level in 2006–07, in line with the 2007 S&T strategy released by a newly elected Conservative government (Government of Canada 2007). Since then, funds dedicated to instruments supporting solely use-inspired basic or applied research increased to the point where these made up nearly 44% of all funds disbursed by the end of our analysis period.

Figure 3 also shows a prominent increase in use-inspired basic research funding in 2007–08—an absolute increase of over C$110 million from prior year (see Online Resource for absolute amounts used in Fig. 3). This is a real change, rather than a statistical recategorization, that can be attributed to policy choices made by a new federal government, which emphasized increased funding for public-private partnerships for R&D and commercialization (Department of Finance Canada 2006: 62; Government of Canada 2007). The policy unveiled in the 2007 S&T strategy, which accounts for a large fraction of the increase in use-directed funding, created the centres of excellence for commercialization and research aiming to “turn research into commerce”; this had immediate impact on expenditures on science (Department of Finance Canada 2007: 23; Government of Canada 2007: 58; Networks of Centres of Excellence 2016). Increases to allocations for applied research in subsequent years were due to expanded support for college-centric programs, which were supplemented with additional funding to enable researchers at community colleges to engage in technical problem-solving for industry (Government of Canada 2007: 58). All of these policy commitments are reflected in NSERC’s budgetary outlays commencing in the 2007–08 fiscal year, showing a boost in programming to serve innovation and the needs of industry.

This agency-specific pattern described above is consistent with a major review of science funding in Canada that pointed to the overall erosion of support for unfettered research (Advisory Panel for the Review of Federal Support for Fundamental Science 2017). Drawing on data from 2006–07 to 2013–14, the review documents a shift across federal agencies in funding from field-initiated research typical of blind delegation to targeted programs for university–industry partnerships and innovation. It concludes that “independent research work saw a decline of available real resources per researcher of about 35 per cent in [the] period” (p. xiv), and that “investigator-led research operating grants” should be emphasized in the renewal of the funding system (p. xxiv).

Among the past and existing instruments, the growth in NSERC’s innovation portfolio can be attributed to a handful of established initiatives over the last 25 years. The top five instruments in terms of total funding account for nearly three-quarters of all investments in innovation-oriented research (see Online Resource for a breakdown of innovation- and industry-oriented funding by key instrument). Although it is not within the scope of this study to describe the details of each, the most supported instruments fund use-inspired basic or applied research. Considered critical to nurturing university-industry partnerships, they support: (i) short-term collaborative R&D projects involving one or a small team of researchers and a firm; (ii) large, multidisciplinary networks of scientists and users in the public and private sectors; and (iii) individual faculty called “industrial research chairs” heading a major research program of relevance to the university and a firm.

What these overarching trends mean for agents is that an increasing portion of funds in recent years has been tied to use and innovation outcomes through funding instruments with alternative modes of delegation. At the same time, the number of scientists applying for funding has also increased (refer to the Online Resource for a breakdown of funded researchers per year). The growth in the number of researchers supported through pure basic research instruments has surpassed slightly the overall growth in the budget for this type of work (i.e. 41% change from 1991–92 in the number of scientists vs. 27% in this type of funding). The number of scientists supported through use-centric instruments has also surpassed the total available funding (98% growth in the number of researchers since 1991–92 vs. 79% in growth for funding). The number of researchers funded through applied research

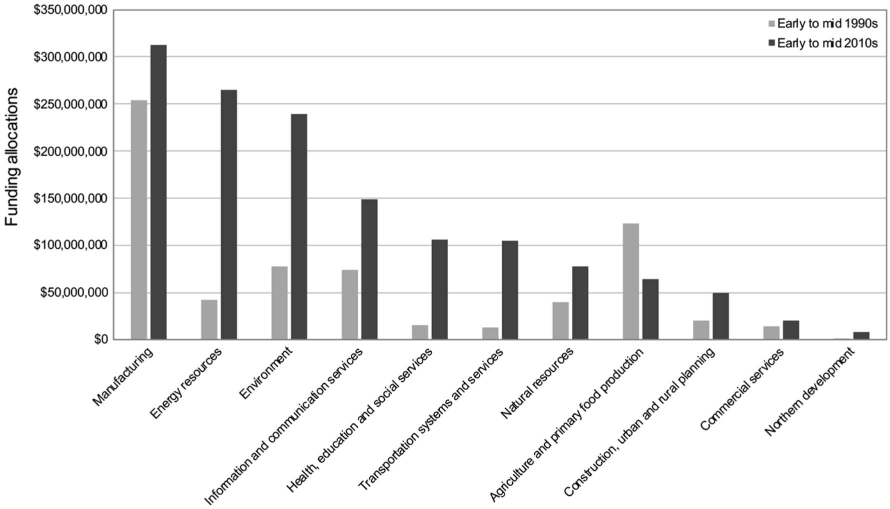

Fig. 4 Use-inspired basic and pure applied research funding broken down by application area in the early to mid-1990s (totals in fiscal years 1991–92 to 1995–96) and early to mid-2010s (2011–12 to 2015–16), in 2015 constant C$. *Source*: Authors' calculations based on total amounts given out each year in NSERC's awards database

instruments is still relatively small (under 200 in 2015–16). However, if the total annual allocations for applied and use-directed research were divided by the number of funded researchers, the pool available to a scientist for that type of work would be significantly higher than for pure basic research (approximately C$283,000 for pure applied research and nearly C$148,000 for use-inspired research vs. approximately C$37,000 per scientist for pure basic research in 2015–16).[5]

While the "per-capita" number for pure basic research has remained relatively constant over two decades, the per-capita figure for use-inspired and applied research remains substantially larger, despite recent decreases to use-inspired research (refer to the Online Resource for a visualization of the "per-capita" funding per researcher). In addition, there is also evidence that when individual funding instruments are considered, the core grants for fundamental research (like the flagship Discovery Grant program that provides, on average, C$35,000 per year/investigator) can be significantly smaller than the average grants disbursed through popular industry-oriented instruments that can offer from two to five times more funding per year (Veletanlić and Sá 2018).

[5] "Funded researchers" refers to scientists listed on successful grants in the awards database. Some scientists serve as principal investigators for "group" or multi-researcher projects, meaning that, in practice, the "per-capita" figure will be further diluted because the number of recipients benefitting from certain grants may be larger in practice.

The shift in goals towards innovation has had material implications in the distribution of resources across research fields. To illuminate the implications of these shifts, we first examine the allocation at NSERC for instruments dedicated to use-inspired basic and applied research. Figure 4 shows the differences in funding in the first and last 5 years of the 25 years under analysis, all shown according to application areas listed on individual project records, ranging from “Manufacturing processes and products” and “Energy resources” to “Commercial services” and “Northern development”.[6] Supports for research in energy resources, environment, information and communication services, and even health, education and social services—all areas that have been prominently emphasized in federal strategies—have risen dramatically over the last 25 years, strengthening their positions in both total funding and percentage changes. This means that either more researchers are directing their work to these areas (and are listing them on their grant proposals) or that the funding envelopes for these specific applications have been increased.

To understand how these trends have impacted the resource allocations for individual academic disciplines, we traced funding in the various fields over the 25-year time horizon. We ranked all fields according to investments in pure basic, use-inspired basic, and pure applied research in increments of 5 years, i.e. the first 5-year period includes funds distributed from 1991–92 to 1995–96; the second 5-year period includes all funds from 1996–97 to 2000–01, and so on—with the analysis repeated for all years up to and including 2015–16.[7,8] (Refer to Tables A3 and A4 in the Online Resource for ranks and absolute amounts used to determine ranks. The resulting heat maps offer a visual guide on what fields have moved up or down in total allocations in each 5-year period.)

Our analysis suggests that applied fields—largely in engineering—have dominated the ranks for use-inspired basic research funding in recent years. Electrical and electronic engineering and materials science and technology, in particular, have been the strong beneficiaries over the entire time span studied. Research related to information technology, mechanical engineering, fuel and energy technology, and chemical engineering have also been more generously funded, rising in ranks for activities inspired by use. On the other hand, some fields have seen a dramatic reversal in their ranking and have seen their funding significantly curtailed since the 1990s. This includes fields such as robotics, space science, and some sub-fields of biological sciences (e.g. microbiology and biochemistry).

Certain research subjects such as electrical and electronic engineering, materials science and technology, and information technology have also been emphasized in instruments for pure applied research. In fact, fields that are likely to

[6] On many funding applications, researchers are asked to provide the primary and secondary areas of application for their research using NSERC’s code tables. NSERC’s database only provides one code, which was used in our analysis.

[7] For this analysis, we excluded instruments supporting both pure and use-inspired basic research because of the difficulty of assigning an appropriate fraction to each research type.

[8] Research subjects were analyzed based on entries in the database, which are usually self-identified by the researchers preparing the applications and are based on code tables provided by the funding agency. NSERC’s database only provides one research subject code.

be supported for use-inspired research are also likely to receive funds for pure applied research: the Pearson correlation between the absolute amounts invested in individual research fields for use-inspired research and pure applied research is $r(50) = 0.87$ in the decade leading up to 2015–16.

How do these trends hold for pure basic research? Our analysis indicates that a certain "pecking order" is retained: many research subjects in the top and bottom funding positions have remained relatively stable over 25 years (refer to Tables A3 and A4 in the Online Resource). While select fields have been exceptionally well funded for more fundamental work, those receiving less support for pure basic research in the 1990s are still funded less. For instance, information technology, physics, evolution and ecology, electrical and electronic engineering, animal biology, and psychology have remained in the top ten over the entire time span studied. In contrast, scientists in physical geography, space science, agricultural engineering, forest engineering, and nuclear engineering still receive the least in absolute amounts.

Cross-referencing across the categories, we see a weaker correlation between fields funded through basic research instruments versus those funded for applied or use-inspired research. The Pearson correlation coefficient between the absolute amounts invested in pure basic and use-inspired research is $r(50) = 0.49$ in the 5 years leading up to and including 2015–16. The correlation between pure basic and pure applied research in the same time frame was even weaker (0.38).

Overall, there are fields in significantly higher ranks for pure basic research but with lower ranks on use-oriented basic or applied research funding in recent years (e.g. animal biology, cell biology, psychology, and earth science). In contrast, fields, like materials science and technology, fuel and energy technology, and environmental engineering, which have climbed to higher ranks for use- and application-related activity but still hold lower or even substantially lower ranks for pure basic research, tend to be more driven toward utility. Arguably, research subjects ranked high on all metrics have been the major beneficiaries in the new funding environment. Among the 55 research field codes used in the database, electrical and electronic engineering and information technology have been present across most types of financial support in recent years.

These findings suggest a divergence in trajectories for different fields over the years, with a potential funding gap between the "winners" and the "laggards". This may have been spurred by the proximity of certain fields to state priority areas. For instance, research in electrical and electronic engineering and information technology maps readily onto the information and communications technologies priority area; work carried out in environmental engineering and fuel and energy can be linked to environmental sciences and technology as well as natural resources and energy. Materials science and engineering activities supported through use-inspired basic and applied research instruments generate novel materials and production methods enabling progress across a range of priority sectors.

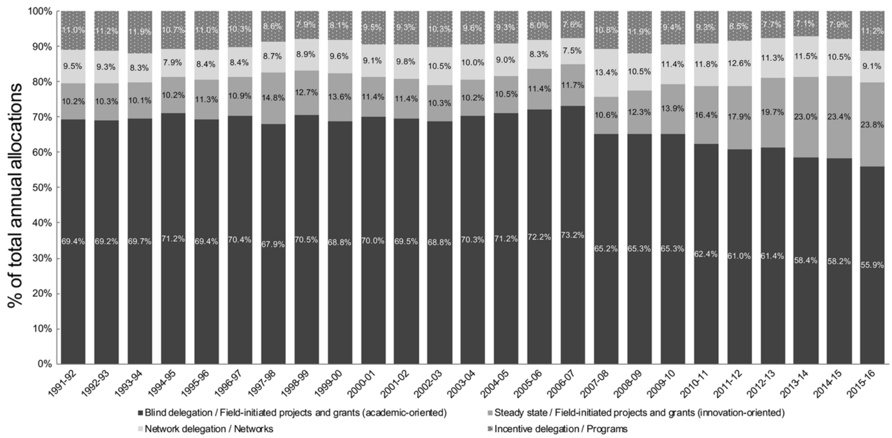

Fig. 5 The distribution of total annual funding for R&D activities broken down by the nature of the funding instrument. *Source*: Authors' calculations based on total amounts given out each year in NSERC's awards database

Changes in Delegation Modes

In addition to classifying instruments according to their goals, we also clustered them according to the underlying contractual arrangement embedded in the instrument, which provides an operational link to the delegation modes (outlined in Table 1). The results are shown in Figure 5. In 1991–92, nearly 70% of funds were provided through granting instruments encouraging *academic-oriented field-initiated projects and grants*. Considered an example of the *blind delegation mode,* the unifying element in these instruments is the autonomy given to scientists to define their objectives, through the conduct of either pure or use-inspired basic research (see Table 2). Lending support for such investigator-defined projects is the core tenet of NSERC (1985). Although these types of projects have constituted the largest fraction of the budget over the past 25 years, their position has been eroded. This trend has accelerated in the last decade: they have been reduced from nearly 70% of the total allocations in 1991–92 to 56% in 2015–16.

Innovation-oriented field-initiated projects and grants have experienced the largest growth with commitments amounting to nearly one-quarter of all funds in 2015–16. Although these supports give scientists or institutions the freedom to define research questions and R&D activity without an explicit priority area given in the program descriptions, they tend to fund activities emphasizing use-inspired basic or pure applied research (Table 2). The funding for this category has been fueled through substantial allocations for existing university–industry programs as well as for new initiatives aimed at colleges, indicating that these instruments still operate within the broader umbrella of industrial problem solving and innovation outcomes. Overall, this represents a prominent increase in the *steady state delegation mode*.

Programs are funding instruments supporting work in federally defined areas and are considered an example of the *incentive delegation mode*, in which scientists

Table 2 Overview showing how the principal–agent theory's delegation modes connect to Stokes' typology for the instruments coded in our study, presented in terms of the number of overlapping instruments between the categories

Delegation mode	Goals				
	Pure basic research (Bohr)	Pure or use-inspired basic research (Bohr or Pasteur)	Use-inspired basic research (Pasteur)	Pure applied research (Edison)	Total
Blind delegation/Field-initiated projects and grants (academic-oriented)	19	34	1		54
Steady state/Field-initiated projects and grants (innovation-oriented)		5	21	17	43
Incentive delegation/Programs	1	3	38		42
Network delegation/Networks	1	1	13		15
Total number of instruments	21	43	73	17	154

are induced to study research questions in specific areas. Since the release of Canada's 2007 S&T strategy, the government has attempted to provide incentives for researchers to pursue projects considered critical to the "national interest". These have included overwhelmingly use-inspired research (Table 2), particularly in areas such as environment and agriculture, natural resources and energy, health and life sciences, information and communications technologies, and advanced manufacturing (Government of Canada 2014). Such priorities are also evident in descriptions of NSERC's funding instruments. Financial support for thematic priorities has increased, although the fraction within the entire budgetary envelope has remained at 7–12% of the annual R&D expenditures (as shown in Fig. 5).

Federal investments in *network* approaches have also increased since the 1990s (Atkinson-Grosjean 2006). These funding instruments reflect the *network delegation mode*, in which the state encourages a critical mass of academic researchers, firms, and end-users to advance knowledge translation and technology transfer in specific areas. The actual funds for networks and centres under NSERC's administration has more than doubled since the early 1990s (although the percentage within the total has remained relatively constant over the time frame, see Fig. 5).[9] Just like the

[9] The notable increase in the fraction of such funds in 2007-08 at NSERC was largely due to federal commitments to create the "centres of excellence for commercialization and research" and to boost the long-standing federal Networks of Centres of Excellence program by injecting funds for private sector-led initiatives.

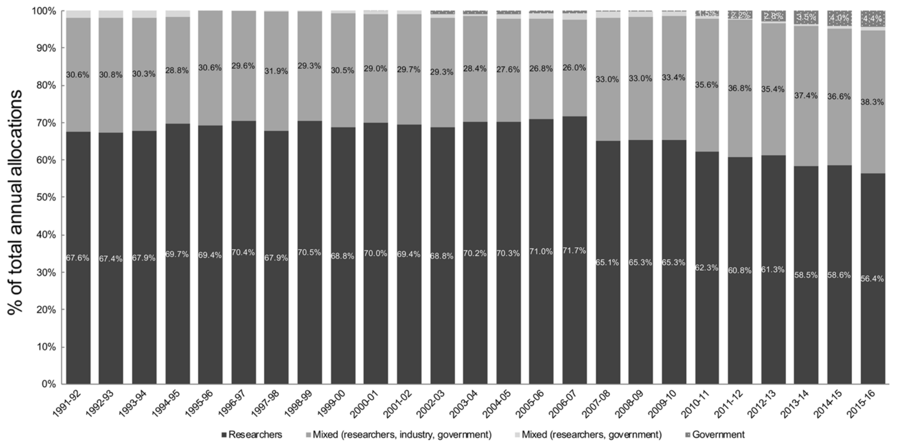

Fig. 6 Fractions of annual funding for R&D activities broken down by evaluation committee membership. *Source*: Authors' calculations based on total amounts given out each year in NSERC's awards database

incentive delegation mode, network delegation in Canada has focused overwhelmingly on use-inspired basic research (Table 2).

Shifting delegation modes have entailed greater participation of non-academic actors in resource allocation decisions. Figure 6 shows the fractions of total annual outlays as decided by four types of committees identified in our database: researchers only; mixed committees made up of academics, industry experts, and government representatives; mixed committees made up of academics and government representatives; and finally, committees with government representatives only. Internal funding agency staff serving as decision-makers in the allocation of funds were also considered as belonging to the government group. Program documentation does not provide insight into the exact breakdown of review committees, but it does specify their composition. In aggregate, researchers-only committees have retained the leadership in the allocation of funds (Fig. 6). This reflects the traditional peer-review process characteristic of the blind delegation mode, in which peer committees adjudicate applications in accordance with scientific standards. However, blind delegation's relative influence has diminished. While scientific committees were used in the allocation of 56% of all R&D funding in 2015–16, this is down from an average 70% in the early to mid-2000s—and in a manner consistent with the decline in funding described earlier for the blind delegation mode.

Unlike the traditional view of blind delegation that "le[aves it] to the scientists to decide on the contents of science policy based on internal procedures such as peer review and scientific publications" (Potì and Reale 2007: 418), the contents of use- and innovation-oriented projects are designed to respond to external signals (e.g. industrial problems). They are also more likely to be evaluated by mixed committees with non-academic stakeholders. The increase in funding adjudicated by government representatives only has also risen more recently.[10]

Put together, the trends outlined above suggest that investments in field-initiated academic research projects allocated through scientific peer review—all typically encountered in the blind delegation mode—have steadily declined as part of the funding portfolio. Many of the remaining instrument types emphasize partnerships and priorities outside the non-academic sector: in fact, nearly 45% of all funds disbursed by the granting agency in 2015–16 were linked to federal priorities, innovation and/or knowledge transfer to non-academic partners—an increasing indication that modes other than blind delegation are at work.

Discussion and Conclusions

Canada's emphasis on innovation in science policy has involved changes within NSERC, with material implications for academic science. The usual assumption among scientists seeking support through granting councils is that programs oriented toward industry and commercial outcomes have substituted for fundamental research (Advisory Panel for the Review of Federal Support for Fundamental Science 2017). Moreover, scholars have argued that Canadian science has become more applied and commercial because of the ostensible policy and programmatic priorities of the federal government (e.g. Doern et al. 2016). However, the precise nature of these changes within key research agencies was not known. Focusing on NSERC as our case, our study shows how the policy imperative to promote innovation has translated into shifting programmatic goals, delegation modes, and resource allocation decisions across research fields over the past 25 years.

Positioned as intermediaries in scholarly debates on the evolution of science policy, funding agencies have been described as sites of contestation between science, strategic priorities, and political actors (Braun 1998, 2003). The empirical focus of our case study highlights the need for more attention to the actual behavior of funding agencies, particularly those tasked with advancing innovation objectives. NSERC's position within Canada's research funding system puts it at the centre of the institutions driving the innovation agenda. The Council is administratively linked to the federal department called Innovation, Science and Economic Development Canada (formerly Industry Canada), which exposes it to policy pressures related to innovation (Skoie 1996) and to demonstrating the relevance of its investments in research (Doern 2009).

Within the Canadian science policy literature, there have been many discussions over the changing priorities of the federal government and policy initiatives to stimulate innovation and ties to industry (Atkinson-Grosjean 2006; Doern 2009; Fisher and Rubenson 2010; Sá and Litwin 2011). However, our study is the first to provide

[10] This is due mainly to the introduction of programs for researchers collaborating with firms, in which applications bypass the academic peer review with funding decisions left to the discretion of the granting council's internal staff.

an in-depth longitudinal examination of the scale and nature of changes in the resource allocation within a major research funding agency. Through the analysis of grant-level data, we have shown that funding for use and application, much of it with innovation- and strategic area-related goals, has increased over the past 25 years and now represents well over 40% of all actual research funds awarded by the agency for R&D. This has been accompanied by a relative decline in allocations for pure basic research, to the point where the combined investments in use-inspired basic and applied research have been almost on par with funds for pure basic research in recent years.

Within the conceptual perspective of research funding agencies as intermediaries between state and science, their funding mechanisms and delegation modes can be framed as the contractual arrangements put in place to ensure that government priorities are addressed. Building upon the related literature (e.g. Braun 1993; Guston 1996; van der Meulen 2003), our study examines how delegation modes interact with decisions regarding funding for specific research fields. Our study is also consistent with previous research documenting changing delegation modes in science policy internationally. Related studies indicate that the blind delegation mode has slowly eroded in certain contexts where it used to be the predominant model. For instance, Lepori et al. (2007) found "complex patterns of similarities and of differences" in how funds are disbursed from country to country in Europe: while some allocation models like centres of excellence and large programs in specific areas have diffused more broadly, there is still significant range in the structure of instruments. This variety is informed by history and political context. Similarly, in examining national funding instruments in Switzerland, Austria, Italy, and Norway, Potì and Reale (2007) also showed how blind delegation in the form of unfettered projects was still prominent in Austria and Switzerland, while Norway and Italy increasingly adopted incentive delegation. Our study offers further insight into the interplay between delegation modes and funding for specific research fields. We identified a small subset of subjects that have been exceptionally well funded over the past few decades, including applied fields with hefty investments across pure basic, use-inspired, and applied activities (e.g. electrical and electronic engineering, information technology), fields with generous funding for pure basic research (e.g. physics, animal biology, psychology), and fields with more significant funding inspired by use or tied to application (e.g. materials science and technology, mechanical engineering).

In coming to our conclusions, we recognize certain limitations brought about by the principal–agent relationship and the complexities of academic science that cannot be captured in grant records alone. We note here in particular two main limitations that warrant further research and analysis. First, the NSERC funding database is an aggregate of choices made by thousands of different agents in response to constraints imposed by the principal. Arguably, our analysis captures the cumulative effect of choices of the intermediary providing the "organisational, financial and infrastructural environment of research production", on the one hand, and the "motivations" and responses of agents to this economic capital, on the other (Braun 1998: 808). This tension is exacerbated by the inherent "problems" in the principal–agent relationship, including problems of responsiveness, adverse selection, and moral hazard (Braun 2003; van der Meulen 1998). Although our method effectively gauges the policy intentions of the state via one of its intermediaries, how scientists respond to these signals and incentives in the field raises excellent questions for further empirical investigation. In many cases, research fields and application areas are dependent on scientists' interpretations, and they often list them on grant proposals. Given that, how do scientists navigate incentives from funding agencies if their fundamental research interests and agendas are incompatible with new priorities and funding schemes introduced? To what extent do they "relabel" or steer their research programs to align them with the interests of the sponsor? How effective are the policies and funding instruments in effecting change in the daily conduct of science? These issues are also relevant at the decision-making stage of the intermediary. For example, the assumption behind the inclusion of non-academic representatives on review committees is that they will change the way projects are evaluated, upholding socioeconomic criteria. However, decisions may not actually be swayed in practice. How the intermediary responds to and manages the policy pressures put on it by the state will depend on its degree of autonomy, internal dynamics, and coalitions with the agents (Braun 1993). There have been reports both in Canada and internationally of a "reluctance" among research councils to acquiesce completely to the policy pressures, with changes that are made "to the extent necessary to satisfy the demands of policy-makers" (Doern 2009; Van Duinen 1998: 386).

The second limitation related to our data sources concerns the gap between research funding records and the actual dynamics of scientific activity supported (e.g. mathematicians working in computer science may select information technology rather than mathematics as their area of work) or the fact that multiple converging scientific advances feed into priority areas (e.g. energy-related applications can benefit from developments in materials, civil engineering, physical chemistry, etc.). A research question posed by a scientist could be directed at innovation but still aim to answer a very fundamental concept behind that innovation. Indeed, scientists arguably use certain research framings to secure resources and prestige (Calvert 2006). These nuances can only be ascertained through in-depth investigations of the research practices of scientists, possibly through ethnographic methods long employed by STS scholars (e.g. Latour and Woolgar 2013).

From the conceptual perspective of research funding agencies as intermediaries between state and science, the relationship between programmatic objectives, delegation modes, and resource allocation provides a mechanism for investigating how state goals for science policy are translated into decisions about what research to support. Our empirical analysis traced the emergence of new delegation modes within NSERC as the council implemented arrangements to ensure that government innovation agendas are addressed. Further, our study identified a long-term pattern of decisions regarding funding for specific research fields that have mobilized nearly half of the agency's investments in R&D, linking them to utility, innovation objectives, and associated instruments.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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