JOHNSON SHOYAMA
Centre for the Study of
Science and Innovation Policy
UREGINA USASK

WORKING PAPER SERIES (2023-3)

Studies in Research Design
Investigating the Genome Canada experience

A collection of recent research

Edited by Peter W.B. Phillips

https://www.schoolofpublicpolicy.sk.ca/csip/

About us

The Centre for the Study of Science and Innovation Policy (CSIP) is an academic research institute in the Johnson Shoyama Graduate School of Public Policy, hosted at both the Universities of Regina and Saskatoon. The centre supports the advancement of understanding about policy options through the application of robust theory, innovative method and evidence informed discussion and provides new opportunities for student training and experience. Our mission is to equip and enable public, private and civil society sectors to successfully consider, debate and make decisions about new discoveries and technological applications.

Check us out at: https://www.schoolofpublicpolicy.sk.ca/csip/

Published February 1, 2023

Centre for the Study of Science and Innovation Policy (CSIP)

101 Diefenbaker Place, Saskatoon, Canada, S7N 5B8

Contents

Acknowledgements

The full citations for the primary articles reprinted in this volume (in order of the collection) are:

- Phillips, P.W.B and Eric Warren. 2022. Managing Large-Scale Science Research Programs: The Genome Canada Experience 2000-2010. CSIP Working Paper, https://www.schoolofpublicpolicy.sk.ca/csip/publications/research-papers-and-technical-notes.php.
- Zhang, L. 2014. Program Evaluation: A case study of Genome Canada Investments, 2000-2012, Unpublished University of Saskatchewan MPP Thesis available at: https://harvest.usask.ca/handle/10388/ETD-2014-01-1438.
- Hassanpour, Ebrahim. 2017. Research Design and Research Systems: An Application of Agent-Based Modelling to Research Funding. Unpublished University of Saskatchewan MPP Thesis available at: https://harvest.usask.ca/handle/10388/8164.
- Sharma, P. 2013. Social Capital in Large-Scale Projects and their Impact on Innovation: A SNA Analysis of Genome Canada (2000-2009). Unpublished University of Saskatchewan MPP Thesis available at: https://harvest.usask.ca/handle/10388/ETD-2012-12-888.

Another work that some of you might find useful is:

- Ryan, C. 2007. Performance of Public-Private Collaborations in advanced technology research networks: Network Analyses of Genome Canada Projects. Unpublished University of Saskatchewan MPP Thesis available at: https://harvest.usask.ca/handle/10388/etd-04272007-091239.

Preface

Over the past 15 years I have had a number of students undertake research that explores aspects of the design, management and impact of Genome Canada on the bioscience research system. This collection provides the key findings in a single package. The students used an innovative mix of theories and methods to test the design features of Genome Canada.

I would like to acknowledge and thank all the researchers who contributed to this work, including Puja Sharma, Ebrahim Hassanpour, Lucy Zhang, Haizhen Mou, Eric Warren, Andrew Phillips, Bethany Penn, Bill Boland, Aaron Hertes, Yvonne Nyake and Simbo Olobobokun.

I also like to acknowledge and thank our funding partners, including SSHRC, Genome Canada, Genome Prairie and the Government of Saskatchewan

Peter W.B. Phillips, Distinguished Professor and Director
Centre for the Study of Science and Innovation Policy
Saskatoon, Canada

Chapter 1

Managing Large-Scale Science Research Programs
The Genome Canada Experience 2000-2010

Peter W.B. Phillips and Eric Warren

Abstract

In September 2000, Genome Canada was created as an arms-length not-for-profit Crown Corporation mandated to fund large-scale science projects and their accompanying science and technology platforms. Given its goal to leverage private sector R&D, Genome Canada provided up to half of the operating capital, on the condition that other eligible partners contribute the remaining funds. In the first decade, Genome Canada conducted four major competitions. In each competition scientific leads prepared and submitted proposals for large-scale projects. Genome Canada then conducted a lengthy review process, evaluating the merit with respect to the scientific and commercial potential, managerial competence, financial capacity, and socio-economic impact. Those judged, through a mixture of in-house and external peer review, to have high potential received Genome Canada funding. The criteria for merit and potential changed over time, or are at least was managed in different ways. The structure of the contests themselves also changed, in some ways quite dramatically. This paper examines Genome Canada's first decade of managerial practices by looking closely at the structure and substance of the major funding competitions.

Key Words

Science management; big science; Genome Canada; genomics; administration

1. Introduction

Research and development has become a cornerstone of modern economic activity. Canada is no different. Increased efforts into research and development and innovation practices by the federal government have resulted in a changing climate for natural and social science research initiatives. Government bodies have been established to offer public funding for R&D and to help network the public, academic, and private spheres to foster collaboration and commercialization of results.

Genome Canada is one example of a quasi-government body established to serve such a purpose. With a focus on genomics, it funds large-scale science projects using an open competition format, whereby the scientific community partners with government, the private sector, and international organizations to carry out research in targeted areas. This study examines the structure and nature of Genome Canada's funding competitions, how it has changed over its first decade of operation, and whether these changes led to a more effective and efficient funding process.

This paper places Genome Canada in the wider federal R&D policy context and then provides thorough examination of the content and processes of each of the four major competitions.

2. Background

During the mid-1990s, it was acknowledged by the Government of Canada that a productivity gap existed between itself and the neighbouring United States.[1] This prompted Canadian policy makers to consider the adequacy and competitiveness of Canada's R&D and innovation regimes. Comparative studies showed that Canada did not have a sufficient commercialization strategy, and as a result, commercial use of results lagged behind other countries, particularly the UK and Sweden.[2] The Canadian government then began a rigorous process of strengthening Canada's knowledge-based economy. Favourable budgets in the late 1990s and early 2000s allowed increased investment of public money into R&D.[3] At first no specific strategy was advocated by the federal government. Rather, a series of ad hoc policies were rolled out, including corporate and capital tax cuts to stimulate private investment, increased support for private, university, and government R&D, and support for graduate work and changes to immigration policy to increase the stock of highly qualified personnel.[4]

In 2000, Paul Martin, then Canada's finance minister, laid the groundwork for future innovation policy in Canada calling for a tripling of government expenditures in R&D by 2010, moving Canada from 15th to 5th among OECD countries.[5] Alan Rock, Minister of Industry at the time, set out to study what Canada needed to do in order to create a competitive innovation regime and meet Martin's proposed objectives in time. This study led to the creation of *Canada's Innovation Strategy* in 2002, which gave organization managers a useable framework for "effective" funding management, helped to coordinate R&D efforts towards commercialization of results, and made recommendations for setting up an appropriate regulatory and business environment to encourage investment.[6] While this strategy was never fully implemented, it did work to inform federal government actions in the areas of R&D and innovation from that point on.

Genome Canada, one of the related developments, provides a particularly interesting window into the federal government's efforts to increase public and private R&D expenditures, conduct research with commercial potential, close Canada's production gap, and bolster Canada's position as an innovation leader. Established as an arms-length, not-for-profit corporation in the February 2000 federal budget,[7] Genome Canada's overarching mandate was to ensure that Canada become a world leader in genomics research in targeted sectors, including agriculture, forestry, fisheries, health, the environment, and later, the accompanying GE^{3}LS

---

[1] Swedish Institute for Growth Policy Studies. 2004. *Innovation Policy in Canada*. http://www.vinnova.se/upload/EPiStorePDF/InnovationPolicyInCanada.pdf pg 23.
[2] Ibid.
[3] Ibid.
[4] Ibid, 23-24. Also see: Doern, DB, P. Phillips., and D. Castle. 2016. *Canadian Science, Technology and Innovation Policy: The Innovation Economy and Society Nexus*. MQUP.
[5] Ibid, 24.
[6] Industry Canada. 2002. *Canada's Innovation Strategy*. http://dsp-psd.pwgsc.gc.ca/Collection/Iu4-5-2002E.pdf1 (June 20, 2009).
[7] Genome Canada. September 2000. *Guidelines and Evaluation Criteria for Genome Centres*. < http://www.genomecanada.ca/medias/PDF/EN/GUIDE18-final.pdf>, 3.

issues. As a non-profit, Genome Canada does not have shareholders or seek dividends, but rather is governed by a board of directors. Genome Canada operations (i.e. salaries, infrastructure, project money) are funded through federal grants, originally administered by Industry Canada and now ISED.[8] Genome Canada is required under the Canada Corporations Act to hold at least one annual board of directors meeting, solicit an external auditor (unless otherwise agreed upon by all board members), produce annual financial statements, and write an annual report.[9] These measures ensure accessible and open information regarding Genome Canada's affairs, and keep the principle of responsibility intact, reporting to Parliament through the Minister of Industry/ISED via annual reports and financial statements. Genome Canada has a number of supporting mechanism for reporting, such as the Performance Audit and Evaluation Strategy, the Risk Management Policy, and the Recipient Audit Framework.

Genome Canada and its original five (now six) regional centres are maintained and staffed using federal conditional grants. Some provinces, especially Quebec and British Columbia, provide core grants or block grants to support projects, while others find it difficult to find funds to support operations and matches for the grants. Large-scale research projects and technology platforms are usually financed using 50% federal funding and 50% funds from other sources, including provincial governments, private industries, and foreign investments. Because of the nature of large scale science, project funding has traditionally been granted based on multi-year investments that enable three to five years of project activity. This was convenient for the federal government in some years, as this structure allowed them to commit funds and expend them in years with budgetary surpluses. In the period under review, Genome Canada and the ministry of Industry/ISED negotiated agreements in 2000 and 2005, with supplementary agreements in 2007 and 2008.

3. Methodology

Using the evolving policy landscape as a backdrop, it is possible to track the evolution of Genome Canada operations, either in sync with, or counter to, changing government policies. On top of this, changes in Genome Canada's practices in and of themselves can be compared. There is no better place to look for analysis than Genome Canada's open and competitive funding competitions, their guidelines, evaluation criteria, and structures.

In order to compare Genome Canada's funding competitions over time, it is useful to analyze each set of competition guidelines and evaluation criteria. These documents shape the application content and process, from the submission of letters of intent, to Genome Canada's announcement of successful projects. Applicants are asked explicitly to follow the competition guidelines and be mindful of the evaluation criteria when drawing up project proposals. Adhering to Genome Canada's instructions increases the likelihood of receiving project funding. A timeline of each Genome Canada funded competition allows for a comparison, at a basic level, of competition processes and how they have changed over time. Contrasting the actual structures and layouts of the competition guidelines makes visible the evolution and shifting focus of the funding competitions. After each competition round, issues that emerged were addressed and

[8] Corporations Canada. January 2009. *General Overview of the Canada Corporations Act Part II.* http://www.ic.gc.ca/eic/site/cd-dgc.nsf/eng/cs02167.html (June 18, 2009).
[9] Ibid.

remedied in the next set of competition guidelines – in effect, Genome Canada had a sort of moving target approach.

As a result, successive competition guidelines became more detailed and on occasion new sections or foci were added. But it is not clear whether this evolution has led to a "better" competition process. The rest of this paper explores whether Genome Canada practices have followed the federal government's vision for research and development in Canada and done so in an efficient and effective way.

4. Observations

4.1 Competition Overview

Before going into the specific details of the project proposal process and criteria, the guidelines provide a general overview of the competitions. This overview is a useful tool for discerning the overall mood, direction, and goals of the competitions. The comparison is made difficult by the nature of the first competition, which included the establishment of the Genome Centres. However, it can be said that due to the structure of Competition I, and its emphasis on creating regional centres, information regarding large-scale project structure and content was vague and limited. In fact, beyond the broad goals of the project proposals being large-scale, genome-wide, and in a sector considered important to Canada (agriculture, health, forestry, fisheries, and environment), there are no explicit references to project content at all.[10]

Competition II provides a lot more detail and gives some context to the term "large-scale", stating that projects must be "of such scale and scope that they cannot currently be funded at internationally competitive levels through existing mechanisms."[11] The guidelines for Competition II also begin to place more of an emphasis on GE^{3}LS. While the first competition simply asked each centre to have a program in place to deal with GE^{3}LS related issues, a few GE3LS specific projects were pitched and funded. Competition II more explicitly allowed projects with a strictly GE^{3}LS focus to be submitted for funding and hinted that embedded GE3LS work would be considered.[12] Still, the background information remains brief.

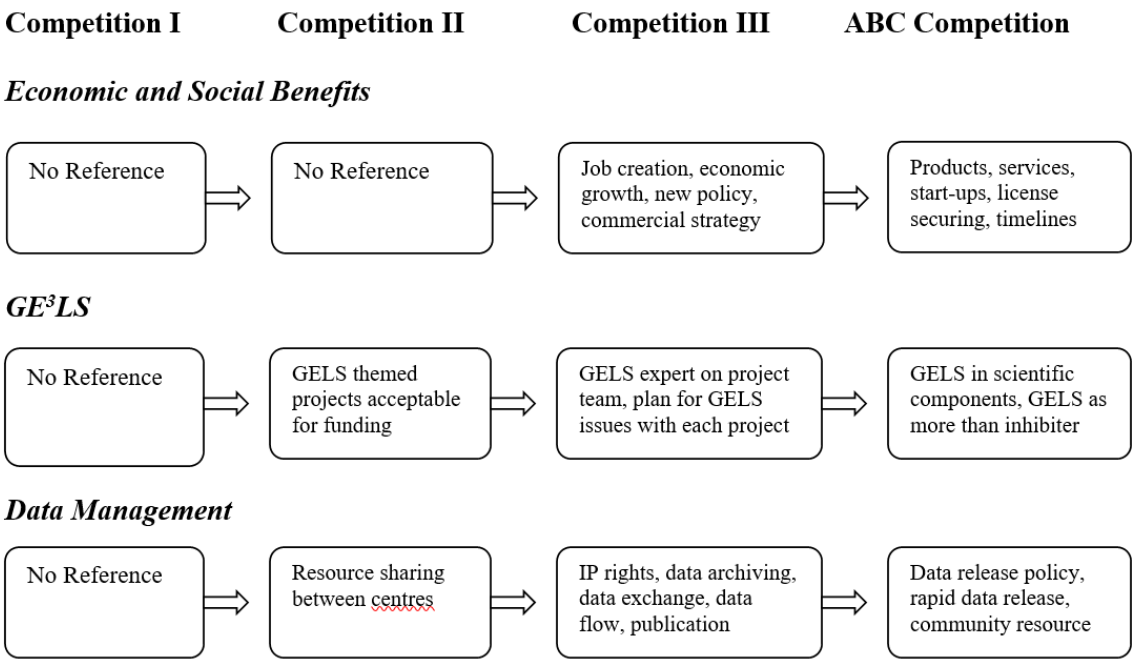
Competition III was marked with some significant changes in its preamble. First off, the competition called for large-scale genomics projects, but added that they were seeking projects with a specific duration of 3 or 4 years.[13] This was simply added for clarification, as all previous projects funded by Genome Canada fell into this range anyway. It also widened the research scope by calling for projects in genomics *or* proteomics, the latter being the study of protein functions and structures.[14] Competition III also directed that applicants have a plan in place to address GE^{3}LS aspects of their projects, sharpening the focus on social issues. Each project was now required to have one or more GE^{3}LS experts as a co-applicant, collaborator, or advisory committee member.[15] Also, an entire section in the preamble was dedicated to social and/or economic benefits of the research. This was made clear by the directive: "Note that in this competition Genome Canada will place much greater emphasis on the potential ability of the

[10] Guidelines for Genome Centres, 3-14.
[11] Guidelines and Evaluation Criteria for Competition II, 4.
[12] Ibid.
[13] Guidelines and Evaluation Criteria for Competition III, 4.
[14] Ibid.
[15] Ibid, 5.

proposed research to lead to social and/or economic benefits for Canada."[16] The guidelines referenced job creation, economic growth, and impact on quality of life, the environment, health, and policy development.[17] It goes on to indicate that the proper plans and personnel must be in place in order to transmit the research into tangible social and/or economic goods and services.[18] There had never been such a blatant focus on realizing economic benefits.

Competition III added another new section that stressed plans for dealing with intellectual property rights, the sharing of benefits between contributors, and a commercialization strategy.[19] Although these issues were brought up in Competition I, they were in reference to the Centres, not to individual projects, and were much less detailed and specific. Also a significant change was a paragraph titled data management. Project applications were required to include a detailed plan for the handling of scientific data generated from the research.[20] This plan included data archiving and data exchange with the wider scientific community. In Competition III, strong attention was paid to realizing economic benefits for Canada and dealing with the storage and sharing of scientific data, as well as a more comprehensive inclusion of GE^{3}LS related issues.

Figure 1: Evolution of Impact Factors in Genome Canada Competitions



Source: Competition Guidelines I, II, III and ABC

The ABC competition further developed the focus on GE^{3}LS by providing more detail about the format of the plan needed by project proposals to address GE^{3}LS issues. There was an indication that in past competitions that GE^{3}LS issues were addressed only as an impediment (economic, legal, or otherwise) to the success of the project. The ABC competition asked project

[16] Ibid.
[17] Ibid.
[18] Ibid.
[19] Guidelines and Evaluation Criteria for Competition III, 6.
[20] Ibid.

proposals to look at the other side of GE^{3}LS issues as well, specifically how they could enhance the research and realize maximum benefits.[21] The guidelines asked applicants to integrate GE^{3}LS issues into the scientific components of their proposals, a concept absent from previous competitions.[22]

The two sections referring to benefits for Canadians and commercialization were melded into one section in the ABC competition. The guidelines also added references to product and service development, the start-up of spin off companies or securing of licenses, and the stipulation that benefits should be realized within five years of project completion.[23] Applicants were instructed to seek out expertise for advice in the commercialization process, including market analysis and marketing.[24] The ABC competition guidelines became more precisely worded, exchanging words like "economic growth and social benefits" for "product and service development."

In the ABC Competition, applicants were also asked to be in compliance with Genome Canada's Data Release and Resource Sharing Policy, created in July of 2005 to formalize a data management strategy.[25] The policy sought to treat Genome Canada funded projects as a "community resource project, defined as a research project specifically devised and implemented to create a set of data, reagents or other material whose primary utility will be as a resource for the broad scientific community."[26] The object was to ensure the rapid release of new data to the wider scientific community to ensure "the timely development of projects that will benefit humankind."[27] The previous statement out of Genome Canada's Data Release and Resource Sharing policy fuses the idea of data management with the realization of economic and social benefits.

4.2 Financial Resources

The initial funding competition in 2000 proposed by Genome Canada was unique in that project proposals were included in a package with an application for the establishment of a Genome Centre. Genome Canada wanted to establish five regional genomics centres in order to engage leading academics and industries across the country, allowing them access to world class science and technology platforms. Before the announcement of the competition, Genome Canada received a grant of $160 million from the federal government to "support a national genomics research initiative."[28] This grant covered the initial costs to start the centres as well as a portion of project funding. In February of 2001, two months after 31 project proposals were chosen for submission to an international panel for peer review, Genome Canada received an additional $140 million in funding from the federal government through industry Canada.[29] Combine, all of the necessary funding for Genome Canada was in place for the first two rounds of funding.

Of the initial grants of $160 million and $140 million from the federal government, Genome Canada committed $135 million to Competition I projects, science and technology platforms,

[21] Ibid.
[22] Ibid.
[23] Ibid, 7.
[24] Ibid.
[25] Ibid, 8.
[26] Ibid, 23.
[27] Ibid.
[28] Guidelines and Evaluation Criteria for Genome Centres, 3.
[29] Genome Canada. 2000. *2000-2001 Annual Report*. <http://www.genomecanada.ca/medias/PDF/EN/2000-2001AnnualReport.pdf>, pg 2.

and the establishment of the five regional genome centres.[30] In July 2001, a further $155.5 million was allocate to 34 large-scale projects and platforms for Competition II.[31]

Competition III differed from the first two endeavors in that, upon its announcement, there was no secured funding in place. Rather, Genome Canada was in the process of "finalizing its five-year strategic plan for submission to the Federal government for funding approval."[32] Genome Canada stated that they were optimistic that funding would be obtained from the federal government, but that delaying or canceling the competition was a possibility.[33] However, Genome Canada received a grant of $165 million in February of 2005, about halfway through the competition, and it proceeded as planned with no delays.[34] This grant was to cover the costs of projects under Competition III for the first three years. In August of 2005, $167.5 million was invested in 33 large-scale projects, the largest investment in a competition by Genome Canada.[35] In March of 2007, an additional sum of $100 million was allocated by the federal government to cover the remaining costs of Competition III.[36] All previous grants had been given to Genome Canada in one lump sum, but according to the new funding agreement with Industry Canada, the grant in 2007 was cash flowed over two years, according to need.[37] While this affected Genome Canada's investment income, more importantly it required tighter control of project funds by way of increased reporting and funding management (to be discussed later).

In 2006, Industry Canada recommended that Genome Canada pursue a different style of funding competition. Competitions I, II, and III left the field of genomics wide open (besides the necessity that the work be important to Canada), which allowing the research community to submit projects of scientific merit on any topic in any of the human, plant, animal and microbial domains. This led to a new process of building priorities.

Genome Canada invited teams of scholars to work collaborative to develop theme papers that made a pitch for research in a subject area. This fell in line with the federal government's new policy, *Mobilizing Science and Technology to Canada's Advantage*, and its focus on targeted research. In 2007 the Position Paper Process—what Genome Canada calls 'an approach for allocating funding to targeted strategic research themes in nationally recognized areas of interest and of socio-economic importance to Canadians' – began to drive Genome Canada programming. The 2007 process yielded the strategic research themes of agriculture–plants and bioproducts (ABC), a combination of two research themes that had been recommended in the first Position Paper cycle. This process also identified two more strategic research themes—child health and agriculture-animals—as areas which merit funding support.

The ABC Competition delivered 12 projects worth $114 million.[38] Genome Canada had received a grant of $140 million in the 2008 federal budget in February, $53 million of which

---

[30] Genome Canada. *Research Portfolio.* http://www.genomecanada.ca/en/portfolio/research/competition.aspx (June 15, 2009).
[31] Ibid.
[32] Genome Canada. July 2004. *Guidelines and Evaluation Criteria for Competition III.* http://www.genomecanada.ca/medias/PDF/EN/Guidelines3.pdf , 4.
[33] Guidelines and Evaluation Criteria for Competition III, 4.
[34] Genome Canada. 2008. *2008-2009 Corporate Plans*. http://www.genomecanada.ca/medias/PDF/EN/CorporatePlan2008-09-english.pdf, 29.
[35] Ibid.
[36] Ibid, 28.
[37] Ibid.
[38] Genome Canada. 2009. *List of Funded Projects in ABC*. http://www.genomecanada.ca/data/Nouvelles/Fichiers/en/330_2_4%20list%20of%20approved%20projects.pdf (June 11, 2009).

was dedicated to fund the Genome Canada share of the ABC competition.[39] Again, these funds will be disbursed according to the annual requirements of Genome Canada. The whole sum of $140 million was spread out over five years.[40]

To summarize, Genome Canada had funding in hand for competitions I and II for their entirety in the form of a lump sum grant from the federal government. Competition III began with no funding but in February of 2005, about half way through the review process, a lump sum federal grant (the last) was received by Genome Canada to fund the majority of the competition. In March 2005, a new funding agreement was negotiated between Genome Canada and Industry Canada requiring that funding be disbursed annually according to cash flow statements and project flow. This forced Genome Canada to modify its funding and management procedures to ensure that projects remained on budget and on schedule.

Table 1: Cash flows related to first four Genome Canada Competitions

	Competition I	Competition II	Competition III	ABC Competition
Grants from Federal Government	$160M + $140M	None	$165M+ $100M	$53M
Cost of Competition	$135M	$155.5M	$167.5M	ongoing
Funding Secured Upon Competition Announcement	Yes	Yes	No	Yes, based on annual need.

Source: Genome Canada Annual Reports 2000-2008

4.3 Objectives

Each competition began with a set of stated objectives. The overriding objective throughout the period was that Genome Canada wished to "become a world leader in selected sectors that are of strategic importance to [Canada], such as health, agriculture, environment, forestry and fisheries."[41] In Competitions II and III, economic, social, and industrial benefits for Canadians were added, representing the first sign of a continuing trend: a focus on projects with commercial potential.[42] The ABC competition added technology development to its list of selected sectors.[43] The ABC also modified the competition objectives to adapt to the new funding agreement signed in 2008.[44] The list contained a number of objectives melded together from previous competitions with some elements omitted or modified, resulting in the list being shortened from nine objectives to just five. Overall, they remained similar, but with a few differences. Particularly interesting is the addition of, "the development and establishment of a coordinated national strategy for genomics research to enable Canada to become a world leader in areas such as health, agriculture, environment, forestry and fisheries", which was listed as the

[39] Genome Canada. 2009. *2009-2010 Corporate Plans*. http://www.genomecanada.ca/medias/PDF/EN/CorporatePlan2009-10-english.pdf, 26.
[40] Ibid.
[41] Guidelines and Evaluation Criteria for Genome Centres, 3.
[42] Genome Canada. December 2001. *Guidelines and Evaluation Criteria for Competition II*, http://www.genomecanada.ca/medias/PDF/EN/CompIIGuidelinesfinal.pdf, 3.
[43] Genome Canada. May 2008. *Guidelines and Evaluation Criteria: Competition in Applied Genomics Research in Bioproducts or Crops.* http://www.genomecanada.ca/medias/PDF/en/Guideline_Evaluation_Criteria.pdf , pg 3
[44] Competition in Applied Genomics Research in Bioproducts or Crops, 3.

first objective.[45] This reflected the new funding agreement with Industry Canada, and its focus on a targeted research effort. The objectives changed over the competition rounds to focus on the economic and social benefits of the research as well as on targeting specific areas of research, the latter evidenced by the thematic nature of the ABC Competition.

4.4. Letter of Intent stage

A letter of intent is used to express interest in a Genome Canada competition. They are brief and general descriptions of projects or tech platforms. Competition I began with the submission of letters of intent. These LOIs included an outline of a plan to establish a Genome Centre as well as a package of large-scale genomics projects and the accompanying science and technology platforms. The whole document had to be kept to a five page maximum with only a single section devoted to the description of potential projects.[46] The project descriptions were to include an indication of the needed platforms and were to be categorized into one of Genome Canada's targeted sectors. The main purpose of the project description was to "facilitate integration of large-scale projects among Centres to stimulate cooperation and avoid unwanted duplication of effort."[47] The five established regions received a combined 275 LOIs for Competition I, a number that Genome Canada had not anticipated.[48] Many projects proposed did not meet Genome Canada's broad eligibility criteria, and some even failed to capture a focus on genomics. This was simply the result of using a new process. Subsequent competition rounds offered more details for the LOI process.

Genome Canada had learned from the high volume of LOIs it received in Competition I, and put greater detail and specificity into the guidelines, evaluation procedures, document structures, and evaluation criteria. In Competition II, the LOI stage was omitted. Instead, a registration process was initiated, which was actually quite similar to the LOI stage. Each registration has a cover page that included the names and affiliations of the principal investigators and co-investigators as well as the signature of the Chairman of the Board and President and CEO of the Genome Centre approving the project for submission.[49] Three pages were then devoted to a summary of each project or science and technology platform and two pages for a description of the role each member of the research team was to play.[50] Next was a preliminary budget complete with cost estimates and cost recovery plans for science and technology platform proposals.[51] The following one page section required applicants to list the collaborators and partners and the role they will play.[52] The registration ended with a form for project leaders to suggest potential reviewers and allowed applicants to indicate anyone whom they would not like to review their proposal.[53] It was a requirement of each Genome Centre submitting projects to ensure that Genome Canada's broad requirements of eligibility were met. The Genome Centres thus took on a greater responsibility in the review process, screening those projects which did not meet the broad criteria. The registration process was not used by Genome

[45] Ibid.
[46] Guidelines and Evaluation Criteria for Genome Centres, 6.
[47] Ibid.
[48] 2000-2001 Annual Report, 2.
[49] Guidelines and Evaluation Criteria for Competition II, 6.
[50] Ibid.
[51] Ibid, 7.
[52] Ibid.
[53] Ibid.

Canada to assess projects but to provide guidance for setting up an appropriate international review team.

Competition III saw a change with Genome Canada taking on the task of reviewing the registration packages. While the initial Genome Canada review was not intended to determine scientific merit, but rather to ensure the projects had potential in terms of proper funding and management criteria; some projects were not invited to submit full proposals. The registration documents included and executive summary, a three page project description, identification of project leaders and collaborators, a management plan, preliminary financial details, and a description of the potential benefits for Canadians.[54] The addition of a two page description of the potential benefits to Canadians reflects the explicit goal of the competition to focus more on economic and social benefits.

Table 2: Evolving structure of the Genome Canada LOIs/Registrations

	Competition I	Competition II	Competition III	ABC Competition
Number of Pages*	Not specific; 5 page document	**7**	**10**	**11**
Description	Clarify sector and needed tech platforms.	List of investigators and collaborators, 3 page summary, preliminary budget, roles of project team, suggested reviewer list	Executive summary, 3 page summary, 2 page benefits section, preliminary budget incl. potential co-funding sources, management chart	5 page summary, 2 page GELS section, 1 page benefits section, list of potential *or secured* co-funders, role of project manager
Standard Form Provided	No	No	Yes	Yes

*excludes budget information
Source: Competition Guidelines and Evaluation Criteria I, II, III, and ABC

The ABC Competition returned to using LOIs. Again, a cover page listing the principal investigators, collaborators, and authorization of at least one Genome Centre was needed. The LOI form stressed that the submissions would be evaluated jointly by all Genome Centres and Genome Canada in order to identify any project synergies and potential for collaboration, due to the thematic nature of the competition.[55] A one-page executive summary of the project was followed by a five-page detailed proposal, outlining the goals of the research and the plans to achieve those goals.[56] The description of the project team included names, roles, time commitments, and reasons for inclusion of the research team members.[57] Next the package required a project management organization chart which included the role of the project manager, whose job was to administer the project and report on its progress, and a description of how the Scientific Advisory Board (SAB) fit into the management scheme.[58] A two-page section on GE^{3}LS followed, directing applicants to demonstrate how these issues were *integrated* into

[54] Competition III Registration Form, 1-11.
[55] ABC LOI Form, pg 1
[56] ABC LOI Form, pg 6.
[57] Ibid, 7.
[58] Ibid ,8.

the overall structure of the project.[59] Individuals with expertise on the subject were to be included. Applicants were also asked to draw up a one-page summary of the expected benefits of the projects research. The summary included potential benefits for Canadians and expected outcomes of the research, as well as a list of individuals with expertise in commercialization, IP rights, or other relevant fields who would help the project realize those benefits.[60] Finally, the LOI required a preliminary financial plan including cost estimates and a list of secured or potential funding sources.[61]

4.5 Full Proposal Stage

For Competitions I and II, no standard form for a full application was provided. Rather, project leaders were to follow the application format in the guidelines of each competition.

Competition I applications involved a maximum of ten pages of text and four pages of figures and tables for each large scale project.[62] A separate detailed budget for each project was also required, details of which were sparing.[63] In total, each research proposal was given roughly fifteen pages to state its case, excluding any budget information. The submission of these applications was somewhat wrapped up with the formation of the regional genome centers, which complicated the presentation.

Competition II also did not use a standard form, but did provide a more detailed outline for the full project proposals. First, a cover page was included with some basic information and the names and contact information for principal investigators and project leaders. The cover page was followed by a one-page lay summary including a description of how the project relates to Canadian genomics strengths, the nature of international impact of the project, and a brief of the potential economic and social impacts of the research.[64] Next was a one-page scientific summary followed by a twenty-page detailed description of the research proposal.[65] The in-depth project description included a discussion of the objectives, research methods, expected outcomes, communication strategy, and management structure, among other things. The project team was then required to include a list of all the researchers involved and what their role and time commitments were.[66] Financial details included commitment for co-funding, or a feasible plan for which co-funding could be secured, and letters showing these commitments were viable.[67] The financial section asked applicants to clearly state what portion of their budget was being requested from Genome Canada and what portion was to be obtained from others. The full application for Competition II was much more in-depth than that of Competition I.

The full application for Competition III was markedly different than in the first two competitions. First off, it was to be drawn up using a standardized form provided by Genome Canada. This allowed Genome Canada to control the process, making applications more predictable and easier to review. The application was much more robust and detailed in nature. It began by identifying the research team and other collaborators.[68] This was followed by a one-

[59] Ibid, 9.
[60] Ibid, 10.
[61] Ibid, 11.
[62] Ibid.
[63] Ibid, 13.
[64] Competition II Guidelines, Appendix C, pg 17.
[65] Ibid.
[66] Ibid.
[67] Ibid.
[68] Competition III Application Form, pg 1.

page lay description and a one-page scientific summary of the project.[69] Next was a twenty-five page in-depth description of the project, five pages longer than that from Competition II.[70] Another new component of the application was a two-page section dedicated to GELS.[71] Two four-page sections, one on project management and one on intended social and/or economic benefits, followed.[72] The budget section, following Competition III's evaluation criteria, contained greater detail and asked for a three page co-funding strategy as well as the appropriate documentation proving viability of co-funding sources, such as written confirmation and audit reports from the source.[73] A budget template was also provided to the Genome Centres and was meant to guide project leaders to display the appropriate budget information.

Competition III include the introduction of the Scientific Advisory Board (SAB) as a part of each project. Its job was to give informed and critical advice and guidance to the research team once the project was off and running. SABs were established by the responsible Genome Centre and were to be sufficiently independent of the research team in order to avoid any conflict of interest. It provided a sort of outside eye and ongoing review process. The SABs overall mandate was to provide expert advice and to ensure that "that the project achiev[ed] its stated goals and milestones." SABs were required to track and submit information for the interim review process. Each project proposal had to include a list of names to sit on the SAB.

A GANTT chart was also used to project milestones and track the progress of the project.

The ABC competition application format used eleven point font rather than twelve, magnifying the length of the application form in comparison to Competition III.[74] It began with a list of investigators, collaborators, and participating organizations.[75] Next was a one-page lay summary and a two-page scientific summary, which was a page longer than in Competition III to accommodate for the inclusion of a discussion of GELS-related issues. It was also noted that the lay summary may be used for communication with the public. The full research proposal description was allowed to take thirty pages, including five pages to discuss any GELS issues arising from the project, significantly more than the two pages in Competition III.[76] Twenty extra pages were allowed for tables and charts, considerably more than the four allowed in Competition I, and something that went unspecified in Competitions II and III.[77] This section contained considerably more detail. A two-page section was then devoted to a data and resource handling plan, another new component. A strategy for the sharing of resources generated from the project with the wider scientific community was to be included. A four-page section pertaining to management of the projects, similar to Competition III, followed. This included an organizational chart showing management structure, previous managerial experience of the research team, and a description of the processes used to oversee the project.[78] Two pages were then dedicated to describing a plan for communications and public outreach. A GANTT chart was also required, as in Competition III.

---

[69] Ibid, pg 6-7
[70] Ibid, pg 8
[71] Ibid, 9.
[72] Ibid, 10-11.
[73] Ibid, 13-15.
[74] Genome Canada. 2008. *ABC Application Form*. http://www.genomecanada.ca/medias/PDF/en/ABC_Application_Form.doc, 1.
[75] Ibid, pg 3-4.
[76] Ibid, 6.
[77] Ibid.
[78] ABC Application Form, 10.

The budget section for the ABC Competition included an interesting caveat not present in previous application formats. It said that the Genome Centres would provide guidance in the preparation of the budget proposal before sending it to Genome Canada.[79] Another interesting addition to the ABC application form was that applicants were to document any previous Genome Canada funded projects that they were involved in, and noted that this information would be used to assess the applicants experience in managing a large-scale project.[80] Applicants who had been part of a previous project were asked to list the project objectives, outcomes, and impacts in a five-page summary.[81] The potential of this consideration is that funding could be concentrated towards those who have worked on a previous Genome Canada project, tightening the network and making it more difficult for new actors to get involved.

Again, similar to the LOI/Registration stage, each successive competition rounds became a more rigorous endeavor, taking more time, effort, and money to secure the necessary parts to be considered for Genome Canada funding. This did, however, put Genome Canada in a better position to fund projects, as strict conditions for co-funding, project management, and project readiness tried to safeguard against fallen partnerships, budget overruns or lapses, and inefficient delays.

Table 3: The evolving structure of the full application

	Competition I	Competition II	Competition III	ABC Competition
# Pages*	10	About 25	About 48	About 63
Details	Detailed research proposal, 5 publications from past five years related to Project	Lay summary, scientific summary, 20 page in depth description, list of researchers, roles, and time commitments, co-funding plan with supporting documentation	25 page in depth description, 2 page GELS discussion, 4 page management plan, 4 page benefits section, 3 page co-funding strategy, GANTT chart	2 page scientific summary with GELS, 30 pages in depth description with GELS, 2 page data management plan, 2 pages communication and public outreach, previous Genome Canada funded project experience, GANTT
Standard Form	No	No	Yes	Yes

*excludes budget information, figures and tables, or sections that do not apply to all projects (i.e. certification forms for human subjects)
Source: Competition Evaluation Criteria and Guidelines I and II and Application Format Competition III and ABC.

4.6 Review Process

In the summer of 2000, five regional Genome Centres were incorporated.[82] Upon incorporation however, the centres existed only on paper. It was Competition I, called on September 15, 2000, that proposed projects which needed the appropriate science and technology platforms to carry out research. Therefore, the first funding competition went hand in hand with the establishment of the regional genomics centres. Not only were Genome Canada and the international review panel evaluating the project proposals, but also the business plans of the

[79] Ibid 12.
[80] Ibid, 15.
[81] Ibid, 16.
[82] Annual Report 2000-2001, 2.

Genome Centre applications. The review process for the first competition was by far the least rigorous in comparison with subsequent contests, another testament to the moving target approach Genome Canada had taken. The Genome Centres received 275 LOIs. After project withdrawals and consolidations, 73 teams developed full proposals for submission to Genome Canada. Out of the 73 submissions, 31 were chosen by Genome Canada to be submitted to an International Panel of experts for peer review. The panel made its recommendations to Genome Canada's board of directors, and 17 projects were chosen to be funded.[83] The review process had three stages and a fourth quasi-stage at which Genome Canada's Board of Directors made the final decision based on recommendations from the international panel. On April 4th of 2001, the winners of the competition were announced. Competition I had the shortest length of time between its announcement and its notice of award, but also used the least rigorous review process.

On July 19, 2001, Genome Canada sent out a request for applications for a second competition for the funding of large-scale genomics projects. Interested persons or groups were asked to submit their project ideas through the appropriate Genome Centre. Each Genome Centre worked with the principles to compile a registration package, which included a short summary of each project. The initial review stage, which was conducted by each Centre's board of directors, screened out those projects which did not meet Genome Canada's broad eligibility criteria.[84] The decision to send proposals to Genome Canada was at each centre's discretion. In total, 67 registration packages were submitted by the Genome Centres to Genome Canada on/before November 1, 2001. The main purpose of the registration package, as stated in the competition guidelines, was to assist Genome Canada in assembling an appropriate panel of peer reviewers, and not to determine eligibility.[85] Project applicants were then invited by Genome Canada to submit a full project proposal. By December 13, 2001, full applications for funding of the projects were submitted to Genome Canada.[86] In Competition II, Genome Canada received 64 full proposals.

The second review process, conducted by Genome Canada, ensured that indeed the projects met the broad eligibility criteria, and that, based on a due diligence review, the financial and managerial plans were reasonably sound, before sending them for peer review.[87] Simultaneously, a panel of domestic external reviewers were solicited to prepare a brief write up of each proposal to assist the international peer review panel; 62 projects were sent for vetting by the international panel of reviewers. Along with the solicited reports, due diligence information was made available to the panel of peer reviewers in advance of their meeting.

A multidisciplinary and international panel was established to provide expert advice in a comprehensive review of each proposal.[88] The panel met in March of 2002, beginning the third round of reviews. They compared each project proposal to the evaluation criteria put forward by Genome Canada. Project Investigators and their teams were invited to the meeting and spoke face to face with the reviewers. The review panel offered recommendations based on its review process to Genome Canada's Board of Directors. Projects were rated A (highly recommended), B (recommended), or C (not recommended). The board conducted the final reviewing stage,

[83] Ibid.
[84] Comp II Guidelines, pg 6
[85] Competition II Guidelines, pg 7.
[86] Ibid.
[87] Ibid, pg 8.
[88] Ibid.

acting on the advice from the international panel of experts. In the first week of April, 2002, Genome Canada announced the 34 winners of the competition. After the notice of award, each project proposal, successful or otherwise, received the evaluation from the peer review outlining the project's strengths and weaknesses.[89] For Competition II, the total process took about 258 days.

Competition III was marked with some significant changes from the first two competitions in terms of its review processes. Again, applicants were asked to submit their project proposals through the appropriate Genome Centre. Each Centre used its own discretion in choosing which projects to send forward in its registration package, filtering out those which did not meet the eligibility criteria (remember, a time parameter of 3 to 4 years was added).

Genome Centres sent in registration packages to Genome Canada, but this time around, Genome Canada did not request full proposals from all project registrations submitted, marking a change from Competition II.[90] Of the 117 registrations received, 93 were invited to submit full proposals.

The third round of reviews took place after Genome Canada received the full applications from the Genome Centres. Due diligence reviews of the financial and management components of the projects were conducted by Genome Canada and hired consultants.[91] The review included face to face meetings with project leaders, co-funders, and Genome Centre representatives. The results were offered as recommendations to Genome Canada's Board of Directors.[92] Proposals that were deemed unfit according to financial and management criteria were either not submitted for peer review or given a chance to be revised and resubmitted.[93] Information collected from the due diligence review process was given to the international peer review panel.

The fourth review process in Competition III was conducted in June of 2005 by a multidisciplinary and international panel of experts. Again, as in Competition II, external domestic peer reviewers were solicited to provide written reports to the panel members in advance of their meeting.[94] This information, along with the due diligence reports, was to assist the international panel in their review of the project proposals. Project leaders had a chance to meet face to face with the panel to discuss any part of the proposal.[95] Once again the panel offered advice to the board of directors at Genome Canada before the final decision was made. Applicants were also provided with a write up from the peer review process of the strengths and weaknesses of their projects.[96] Competition III saw 33 projects approved out of 93 full proposals submitted in a process and took roughly 391 days to complete.

In 2006, Genome Canada decided to pursue a different style of funding competition. This "new strategy for the future [would] focus on Canadian strengths, for example, research areas that reflect[ed] Canada's unique biodiversity, diverse population, and Canadian sectoral strengths."[97] The premise was that research funding would be targeted towards specific areas of strength and socio-economic importance to Canada. This way, money could be pinpointed into

[89] Ibid.
[90] Comp III, pg 7.
[91] Comp III, pg 8.
[92] Ibid.
[93] Genome Canada. March 2004. *Interim Evaluation of Genome Canada.* http://www.genomecanada.ca/medias/PDF/EN/GCReport-Mar31041.pdf
[94] Ibid.
[95] Ibid.
[96] Ibid.
[97] Genome Canada. 2006-2007 Request for Position Papers, 1.

particular sectors, resulting in a more efficient use of funds. After a Genome Canada retreat in February of 2006, and a subsequent summer tour, it was agreed that the theme areas would be determined through a position paper process.[98] This was not the first themed competition. In 2004, Genome Canada undertook a directed funding competition in Applied Human Health, but that topic was "handed down" by the federal government. In this competition, the task of choosing themes was left up to the scientific community and other collaborating stakeholders. It was argued that the position paper process would engage interested persons, organizations, and industry and allow projects easier access to co-funding.

The position paper process began on October 2, 2006, with an advertising campaign run by Genome Canada to inform interested parties of the new style of competition. The first step called for the submission of expressions of interest (EOIs). The EOI was to be submitted by a "champion" of the theme and address a number of broad criteria in order to be considered for development into a position paper. Beyond the basic content, such as the title of the theme and contact information for theme leaders, the criteria included, first and foremost, a discussion of the "importance of the problem(s) to be tackled and the expected socio-economic outputs, outcomes and impacts on the sector or discipline covered by the themes in the short to mid-term (~ five years)."[99] Other content included the state of infrastructure and human resources currently available, a list of supporters, a discussion of the state of the science in Canada and internationally, and letters of support from two Genome Centres.[100] Also interesting is that the EOIs were posted on Genome Canada's web site: "The web site will be a transparent vehicle for the dissemination of information to all interested individuals. In addition to viewing the EOIs and registration of support, a discussion space will be made available to allow comments and suggestions to flow between the proposed champions and interested parties."[101] This allowed supporters to view the submission, and register their interest as a co-funder or otherwise. Part of Genome Canada's advertising awareness campaign was directed at luring Canadian and international support.[102] The website operated for about a month allowing potential themes to gain support.

From December 15, 2006, until January 15, 2007, Genome Canada's staff, Genome Centre representatives, and the SIAC evaluated the EOIs.[103] Genome Canada placed a cap of 15 themes to be developed into full position papers.[104] This meant that potential themes needed to be prioritized and that even if an EOI met the eligibility criteria (to be discussed later), it may not be developed into a position paper. It was also noted that some EOI titles might change due a merging of two or more into a broader theme.[105] Theme champions were notified in order to choose a leader, if indeed this were the case.

The first cycle of the position paper process attracted 60 EOIs.[106] Following consolidation by the SIAC, and a series of consultations and workshops, 11 position papers were invited to be developed by July 2007.[107] Developing a position paper required a significant effort

[98] Ibid.
[99] Genome Canada. 2006-2007 Criteria and Guidelines for the Position Paper Process, pg 7.
[100] Ibid.
[101] Ibid, 6.
[102] Ibid, 7.
[103] Ibid.
[104] Ibid.
[105] Ibid.
[106] 2008-2009 Corporate Plans, 8.
[107] Ibid.

by the champions who were asked to spend substantial time over a six-month period fact finding, writing, and building support for their theme through national workshops.[108] Genome Canada made a maximum of $15,000 available to each theme champion in order to develop the position paper.[109] This cost covered administrative needs, fact finding exercises, and market studies, but could not be used for the salary of the champion. Genome Canada also paid for any national workshops held for the position paper. In the end, from 11 position papers, the international peer review committee selected two themes, Agriculture–Plants (Crop Genomics for a Healthy Canada), and Bioenergy and Bioproducts (Securing Canada's Future Bio-based Economy through Genomics), to run a new style of open competition. In total, the theme identification process took 332 days.

Table 4.1: Competition timelines Competitions I-III (Days to complete stage)

	Announcement of Competition to LOIs/Registration Due (To Centre)	LOIs/ Registration Due to Invitation for Full Proposals	Invitation for Full Proposals to Due Date for Submission to Genome Canada	Length of International Peer Review Process	Completion of International Peer Review to Notice of Award	Total days
Comp I	53	~ 20 *	~ 37 *	35	33	201
Comp II	104	43		~ 30 *	~ 15 *	258
Comp III	93	14	74	~ 20 *	~ 61 *	391

*Only specified by time of month (i.e. early June), exact dates not known. All total times are correct.
Source: Competition Guidelines I, II, III and Annual Reports 2000-2008.

Only after the completion of the position paper process could the ABC competition begin. During June of 2008, Genome Canada conducted information sessions in each of the six regions in order to clarify the guidelines and scope of the competition for those approved to submit a full proposal.[110] The development and review process for the ABC competition reverted back to the submission of LOIs. Due to the thematic nature of the competition, potential synergies and overlap had to be assessed. Project leaders were contacted confidentially if a partnership appeared logical.[111] Those LOIs that did not meet Genome Canada's broad eligibility criteria were not asked to submit full applications. No quotas were attached to each theme. That is, projects were assessed and approved based on excellence, and no specific amount of money was held for each theme.[112] Although not mentioned in the project application guidelines, the due diligence evaluation was no longer conducted before the international peer review, but instead at the same time.[113] This change was initiated because of concerns in previous competitions that a number of projects with scientific merit were dropped from competitions because of the results

[108] 2006-2007 Position Paper Process, 5.
[109] Ibid, 9.
[110] 2009-2010 Corporate Plans, 19.
[111] Genome Canada. *2008-2009 Request for Position Papers*. http://positionpapers.genomecanada.ca/pdf/request-for-position-papers-2008-2009.pdf, 9.
[112] Ibid.
[113] KPMG. March 2009. Genome Canada Performance Audit 2009. http://www.genomecanada.ca/medias/PDF/EN/Performance_Audit_Report09.pdf (June 21 2009). 9.

of the due diligence evaluation, which assessed their managerial and financial stability rather than their scientific merit.

The ABC competition added an additional review process in response to a high volume of LOIs (48) accepted and developed into full proposals.[114] In order for the face to face full review meetings with project investigators to remain feasible, Genome Canada on August 1, 2008, introduced an interim step, with each proposal being given a full scientific review by selected members of the international review panel.[115] Those deemed "non-competitive" by the majority of reviewers were dropped from the competition. All panel members were then given an opportunity to make their case for any project and save it from elimination.[116] In the first week of December, unsuccessful applicants were informed that they did not pass the streamlining process, and were sent copies of the panel review.[117] Out of 48 full proposals, 27 were sent to full peer review.

In KPMG's 2009 performance audit report, it was suggested that Genome Canada continue to hold open competitions to encourage new actors, ideas, and the recognition of emerging themes, as well as to shorten the approval process.[118] Also noted in the performance audit was that, due to the time and effort required, "there is a concern that past participants in the process may lose interest in participating in future years."[119]

Table 4.2: Position Paper and ABC Competition timelines

First	Announcement of Process to LOI Due Date	LOI Analysis	LOI Due Date to Announcement to Submit Full Position Paper	Announcement of Successful LOIs to Position Paper Submission	International Peer Review of Position Papers	Total days
Pos. Paper	53	31	52	169	57	332
Then	Announcement of Competition to LOIs/Registration Due (To Centre)	LOIs/ Registration Due to Invitation for Full Proposals	Invitation for Full Proposals to Due Date for Submission to Genome Canada	Length of International Peer Review Process	Completion of International Peer Review to Notice of Award	
ABC Comp	31	~ 25 *	129	~ 40 *	~ 95 *	384

Source: Competition Guidelines Theme Call I and ABC and Annual Reports 2000-2008.

Overall, the development and review process grew from a modest 201 days in Competition to 716 days to get through the combined position paper and ABC competitive process.

[114] Genome Canada. August 1, 2008. *ABC Competition Streamlining Memo*. http://www.genomecanada.ca/medias/PDF/EN/Streamlining_memo_applicant.pdf (July 10, 2009), 1.
[115] 2009-2010 Corporate Plans, 19.
[116] Streamlining Memo, 1.
[117] Ibid.
[118] KPMG Performance Audit, 11.
[119] Ibid.

4.7 Competition Success Rates

The processes above solicited about 517 intentions/registrations of research teams, each which on average would include at least 5 investigators, collaborators or researchers. While there is some obvious repeat activity by some individuals and teams, this level of interest would represent something in the range of 2,500 investigators showing some level of interest in the funding area. Just over half of those expressing interest (213) actually submitted a full proposal. The review processes culled 65 before full peer review (23%). The overall success rate for applicants of this tranche of competitions was about 35%, with the highest success rate in Competition II and the lowest in the ABC competition.

Table 5: Project flow through the development and review process

	Competition I	Competition II	Competition III	ABC Competition	Totals for 4 Comps
Letters of Intent/Registrations	275	67	117	58	517
Full Proposals	73	64	93	48	278
Submitted for Peer Review	31	62	93	27	213
Approved	17	34	33	12	96
Approved % full proposals	28%	53%	36%	25%	35%

Source: Genome Canada, Genome Canada website Competitions and Initiatives

Overall, the four competitions allocated $750 million over the 2000-2010 period for the four open competition. In total, the average approved funding (50% from genome Canada and 50% from partners) was about $7.8 million over an average of about four years, with average annual flows of just under $2 million.

Table 6: Funding approved by competition and project, Comps I, II, III and ABC

	Approved projects	Total Approved Funding $M	Average funding per project $M
Competition I	17	136	8.0
Competition II	34	155.5	4.6
Competition III	33	346	10.5
ABC Competition	12	112	9.3
Total	96	$749.5	7.8

Source: Calculation from Genome Canada Corporate plan 2011-2012, Ottawa.

4.8 Funding requirements and financial management

Generally, Genome Canada covers 50% of the eligible costs of each project that is approved, although as of March 1, 2008, it had actually contributed 47% of project funding, amounting to $900 million.[120] Over the competition rounds, the definition of eligible costs has changed, and so have the requirements for securing co-funding prior to the projects actual approval. Overall, Genome Canada has requested a more comprehensive plan and detailed documentation in order to be approved for the international review stage. This has mitigated some of the risk of Genome Canada funding, ensuring that feasible funding plans are in place

[120] 2009-2010 Corporate Plans, 7.

prior to the release of public monies, but has also led some in the scientific community to question whether projects with a high degree of scientific merit are being dropped for administrative reasons.

Competition I initiated Genome Canada operations and was very vague regarding the projects funding requirements. It simply states that maximum effort must be given by the Genome Centres to secure funding from other institutions, government bodies, the private sector, and international organizations.[121] Financial details were quite sparing in reference to the research projects themselves, but were eluded to in general terms in discussion of the centres. For example, the guidelines state that eligible costs include "the cost of salaries of researchers, trainees, technicians, management, and support staff needed for the operation of research infrastructure."[122] Some of these costs would obviously be incurred by a project, but are discussed in terms of the overall budget of the centre.

Much greater financial detail was present in the guidelines for Competition II, which added that Genome Canada would provide up to 50% of eligible costs and that at the time of application the remaining 50% must be confirmed or have a reasonable strategy in place to secure the additional funding.[123] The strategy needed approval from Genome Canada and funding was not dispersed until the remaining funds were secured. The list of eligible costs was modified as well. Costs pertaining to research into new technology development and development costs to host institutions were included, as were reasonable administrative costs.[124]

Competition III clarified a few technicalities, such as the ineligibility of the opportunity costs of using existing infrastructure, salaries of those funded by their host institutions, and budget items already approved for funding from other sources.[125] There were also a couple of interesting additions. Included in the list of eligible costs was funding for research into the GE^3LS related issues of the project.[126] Costs associated with developing a strategy to obtain social and economic benefits, including consultation with experts (e.g. market analysts and IP experts), were considered eligible. Also, the guidelines affirmed that administration costs could not exceed 5% of the total budget and salaries could be adjusted to inflation, calculated at 2%.[127]

Competition III guidelines regulated co-funding procedures more carefully than previous competitions. Previously, letters of collaboration and support sufficed. Documentation was now required to ensure the reliability of co-funding sources. All examples of what constituted appropriate documentation were listed in brackets after a general statement, and it was unclear which documents, or combination of documents, were preferred by Genome Canada. For example, the following statement comes from the co-funding section the Competition III guidelines: "Provide documentation to support the financial viability of the company and its ability to fulfill its commitment to the project (e.g. cash flow statement, a recent audited financial statement, a press release announcing significant new funding, etc.)"[128]

Competition III laid out the procedure for funding an approved project. If at the start of the project, co-funding agreements were secured, but had not yet kicked in, Genome Canada would fund the entire costs quarter by quarter to front end their contribution. If co-funding had not been

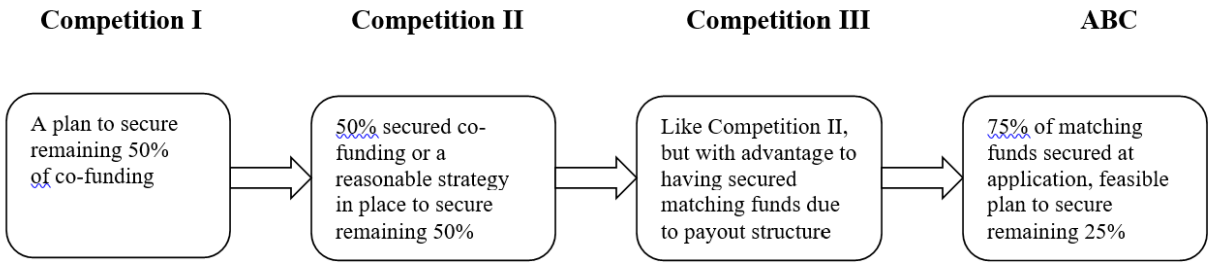
[121] Guidelines and Evaluation Criteria for Genome Centres. 7.
[122] Ibid, 7
[123] Guidelines and Evaluation Criteria for Competition II. 8.
[124] Ibid.
[125] Guidelines and Evaluation Criteria for Competition III. 9-10.
[126] Ibid, 10.
[127] Guidelines and Evaluation Criteria for Competition III, 10.
[128] Ibid, 11.

secured, Genome Canada would only release funds based on 50% of the quarterly budget. Therefore, it was advantageous for a project to secure funding as soon as possible in order to avoid any delays due to lack of money. This was a reaction to the change in the funding at Genome Canada. Genome Canada did not have committed funding when Competition III was announced. If Genome Canada had to fund the entire project until co-funding was secured, they may have ran out of funding before the competition was over, and if co-funding fell through, the projects would be stuck.

The ABC competition would build on the new cautious principles for co-funding sources, explicitly stating what documentation was required. The ABC Competition presented more in-depth and additional funding criteria. First off, it noted that costs eligible for funding must be incurred after the notice of award, although there were some circumstances where funding could be obtained for project development six months previous of award.[129] The documentation required to support the evidence of reliable co-funding sources became a focus of the ABC competition's funding guidelines. A write-up describing how the funding will *directly* support the goals of the project and an *explicit* acknowledgement that the co-funder would use said funds to support the project were required. Universities often retain some of the funds to cover indirect costs, but these costs were not considered eligible.[130]

Genome Canada also asked, as in Competition III, that project applications include evidence that its co-funding sources were viable. These criteria were mentioned in the Competition III guidelines, but in much less detail. Specifically, the ABC competition required a written letter from a CEO, a board resolution referring to the commitment of funds, or a report of cash flow projections to confirm the matching support.[131] For large cash commitments, audited reports or full financial statements were required, and for smaller funding contributions, a letter from the CEO could suffice. Both the layout and detail of co-funding guidelines had changed in the ABC competition, reflecting an emphasis on ensuring the viability and commitment of co-funding sources.

Figure 2: Funding requirements



Source: Guidelines and Evaluation Criteria Competitions I, II, II, ABC.

The most significant change in the funding criteria for the ABC competition was that at the time of application projects needed to have the remaining funding either in place or to have a well-developed and feasible plan for securing said funds. Once a grant was awarded, Genome Canada required that 75% of the necessary co-funding was already secured, and again, a feasible

[129] ABC Competition Guidelines, 11.
[130] Genome Canada. ABC Information Session FAQ http://www.genomecanada.ca/medias/PDF/en/ABC_infoSession.pdf, (May 30, 2009), 2.
[131] Ibid.

plan for obtaining the remaining 25%.[132] Genome Canada was now receiving grants based on its need on an annual basis. This forced them to change the way they funded projects and required co-funding sources to be secure and ready for the start of a new project. Similar to Competition III, if co-funding was secured via a binding agreement, Genome Canada was willing to adjust the timing of its release of funds in order to allow the project to progress.[133]

5. Concluding comments

As Genome Canada matured, it imposed more structure and design to each successive open competition. The goals became more specific, the 'priorities' expanded from world-class science to include GE^{3}LS, commercialization and data management, the proposals became more detailed, the development and review process more than tripled from the first to fourth competition, the financial matching became more rigorous, and the oversight and management of the approved projects became more proscribed. All of these changes added time, money, and effort to both the successful teams but also for those who competed and failed. On the upside, success rates have remained reasonable (about 35% over the period) and the size of the grants warrants more effort both by the granting body and the applicants. A logical next step would be to do a cost-benefit analysis to assess the programs individually and collectively for their efficiency.

As a parting note, we have undertaken a range of analyses of the efficiency and effectiveness of the Genome Canada system, including:

Bibliography

Bearing Point. March 2004. *Interim Evaluation of Genome Canada.* http://www.genomecanada.ca/medias/PDF/EN/GCReport-Mar31041.pdf.

Corporations Canada. January 2009. *General Overview of the Canada Corporations Act Part II.* http://www.ic.gc.ca/eic/site/cd-dgc.nsf/eng/cs02167.html (June 18, 2009).

Department of Finance. 2006. *Advantage Canada.* http://www.fin.gc.ca/ec2006/pdf/plane.pdf (June 19, 2009).

Doern, DB, P. Phillips., and D. Castle. 2016. Canadian Science, Technology and Innovation Policy: The Innovation Economy and Society Nexus. MQUP.

Farazmad, Ali. 1996. *Public Enterprise Management.* Greenwood Press, Connecticut.

Genome Canada. 2000. *2000-2001 Annual Report*. http://www.genomecanada.ca/medias/PDF/EN/2000-2001AnnualReport.pdf.

Genome Canada. September 2000. *Guidelines and Evaluation Criteria for Genome Centres*. http://www.genomecanada.ca/medias/PDF/EN/GUIDE18-final.pdf.

Genome Canada. December 2001. *Guidelines and Evaluation Criteria for Competition II,* http://www.genomecanada.ca/medias/PDF/EN/CompIIGuidelinesfinal.pdf.

Genome Canada. 2004. *Annual Report 2003-2004.* http://www.genomecanada.ca/medias/PDF/EN/2003-2004AnnualReport.pdf.

[132] ABC Competition Guidelines, 12.
[133] Ibid, 12.

Genome Canada. July 2004. *Guidelines and Evaluation Criteria for Competition III.* http://www.genomecanada.ca/medias/PDF/EN/Guidelines3.pdf.
Genome Canada. 2006-2007 Criteria and Guidelines for the Position Paper Process.
Genome Canada. 2006-2007 Request For Position Papers.
Genome Canada. 2007. *Corporate Plans 2006-2007.* http://www.genomecanada.ca/medias/PDF/EN/CorporatePlan2006-07-english.pdf.
Genome Canada. 2008. *ABC Application Form.* http://www.genomecanada.ca/medias/PDF/en/ABC_Application_Form.doc.
Genome Canada. August 1, 2008. *ABC Competition Streamlining Memo.* http://www.genomecanada.ca/medias/PDF/EN/Streamlining_memo_applicant.pdf (July 10, 2009).
Genome Canada. May 2008. *Guidelines and Evaluation Criteria: Competition in Applied Genomics Research in Bioproducts or Crops.* http://www.genomecanada.ca/medias/PDF/en/Guideline_Evaluation_Criteria.pdf.
Genome Canada. 2008. *2008-2009 Corporate Plans*. http://www.genomecanada.ca/medias/PDF/EN/CorporatePlan2008-09-english.pdf.
Genome Canada. 2009. *Annual Report 2008-2009.* http://www.genomecanada.ca/medias/PDF/EN/CorporatePlan2008-09-english.pdf.
Genome Canada. 2009. *List of Funded Projects in ABC*. http://www.genomecanada.ca/data/Nouvelles/Fichiers/en/330_2_4%20list%20of%20approved%20projects.pdf (June 11, 2009).
Genome Canada. *2008-2009 Request for Position Papers*. http://positionpapers.genomecanada.ca/pdf/request-for-position-papers-2008-2009.pdf.
Genome Canada. 2009. *2009-2010 Corporate Plans*. http://www.genomecanada.ca/medias/PDF/EN/CorporatePlan2009-10-english.pdf.
Genome Canada. *ABC Information Session FAQ.* http://www.genomecanada.ca/medias/PDF/en/ABC_infoSession.pdf, (May 30, 2009).
Genome Canada. *Research Portfolio.* http://www.genomecanada.ca/en/portfolio/research/competition.aspx (June 15, 2009).
Genome Canada. *Science Advisory Board Guidelines*. http://www.genomecanada.ca/medias/PDF/EN/SAB_terms_reference.pdf, 1.
Industry Canada. 2002. *Canada's Innovation Strategy*. http://dsp-psd.pwgsc.gc.ca/Collection/Iu4-5-2002E.pdf1 (June 20, 2009).
Industry Canada. 2007. *Mobilizing Science and Technology to Canada's Advantage.* http://www.ic.gc.ca/eic/site/ic1.nsf/vwapj/S&Tstrategy.pdf/$file/S&Tstrategy.pdf (June 19, 2009).
KPMG. March 2009. Genome Canada Performance Audit 2009. http://www.genomecanada.ca/medias/PDF/EN/Performance_Audit_Report09.pdf. (June 29, 2009).
Science Technology and Innovation Council. 2008. http://www.stic-csti.ca/eic/site/stic-csti.nsf/vwapj/08-141_IC_SOTN_EN_Final_no_trans2.pdf/$FILE/08-141_IC_SOTN_EN_Final_no_trans2.pdf (July 7, 2009).
Swedish Institute for Growth Policy Studies. 2004. *Innovation Policy in Canada*. http://www.vinnova.se/upload/EPiStorePDF/InnovationPolicyInCanada.pdf (June 16, 2009).

Chapter 2

Evaluating Program Fit

A case study of Genome Canada programming, 2000-11

Lucy Zhang, Haizhen Mou and Peter Phillips

Abstract

This paper assesses the fit between project allocations and the strategic objectives of Genome Canada (GC), a major research funder in Canada. A regression model was used to test the relationship between the objectives of the organization (using data available to decision makers) and the share of funds allocated to specific projects, both in the total pool of investments and open competitions. The overall fit between 2001 and 2011 was about 35%, with the impact factor of the principal investigator being the most significant driver. The fit decreased for the open competitions alone, suggesting directed investments more strongly fit organizational goals.

Key Words

Evaluation; research management; Genome Canada; program assessment.

1. Introduction

Genome Canada (GC) is an independent non-profit organization established in April 2000 that provides funding, coordination and information resources for genomics and proteomics research in Canada. GC targets the development and implementation of large-scale research projects in key bio-science areas (health, agriculture, environment, forestry, fisheries, mining and energy) to help Canada become a world leader in genomics and proteomics research, as well as in the promotion of the ethical, environmental, economic, legal and social (GE^3LS) aspects of genomics research.

GC is designed to effectively translate research results into broader commercial outcomes, through the funding and management of large-scale interdisciplinary and internationally peer-reviewed research projects along with S&T (science and technology) Innovation Centres. GC operates in close collaboration with its primary partners—the six Genome Centres representing British Columbia, Alberta, the Prairies, Ontario, Quebec, and the Atlantic region. The relationship between GC and each of the Genome Centres is defined by means of a funding agreement that "not only acknowledges the independence of each Genome Centre, but also specifies the parameters in which each Centre is to operate and contribute to GC's overall mandate" (KPMG 2009).

This paper reviews the basic theory of evaluation, reviews the background on Genome Canada investments decisions and undertakes an economic evaluation of the fit between the visible evaluation criteria and the investment decisions.

2. Policy and Program Evaluation

Evaluation is a critical part of the public policy system, as it helps to define problems, delimit options, aid with decision making and improve operational efficiency. Evaluation is defined as the systematic determination of merit or worth using criteria against a set of standards. At the organizational level, evaluation is a critical link in Simon's (1997) ends-means causal chains. For organizational evaluation, the focus is on how specific activities or processes contribute to the goals of the institution or agency.

The design of a particular evaluation approach depends on the actors involved and the situation. Standards and principles of evaluation provide some sense of direction, along with the base of ethical norms, commitment and integrity. In our study, the stated objectives of GC are the foundation of the whole process for project evaluation.

In an early paper on performance evaluation, Arvidsson (1986) focuses on the pressures facing public services, expressing that government performance evaluation could be measured in several ways, by examining objectives, timing and the procedures of administration. King (1987) asserts that research evaluation "makes use of a variety of indicators to draw as complete a picture as possible of the complex aspects that account for the performance of research."

Rossi et al. (2004) defined program evaluation as the use of social research procedures to systematically investigate the effectiveness of social intervention programs, adapted to the political and organizational environments and designed to inform social action in ways that improve social conditions. Comprehensive evaluation is an assessment of a program that covers the need for the program, its design, implementation, impact, and efficiency.

The differences between policy analysis and policy evaluation are widely known but often unrecognized. Geva-May and Pal (1999) compare policy evaluation and policy analysis in terms of concept, methodology, problems and data description. Evaluation tends to adopt a focus on the process which is being used to make policy choices.

Theory-based evaluation (TBE) has become widely discussed and occasionally practiced in the recent years. Birckmayer (2000) identified evaluations may be needed beyond operational assessment. Supporters think this approach will help to explain how and why formal project assessments predict the results. Very often, this type of evaluation will follow each step in a sequence to see whether the expected steps actually occurred.

One way to look at the challenge of evaluating research systems is through an outcomes management framework, such as used by the Treasury Board of Canada – in this context, evaluation could focus on efficiency and effectiveness, with efficiency analysis investigating the causal path between inputs, activities and direct outputs. With respect to GC, the inputs could be translated as the allocation of funds from Industry Canada. The focus of this work is on the 'activities' undertaken by GC to allocate funds to specific science projects (the outputs).

Luukkonen (2002) notes that research evaluation is also connected with the assessment of applicant performance and on the embedded decision-making sub-systems, such as peer review. Patton (2002) explains,

> [A] successful evaluation emerges from the special characteristics and conditions for a particular situation—a mixture of people, politics, history, context, sources, constraints, values, needs, interests, and chance. Despite the rather obvious, it is not at all obvious to most stakeholders who worry a great deal about whether an evaluation is being done right. Indeed, one common objection stakeholders make

to getting actively involved in designing an evaluation is that they lack the knowledge to do it right.

In essence, performance evaluation is described as comparing results against objectives, which will vary with different situations. It could also be applied in many ways. Ruegg and Jordan (2007) offer a range of evaluation methods, including: benchmarking; surveys; technology commercialization tracking; historical tracing; case study; peer review/expert judgment; tracing; network analysis; benefit-cost case study; and econometric modelling.

A critical part of any effective public policy assessment is to compare activities and outputs against the proposed goals and objectives of the initiative. In most cases, the outputs are assumed to conform to the stated goals and objectives but are not assessed as part of a formal evaluation.

3. Background on Genome Canada Investments and Evaluation

While GC has undergone organizational, administrative and financial reviews, it has not undertaken any specific evaluation of the process of targeting its operating model to realize its stated goals. This project explicitly assesses the choices made by GC in the context of its funding competitions to determine how the organizational goals are reflected in the projects selected.

GC identified five key objectives to help move Canada onto the world stage in its 2007 corporate strategic plan (Genome Canada 2008). Specifically, the organization seeks to:

1) Develop and implement a coordinated strategy for genomics and proteomics research.
2) Support large-scale genomics and proteomics research projects of strategic importance to Canada, by bringing together industry, governments, universities, research hospitals and the public.
3) Provide accessibility to Science & Technology Platforms to researchers in all genomics and proteomics related areas through six regional Genome Centres across Canada (Atlantic, Québec, Ontario, Prairie, Alberta and British Columbia). The relationship established between GC and each of the Genome Centres is defined by means of a funding agreement that not only acknowledges the independence of each Genome Centre, but also specifies the parameters in which each Centre is to operate and contribute to GC's overall mandate.
4) Encourage external investment in the fields of genomics and proteomics, attracting co-funding for projects from both domestic and international investors.
5) Sustain leadership in research areas on ethical, environmental, economic, legal and social issues related to genomics and proteomics research, and promote the communication of the relative risks, rewards and successes of genomics and proteomics research to the Canadian public.

GC has developed a detailed operational process for determining its allocation of funding. While the order of the early steps in each competition might vary, all of the competitions have followed a common path.

First, after consultation with industry, government, the scientific community and end-users, (sometimes informally and sometimes through the use of formally structured theme papers), GC frames a funding request for Industry Canada that states what area the organization will focus on and what the money will be used for. If successful, GC then devises competition objectives. Most federal requests are only partially awarded.

Second, GC issues a call for proposals, which articulates the focus and scale of projects that could be funded. In most cases letters of intent are first reviewed and in a few cases have been used to triage the proposals. Projects are evaluated and invited to submit full proposals. Full proposals for the open competitions are peer-reviewed and assessed by panels of international reviewers, which rank the projects for funding. The GC Board then approves the allocations. Each approved project embodies milestones that trigger quarterly progress reports and a final statement of activities and outputs.

In the context of this effort, GC regularly undertakes audited financial reporting, has engaged in organizational and process evaluations and has assessed the outputs of the competitions. To date, GC has used a range of these methods. The most prominent choices have been document review, peer review (used for Competition I, II, III, and ABC) and case study. The KPMG Evaluation of Foundations evaluation team reviewed a broad range of documentation on the government's use of foundations to achieve policy goals, the evolution of the terms and conditions under which foundation funding has been provided, and the results achieved by various foundations. The team also undertook case studies to obtain insights into the appropriateness, effectiveness and costs of specific foundations. KPMG's review in 2009 used a mixed method approach, including peer-reviewers, expert judgment, survey and benefit cost. So far, the organization has not assessed the efficacy and appropriateness of the funding allocation decisions and their fit to the organization's mandate and objectives.

As of 2012 GC had committed $915 million in funding and researchers had secured approximately an additional $1,085 million in co-funding, representing a total investment of over $2 billion in completed or planned genomics research in Canada. All these investments have laid a foundation for a rich, vibrant genomics research community in Canada, and as noted below, have transformed the quantity, scope, scale and quality of such research (KPMG 2007).

The overall efforts of GC can be summarized by the following: $2 billion invested, with more than half secured from partners; 156 large scale research projects across the life science sectors; six world-class S&T Innovation Centres; more than 200 project leaders, who have developed the skills to manage complex science knowledge into application; more than 4,500 research publications, contributing to raising Canada to the top five in the world in the world in terms of scientific impact, and fourth in research related to science and society; more than 20 companies created; more than 10,000 highly skilled people trained and employed; and more than 350 patent applicants/awards, and 24 license agreements, placing Canada first in the multi-criteria ranking for intellectual property in genomics in 2005–2007 (Genome Canada 2012).

Table 1: Genome Canada large-scale open competitions

	Start Date	**Total approved budgets**	**Number of approved projects**
Competition I	April 4, 2001	$136 million	17
Competition II	July 19, 2001	$155.5 million	33
Competition III	July, 2004	$346 million	33
ABC	April, 2008	$112 million	12
Total		$749.5 million	95

Source: Calculation from Genome Canada Corporate plan 2011-2012, Ottawa, 2012.

As shown in table 1, GC has engaged in four large-scale, open research competitions, commonly named competitions I, II, III and the applied genomics in bio-products and crops (ABC) competition. The rest of the funding allocations were to directed projects/programs (called 'other' in this study) that were more directly managed and coordinated by GC or the genome centres**.**

GC has been extensively reviewed. In 2007 KPMG prepared an Evaluation of Foundations report for the Treasury Board Secretariat, presenting the findings of an evaluation of the use of foundations (i.e. special operating enterprises) as instruments of public policy. This study examined six foundations, including GC, and was conducted by KPMG LLP on behalf of the Government of Canada between September 2006 and January 2007 (KPMG 2007). The evaluation team started with a review of the government's use of foundations to achieve policy goals, the evolution of the terms and conditions under which foundation funding was been provided, and the results achieved by various foundations. KPMG reported on three aspects of the government's use of foundations. First, they examined the appropriateness of the foundation model as an instrument of public policy, concluding that the model exhibited generally strong degrees of alignment with the guiding principles published in Budget Plan 2003 (Department of Finance 2003). Second, they examined the effectiveness of the foundations, reporting on their progress against objectives, coordination with related government programs, alignment with government policy goals and their accountability mechanisms. The general conclusion was that the foundations were doing well on all measures, albeit with some range of effectiveness. Third, KPMG examined the operating and administration cost structures, focusing on structured and transparent processes for reviewing and selecting projects to support, and supporting systems for project tracking and financial management. The conclusion was that operating and administration costs are driven by needs to efficiently manage project workloads and to provide timely support for governance and accountability requirements. Foundation resource levels and costs appear to be closely matched to, or follow, the trends in the project workloads. In effect, KPMG offered an organization and operational review of the processes and structures, but did not undertake any specific analytical assessment of the fit of those processes to the overall goals or objectives of the organizations.

In 2008 KPMG was contracted by GC to do an overall evaluation of the impact of GC investments. GC is directed to undertake an evaluation every five years as a requirement of their funding agreement with Industry Canada. This evaluation focused on the impact of the funding allocations. The methodology involved a review of internal documentation and databases, web-based surveys and interviews and a partial cost-benefit analysis of GC research investments and outcomes. As an outcomes-based approach, the analysis did not directly assess the fit between the research funding decisions and the strategic goals of GC.

In 2008, GC articulated a full performance, audit and evaluation strategy (PAES). The strategy was developed as a high level framework which addresses key elements that GC had implemented or planned to put in place to ensure accountability in the achievement of objectives from the perspective of performance, audit, evaluation and reporting. These processes are designed to contribute to more effective operations and to ensure compliance to the funding agreements signed with Industry Canada with respect to the use and accounting of funds received from the federal government. GC also signs individual funding agreements with each of the six Genome Centres, where the undertakings agreed to with Industry Canada are carried out.

The PAES is comprised of three key frameworks: 1) performance monitoring and measurement; 2) audit; and 3) evaluation. All elements provide a foundation for strengthening internal management.

While these efforts to assess the operations of the organization address its goals and objectives, this work has been mostly in the form of institutional audits and qualitative assessments. This study extends that work. It offers an empirical, quantitative assessment of the fit between the institutional goals and objectives and the funding allocations of the organization to determine the relative balance and impact of the diverse objectives on their core activity of funding research.

4. Methodology, Model & Data

This section explains the logic for assessing the operational fit between Genome Canada's investment program between 2001 and 2012 and the organizational mandate. The hypothesis is that there should be a positive and significant fit between the objectives and the direction of the funding allocations. The goal is to undertake a strategic analysis of the GC funding allocation process. The logic of this process is laid out in Figure 2.

The funding agreement between the Government of Canada and GC lays out the organization's objectives. Those objectives are taken as high level criteria by which GC will allocate the funds provided by the government, whose overall science and technology policy direction is the production of scientific knowledge and the advancement and commercialization of technical knowledge.

From 2000 to 2012, the overarching goals of GC were: (1) developing and implementing a coordinated strategy; (2) bringing together industry, governments, universities, research hospitals and the public to support large-scale genomics and proteomics research projects; (3) providing accessibility to Science & Technology Platforms to researchers; (4) assisting in attracting co-funding for projects from both domestic and international investors; and (5) sustaining leadership.

These goals then translate into five core objectives that should be reflected in the funding allocation decisions:

- Objective 1 is to develop and implement a coordinated genomics research strategy. In practical terms, this translated into a series of internal processes to assess and identify coordinated strategies for genomics research to enable Canada to become a world leader in areas such as health, agriculture, environment, forestry, fisheries, technology and GE^3LS.
- Objective 2 is about providing leading-edge technology, in particular to researchers in all genomics-related fields.
- Objective 3 is to support large-scale research. Given the nature of the publicly-available GC database, which does not include the projects that were rejected, it is not possible for this study to show the effect of scale. One way to consider scale is to compare GC funding allocations with allocations on genomics-related research by the Canadian Institutes for Health Research (CIHR) and the Natural Science and Engineering Research Council (NSERC). The average size of GC allocations are about 10 times the size of the average CIHR grant and about 65 times larger than comparable awards by NSERC (Zhang 2014).

- Objective 4 is to assume GE^3LS leadership and to communicate more effectively with Canadians. This can be assessed by the role and position of GE^3LS in the structure of each competition and in the related projects.
- Objective 5 is to encourage investment by others. In practice, this can be measured by determining whether the projects leverage co-funding from non-governmental sources, including international sources (Genome Canada 2012).

The purpose of our study is to explore the influence of key factors in the selection and allocation of funds to projects. While the ultimate concern is the efficacy and accountability of the choice systems used by GC, the key processes are not directly measureable—they are effectively in a black box. Nevertheless, they are indirectly discernible through examining the information available at the time of decision-making and the resulting allocations of funds.

An econometric approach was used to fit proxies for the stated objectives to the share of the portfolio allocated to each project. A series of regressions is used to determine the proportion of the funding allocations that are explained by the objectives. The residual could be interpreted as the influence of soft factors, like the personal preference of the reviewers and GC staff, the cognitive bias of the various decision makers, the context of the specific science platform and the uncertain environment.

The basic equations in the model involve running regressions with the allocation decisions as the dependent variable and the key organizational and program objectives as the independent variables. The basic estimation equation is:

$$Y = a + b_1 * GE^3LS + b_2 * \textit{Technology} + b_3 * \textit{International co-funding} + b_4 * \textit{PI reputation} + b_5 * \textit{Institution research intensity} + b_x * \textit{Competition, section and regional dummies}$$

Two dependent variables have been tested, that is Y_1 (*GC-total*) and Y_2 (*open-comp*). The regression using the total pool of investments provides insights into the performance of the organization across the entire portfolio of investments (Table 2). This portfolio is chosen through two discrete systems. The main portion of the funding is allocated through open competitions, where investigator-led teams submit competitive proposals that are adjudicated through a competitive peer-review process. The rest of the portfolio involves directed projects, where GC, one of the regional centres or a partner has developed a project to fit a specific strategic or tactical need. These projects are internationally peer-reviewed but there is little in the way of competition in the process. The second regression tests to see how the choices in the open competitions conform to the objectives of GC. Any difference in fit between the open competitive process and the overall pool would provide some information about the efficacy of the process of developing directed projects.

The percentage share of each project in the total fund pool is a way to measure the allocation of funding. Each project will share Yr% of the funding pool in both the total and open competitions. The dependent variable Y_1 (*GC-total*) is the percentage share of GC contribution of each project in the total fund pool of all GC contributions. This pool involves 156 projects which shared $683 million invested by GC. It is calculated as the GC contribution dollar of each project (Ai) as a percent of the entire portfolio. While GC has invested $996 million, about one-third of the commitments and disbursals is for infrastructure and operations and not to fund

research projects. The dependent variable Y_2 (*open-comp*) is the percentage share of the GC contribution of each project in the open pool of GC contributions in Competitions I, II, III and ABC. From the calculation, we know that the total open pool $\sum_{i=1}^{m}$ Ai (i~[1,95], m=95) equals $485 million. Ai is the GC contribution of each project.

Table 2: Explanations of dependent variables

GC-goals Objective	Variable	Unit	Description	Calculation	Source
Allocation of Fund	Y_1 (*GC-total*)	%	% share of GC contribution of each project in the total fund pool of all GC contribution	Ai/ $\sum_{i=1}^{n}$ Ai (%) (i~[1,156], n=156)	Genome Canada Reports[1]
	Y_2 (*open-comp*)	%	% share of GC contribution of each project in the open pool of GC contributions in I, II, III and ABC competitions.	Ai/ $\sum_{i=1}^{m}$ Ai(%) (i~[1,95], m=95)	

Table 3 shows the variables to represent the key objectives, where:

- PI and Research Intensity as a measure of Leadership: The coordinated genomics research strategy is designed to support leadership, which for this analysis is represented by the Principal Investigator's (PI) research capability measured by the Harzing Index (HI) (X1). The HI index (X1) was proposed by Hirsch (2005) and aims to measure the cumulative impact of a researcher's output by looking at the amount of citations among the most highly cited parts of his/her work. The calculation tool Publish or Perish calculates and displays the h index, its associated proportionality constant a (from Nc,tot = ah2), and the rate parameter m (from h ~ mn, where n is the number of years since the first publication).
- Given that one of GC's objectives is to generate globally competitive research capacity, it is be appropriate to assess whether prior institutional capacity is influential in determining the allocation of funds. The relative research intensiveness of the host institutions, as measured through the *Maclean's* institution research reports (X2) is one way to rank the host institution research capability. The annual *Maclean's*[134] rankings assess Canadian universities on a range of performance indicators in six areas. We chose the Total Research Dollars reported in *Maclean's* (including income from sponsored research such as grants and contracts, federal, provincial and foreign government funding, and funding from non-governmental organizations) adjusted for the relative size of each institution (using a capitation formula based on full-time faculty). The research capability of the host institution was rebased to 10,000 dollars per full-time faculty member. The range of this variable is 0.43 to 3.51, with a mean of 2.51.
- GC seeks to generate leadership in GE^{3}LS and other issues related to genomics research and the communication of the relative risk, rewards and successes of genomics to the Canadian public (X_4). Projects can either embody integrated research (INTERGE^{3}LS) or can be stand-alone GE^{3}LS projects. This is a dummy variable with a value of 1 if GE^{3}LS

[134] http://tools.macleans.ca/ranking2008/selectindicators.aspx

is embodied in some way in the project and 0 otherwise. Of the 156 projects, 11 are stand-alone GE^{3}LS projects and 50 are INTERGE^{3}LS.

- GC established ambitious co-funding goals for their projects (Objective 5). The minimum threshold was 100% matching, in cash or in kind. All approved projects by definition met that goal. Over the past decade, GC has attracted $1 billion in co-funding to complement the $980 million committed by the Government of Canada (Genome Canada 2012). There is little difference in leveraging among projects except whether they have attracted international co-funding, which is signalled by a dummy with 1=yes.
- The variable Technology (X_5) aligns with the goal of providing leading-edge technology. We coded this variable based on GC's annual report, which determines whether the project is in the "technology category" (value of 1) or not (value of 0).

Table 3: Explanations of independent variables

GC-goals Objective	Subject	Unit	Description	Calculation	Source
(a) Sustain leadership and coordinated strategy	X_1 PI (lead Harzing index)	Index	Principal Investigator (PI) research capability: measured by HI index (collected 2012.7)	Lead Harzing Index-HI Index	www.harzing.com
	X_2 Research intensity	$10K	Host institution research capability measured by total research funds/ per full-time faculty	Total Research Dollars ($10,000 per full-time faculty member)	*Maclean's* University Ranking
(b) Support GE3LS	X_3 GE3LS		Whether the project supports GE3LS	Yes=1; No=0	Genome Canada Reports [1]
(c) Encourage P3s	X_4 International co-funding		International co-funding source	Yes=1; No=0	
(d) Provide leading-edge technology	X_5 Technology		Does technology activity represent leading-edge?	Yes=1; No=0	

A range of regional, sectoral and competition dummies were used to help to differentiate the different aspects of the economy and the subject areas. Given that there were four competitions as well as directed investments, seven priority research areas and six geographic regions, it is possible that these contextual elements may have been a determining factor in the funding allocations. Table 4 shows how those factors have been converted into dummies. The only significant change was to combine Genome Alberta and Genome Prairie, on the basis that their activities were highly correlated. Genome Prairie, located in Edmonton, served the three Prairie Provinces until 2005, when Genome Alberta became an independent centre and Genome Prairie moved operations to Saskatoon. Since then they have collaborated closely on

development and management of a range of successful projects, making it problematic to include them as fully independent contextual variables.

The sum of dummies for each category above is equal to one, as all variables cover all the possibilities in each category. For example, a project by definition must be in one of the regions (British Columbia, the Prairies, Ontario, Quebec and the Atlantic), sectors (health, agriculture, environment, forestry, tech, GE3LS) and Competition category (com1, com2, com3, ABC, Directed). To avoid over definition of the regression, at least one variable from each category is excluded in each regression. Zhang (2014) constructed a correlation matrix of all the behavioural variables and dummies and constructed t-tests to look for evidence of correlation. The regional dummies for BC and Ontario were negatively correlated, which was controlled for by leaving the Ontario dummy out of the regression. The fishery dummy was also significantly positively correlated with the Atlantic region; fisheries were combined with the environment to remove that concern. These two fixes solved all the significant correlations.

Table 4: Description of dummies

Part	Variable = 1	Description	#	mean	% of fund
Sector	Health		82	0.52	62.26%
	Agriculture		16	0.096	8.55%
	Environment	Environment, energy, fishery	19	0.09	15.53%
	Forestry		11	0.071	6.21%
	Technology	Providing leading-edge technology	18	0.115	4.14%
	GE3LS	Ethical, environmental, economic, legal and social (GE3LS) aspects	11	0.071	3.32%
Region	BC		40	0.256	22.64%
	Prairie	Alberta, Saskatchewan & Manitoba	21	0.134	15.61%
	ON	Ontario	52	0.339	37.06%
	Quebec		34	0.218	21.15%
	Atlantic		8	0.051	3.59%
Compet -ition	com1	Competition I	17	0.109	11.82%
	com2	Competition II	33	0.212	21.43%
	com3	Competition III	33	0.212	29..99%
	ABC	Applied genomics research in Bio-products or Crops(ABC)	12	0.077	7.77%
	Directed competitions	Other categories	61	0.391	28.99%
Total			156		

Once the dataset was constructed, STATA (version IC/11.1) statistical package was used to estimate regressions. The OLS method is chosen to estimate the model for two reasons. First, the lack of any obvious correlations between the independent variables suggests that the variables may be independently considered in the decision system. Furthermore, there was no obvious direction or effort to differentially assess and apply the independent variables in the decision system—i.e. GC does not direct specific weights be used nor does it provide any

architectural design to the consideration of these variables. All variables are considered equally in the decision system, with weights being revealed through choice rather than assigned a priori. Thus, in absence of any other evidence to the contrary, the OLS was chosen as the most appropriate method of calculating the influence of these variables on the overall decisions.

5. Empirical Analysis

This section presents and discusses the multivariate model results. The goal of the model is to quantify the relationship between the goals and funding allocations of GC. Table 5 presents the results of estimating OLS with Y_1 (*GC-total*) as the dependent variable. Four separate regressions are presented; models B-D add additional dummies to test for structural explanations for the allocations.

Table 5: OLS estimation result for Y_1 (*GC-total*)				
Dependent Variable Y_1 (GC-total)				
Independent Variable	**Model A**	**Model B**	**Model C**	**Model D**
Intercept	0.21	0.16	0.18	0.32**
Leadership indicators (PI-HI)	0.01***	0.01***	0.01***	0.02***
Research intensiveness (Maclean's rank)	0.06	0.03	0.02	0.007
Partnerships (International co-funding)	0.23***	0.2**	0.2**	0.21***
Integ-GE3LS	0.26***	0.25***	0.26***	0.19**
Dummy: Health sector		0.3***	0.3***	0.26***
Dummy: Ontario			0.05	0.07
Dummy: directed competition				-0.41***
Number of observations	155	155	155	155
F Statistics	7.75	9.97	8.33	12.80
Adjusted R^2	0.15	0.23	0.22	0.35
Significance levels (*p* value): * p<0.1; ** p<0.05; *** p<0.01				

Model D in Table 5 has the highest R^2. The basic equation of this model is as follows:

$$Y_1 = \underset{(2.40)**}{0.32} + \underset{(4.69)***}{0.02*(PI)} + \underset{(0.14)}{0.007*(Research)} + \underset{(2.77)***}{0.21*(International)}$$

$$+ \underset{(2.51)**}{0.19*(INTERGE^3LS)} + \underset{(3.79)***}{0.26*(Sector\text{-}health)} + \underset{(0.92)}{0.07*(Region\text{-}ON)} - \underset{(5.46)***}{0.41*(Directed)}$$

The intercept term is equal to 0.32, which means the funding share of a project in the total fund pool of competitions when the value of all other independent variables are equal to zero would be 0.32% (significant at 95% level). The reputation of a project's Principal Investigator (PI), measured by the HI index, increases the project share by just 0.02% for each unit increase index in HI (significant at 99.9% level). The host institution also has little effect. The project's host institution index is measured by the total research dollars per full time faculty member. The share of GC contributions to each project will increase 0.007% for each additional

index point (not significant). Projects with international co-funding receive approximately 0.21% (99% confidence level) higher funding than a project which has matching funds only from domestic sources, other things being equal. A project with an INTERGE^{3}LS is expected to have approximately 0.19% (95% confidence level) more funds than a project without a GE^{3}LS component. Moving on to the coefficient for the sector, a health project is expected to have approximately 0.26% (99.9% confidence level) more funding than a project in other sectors. For the region dummy, a project in Ontario is expected to receive 0.07% (not significant) more funding than projects not in Ontario, In short, there is no evidence of regional bias. A project not from Competitions I, II, II and ABC (i.e. directed funding) is expected to receive approximately 0.41% (99.9% confidence level) less funding than an open-competition project.

When only the open competitions were tested (Y_2 dependent variable) the competition dummy is not suitable to test in this section and was dropped. Table 6 shows the results of this regression.

Table 6: OLS estimation result for Y_2 (open-comp)			
Dependent Variable Y_2 (open-comp)			
Independent Variable	**Model A**	**Model B**	**Model C**
Intercept	0.57**	0.52**	0.65***
Leadership indicators (PI-HI)	0.02*	0.02	0.02*
Research intensity of host institution (Maclean's rank)	0.07	-0.00	-0.09
Partnership (International co-funding)	0.27*	0.21	0.20
INTERGE^{3}LS	0.26*	0.29**	0.28**
Dummy: Health		0.47***	0.48***
Dummy: Ontario			0.30*
Number of observation	94	94	94
F Statistics	3.27	5.65	5.47
Adjusted R^2	0.15	0.20	0.22
Significance levels (p value): * p<0.1; ** p<0.05; *** p<0.01			

Model C in table 6 delivered the highest R^2. The basic equation of this model is as follows:

$$Y = \underset{(2.74)***}{0.65} + \underset{(1.77)*}{0.02*(PI)} - \underset{(0.97)}{0.09*(Research)} + \underset{(1.44)}{0.2*(International)}$$

$$+ \underset{(2.10)**}{0.28*(INTERGE^3LS)} + \underset{(3.81)***}{0.48*(Sector\text{-}health)} + \underset{(1.92)*}{0.3*(Region\text{-}ON)}$$

The intercept term is equal to 0.65, which means the funding share of a project in the open pool of competitions (I, II, III, ABC) when the value of all other independent variables are equal to zero would be 0.65% (significant at 99% level). Leadership continues to matter. The impact of a project's Principal Investigator (PI) translates to 0.02% more of the funding share of a project (90% confidence level) for each unit increase index in HI. International co-funding improves a project's budget share by 0.2% (not statistically significant) more than a project which is only supported from domestic sources. The host institution has little effect. On average,

the GC contribution to each project in the open competitions increases by 0.09% for each additional institutional index point (not significant). An INTERGE^{3}LS project is expected to receive 0.28% (95% confidence level) more funding than a project with no GE^{3}LS component. A health project is expected to have approximately 0.48% (99.9% confidence level) more funding than a project in other sectors. On average, each Genome Ontario project is expected to have a 0.3% (90% confidence level) higher share of GC funding in the open competitions than a project from the other regions. This result, compared to that for the total of GC-funded projects, suggests that the peer reviewers appear to be more influenced by the location of the project than GC staff. Model C contains the regional dummies and the sector dummies. The adj-R^2 reaches a peak at 22%; more specified models with other contextual variables were tested but they offer little additional explanatory power (based on the static adjusted R^2).

Overall, this model suggests the processes in Competitions I, II, III and ABC delivered a weaker fit with the strategic of objectives of GC than the processes used by GC staff to develop the directed projects. This may be an artifact of the lessons learned from the earlier open competitions that were applied to the directed investments. However, there is some possibility that there may have been cognitive biases operating in the open competitions, as the dummy for the Ontario region is positive and significant at 90% level, which should not be observed in a competition where research excellence is the goal rather than allocations based on past capacity.

6. Conclusion and Policy Implications

This study has added to the policy evaluation literature, offering specific insights into an evaluation of Genome Canada. The analysis revealed that the overall fit for the entire investment program between 2001 and 2011 was about 34%, which is quite strong. We found the most important variables affecting resource allocation were the sector, presence of international partners, integrated GE3LS and the quality of the principal investigator. Other stated objectives of GC were either less important or insignificant. By segmenting the analysis into the open competition investments alone, we discovered the fit deteriorated (R^2 dropped from 34% to 22%), which suggests the directed investments are a stronger fit with the organizational goals. While the cause could not be conclusively determined, it might be attributed to (1) weaknesses in the peer-review processes involving a large number of competitive projects, (2) greater competence in adjudication as the directed investments mostly followed the four open competitions, or (3) effective and strategic effort by GC staff. Further analysis would be needed to determine this.

The results of our study show that about up to 35% of the variance in funding by project can be explained by the specific objectives of GC. The fit for the open competitions was not as strong as for the entire portfolio. By inference, this means that the allocations directed by GC staff (i.e. not engaged in open competition) were generally more strategic (this study cannot confirm that their outputs and outcomes were any different—that would be a different type of analysis). This may be surprising to many, as there is a general view that bureaucrats are more susceptible to political interference than arms-length openly competitive processes. One of two factors could be contributing to this divergence. It is possible that the competitive process triggers cognitive gaps and biases among the peer-reviewers. There is some theory and evidence that peer review systems that are directed to assess multiple projects over a diverse set of variables will revert to system 1 decision-making, in other words fast and intuitive thinking that would lead to anchoring on a few operative factors and satisficing activity (Kahneman 2002;

Simon 1956). Whether that theory applies here would have to be examined experimentally. The importance of sector and region for peer reviewers is significant. It may be that the staff of GC and the regional genome centres are susceptible to incentives as many might hypothesize, but that their incentives drive them to proactively backfill and compensate for any gaps in the open competition results. It would be necessary to look at the incentive and operational mandates of the GC staff to determine what drives these behaviors.

This study was limited to using publicly available data. Access to internal GC data—including the detailed proposals for the projects—would enable the model to be calibrated more precisely and would determine if there are any learning by doing effects as the organization has matured. We also lacked counterfactuals. The share of allocations was used as an in-sample differentiator. In a perfect world there would be full access to the structure and details of those proposals that failed to advance from LOI to full proposal and were not funded. That would provide an all-in analysis of the efficacy and fit of the GC decision system relative to its stated goals.

This study raises two interesting possibilities for further work. With access to more detailed data on both successful and unsuccessful projects, it should be possible to more effectively refine the model and isolate the effect of key variables in decision-making. This then could be used to assess the effect of framing and choice architecture in research decision-making. As noted above, this analysis tends to provide empirical evidence in support of the possibility that peer-evaluation systems are cognitively limited in the context of open competitions. Experimental work specifically related to the choices facing the peer-reviewers in GC could help more effectively develop appropriate choice architecture.

References

Arvidsson, G. 1986. 'Performance Evaluation'. In Guidance Control and Evaluation in the Public Sector (Berlin: Walter de Gruyter), 625–43.

Birckmayer, J. and C. Weiss. 2000. Theory-Based Evaluation in Practice: What Do We Learn?, Evaluation Review 24:4,.407-431.

Department of Finance. 2003. Budget Plan 2003. Ottawa. http://www.fin.gc.ca/budget03/bp/bpc1-eng.asp.

Genome Canada. 2009. Guidelines and Evaluation Criteria - Competition in Applied Genomics Research in Bio-products or Crops. Ottawa. http://www.genomecanada.ca/en/portfolio/research/applied.aspx

Genome Canada. 2010, Guidelines and Evaluation Criteria for Competition III. Ottawa. http://www.genomecanada.ca/data/Nouvelles/Fichiers%5Cen%5C320_1_FinalGuidelinesandEvaluationCriteria_en.pdf

Genome Canada. 2012. Genome Canada Annual Reports 2011-2012. Ottawa. http://www.genomecanada.ca/medias/PDF/EN/2011-2012AnnualReport.pdf

Genome Canada. 2012. Genome Canada Corporate plan 2011-2012. Ottawa. http://www.genomecanada.ca/medias/PDF/EN/CorporatePlan2011-12-english.pdf

Genome Canada. 2013. Performance, Audit and Evaluation Strategy 2012-2017, Ottawa.

Genome Canada. 2001. Guidelines and Evaluation Criteria for Competition II, Ottawa. http://www.genomecanada.ca/medias/PDF/EN/CompIIGuidelinesfinal.pdf

Genome Canada. 2000. Guidelines and Evaluation Criteria for Genome Centres. Ottawa. http://www.genomecanada.ca/medias/PDF/EN/GUIDE18-final.pdf
Genome Canada. 2008, Genome Canada Corporate plan 2007-2008. Ottawa.
Genome Canada. 2007. Performance, Audit and Evaluation Strategy. Ottawa. http://www.genomecanada.ca/medias/PDF/EN/PerformanceAuditandEvaluationStrategy.pdf
Geva-May, Iris and L. Pal, 1999, Good Fences Make Good Neighbors: Policy Evaluation and Policy Analysis - Exploring the Differences. *Evaluation*, 5 (3), 259-277
Hirsch, J. 2005. An index to quantify an individual's scientific research output. *Physics and Society* (physics.soc-ph).
Kahneman, D. 2002. "Maps of bounded rationality: A perspective on intuitive judgment and choice." Nobel Prize Lecture vol. 8.
King, J. 1987. A review of bibliometric and other science indicators and their role in research evaluation, *Journal of Information Science*, 13, 261-271.
KPMG. 2007. Evaluation of Foundations, Prepared for Treasury Board Secretariat, Ottawa. http://www.genomecanada.ca/medias/PDF/EN/Foundations Eval - Final - Mar 14-071.pdf
KPMG. 2009. Evaluation of Genome Canada –Final Report. http://www.genomecanada.ca/medias/PDF/EN/Five-year_Evaluation.pdf..
Luukkonen, T. 2000. Research evaluation in Europe: State of the art. Research Evaluation (2002) 11 (2): 81-84.
Patton, Michael. 2002. Utilization-focused Evaluation. Evaluation Models, 49: 425-438.
Rossi, P., Freeman, H., and Lipsey, M. 2004. Evaluation: A Systematic Approach (7th edition), Sage Pubs. ISBN: 0761908943
Phillips, P. and Eric Warren. 2010. Managing Large-Scale Science Projects: The Genome Canada Experience. VALGEN Working Paper, www.VALGEN.ca.
Ruegg, R. and Jordan, G., 2007, Overview of Evaluation Methods for R&D Programs, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington: DOE. http://www1.eere.energy.gov/analysis/pdfs/evaluation_methods_r_and_d.pdf
Simon, Herbert A. 1956. "Rational Choice and the Structure of the Environment" (PDF). Psychological Review. 63 (2): 129–138.
Treasury Board of Canada Secretariat. 2014. Policy on Evaluation. http://www.tbs-sct.gc.ca/pol/doc-eng.aspx?section=text&id=15024#appA.
Zhang, L. 2014. Policy Evaluation: A case study of Genome Canada Programming, 2000-11. Unpublished MPP Thesis, University of Saskatchewan. https://harvest.usask.ca/handle/10388/ETD-2014-01-1438.

Chapter 3

Exploring trade-offs in grant design

An Application of Agent-Based Modeling to Research Design

Ebrahim Hassanpour and Peter W.B. Phillips

Abstract

Agent-based modeling has been used in various context, including investigation of a variety of aspects of innovation policy. A simulation model is developed here to assess the impact of some design choices on the outputs of large-scale investment in R&D. To compare the outcomes for policy choices, we use a Gini index approach to develop a range of new measures of efficiency and equity to compare and evaluate the impact of different strategies. Based on the real academic investigation process, a general ABM model is designed and calibrated to simulate Genome Canada's granting process and is run with different parameter values. GC has shown a willingness to change various parameters to get different results for efficiency and equity. We demonstrate that such a model can be used to analyze the system output in response to policy changes and investigate new approaches to research design and management.

Key Words: evaluation; research granting; agent based modelling; efficiency; equity

1. Introduction

As a key element in the pursuit of economic prosperity and superiority, science and technology (S&T) policy covers the public-sector measures designed for the creation, funding, support, and mobilization of scientific and technological resources (Arvanitis, 2003). A typical S&T policy includes public activities such as direct investment in R&D, direct and indirect involvement in business R&D, and other innovation-promoting measures. These activities should be evaluated and monitored for their effectiveness and efficiency. Various methods and techniques have been developed and applied for such an impact assessment; one such technique is simulation.

Developed in the 1950s (Urban et al., 2011), Agent-Based Modeling (ABM)[135] is one of the simulation methods applicable for policy studies. The real-world situation is modeled as an environment in which agents live and interact with each other and with the environment. Policy tools can be considered as features of the environment which affect the behaviour of the agents and ultimately the performance of the whole system. The extensive use of ABM in the social sciences started in the 1990s, and towards the end of the decade, it found its way into the natural sciences.

[135] It is also called Individual-Based Modeling (IBM) in fields such as ecology (see e.g. Grimm and Railsback, 2005; Railsback and Grimm, 2012) and Multi-Agent Modeling by some authors (see e.g. Gilbert and Troitzsch, 2005).

Following a definition and classification of simulation models, Gilbert (1997) simulated Lotka's law, which states that for scientists publishing in journals, the number of authors is inversely proportional to the square of the number of papers published by them; a distribution called Zipf applies for this phenomenon. Considering science as an evolutionary process, Gilbert used 'papers' and 'authors' to characterize the institution of science in which each paper brings a new quantum of knowledge. In order to represent a quantum of knowledge, he used a sequence of bits, and he called these sequences 'kenes'—drawing an analogy with genes. A kene is therefore the knowledge contained in a paper, and that kene can represent the relevant paper. "Papers are generated from other papers, sharing a kene with their generator, but modified according to the kenes of the papers which it cites" (Gilbert, 1997, paragraph 8.2). Assuming two coordinates for the kenes and putting time as the third dimension, the model was run for 1,000 time-steps, with the results showing that papers cluster in certain locations. Lotka's law regarding the distribution of citations among authors was reproduced, and many of the features of the structure of academic science were generated using the simulation.

The notion of the 'kene' was used in some later studies, and in the European Self-Organizing Innovation Networks (SEIN) project for which the SKIN model was developed (Gilbert et al., 2001; Ahrweiler et al., 2004; Gilbert et al., 2007; Pyka et al., 2007; Ahrweiler et al., 2011a; Ahrweiler et al., 2011b; Triulzi and Pyka, 2011). Outside this context, Teitelbaum and Dowlatabadi (2000) used the ABM simulation approach to study the innovative behaviour of heterogeneous firms and their interactions.

A review of ABM application in the field of innovation policy shows that the literature, which originated in the late 1990s, has mainly concentrated on the European SEIN project and focused on specific industries. Most of these applications are limited to that specific notion of science process put forward by Gilbert. However, the academic investigation may be defined and analyzed in other ways, one of which will be developed and applied here for a Canadian research policy.

It is first essential to briefly review Canadian innovation policy. The growing importance of genomics led the federal government to create the five-year Canadian Genome Analysis and Technology (CGAT) program in the 1990s, which was replaced by Genome Canada (GC) in 2000 (Genome Canada, 2010). As a non-profit organization, GC connects ideas and people across public and private sectors to find new uses for genomics, invests in large-scale science and technology to fuel innovation, and translates discoveries into solutions (Genome Canada, 2016). GC delivers its mandate through six Genome Centres in British Columbia, Alberta, the Prairies, Ontario, Quebec, and the Atlantic region. These centres administer funding to research projects and are responsible for identifying regional strengths and opportunities, monitoring compliance and performance, and helping to secure co-funding from partners.

The principal focus of Genome Canada is large-scale research carried out by teams of researchers bidding on multi-year, interdisciplinary research contracts (Doern et al., 2016). For this, Genome Canada has periodically conducted competitions to fund genomics-related R&D projects. Since the start of the program, it has administered seven major competitive research competitions and almost 20 smaller-scale, more-focused research initiatives. While the first three major competitive calls were open to any applicant, the last four have been targeted toward specific domains.

Any competition usually starts with an announcement (the call for proposals), and then letters of intent (LOI) are received from scholars. When initial approval is granted, the leading or principal investigators start forming teams and writing proposals to secure grants. The proposals

undergo an evaluation process, and upon approval, the size and method of funding is decided by GC. The funds are allocated and the investigations are carried out in their respective universities or other research centres. Upon the accomplishment of a project, its outcomes include papers published or presented, inventions or innovations patented or not, and training of human capital in the form of students or researchers.

With the objective of improving genomics in Canada, GC must make choices about certain parameters when granting funding. The size of the fund for every round, the size and diversity of the project team members, the target population, and the maximum grant for any single project are among the policy variables of GC. In order to make informed decisions about these variables, some knowledge about their impacts on the outcome is necessary. The objective of this paper is to develop a simulation model to assess the impact of such parameters on the outcome of the program. To compare the outcomes for policy choices, indexes or measures of the outcomes are needed for both efficiency and equity. Policy options will be compared according to outcome measures, making it possible to draw conclusions for GC regarding policy implications.

2. Model

Based on the real academic investigation process, a general model is designed and calibrated for Genome Canada's granting process. This is the basic version of the model, excluding some of the real-world features of the situations and processes. Since the main objective is the applicability of ABM, a combination of real and assumptive parameters is fed into the model and simulation. The reason for this is that the exact value of some parameters does not matter at all, or is of little importance.

2.1 Design

Academic research is partly conducted as a learning process for graduate students and does not always depend on external funding. In such cases, the laboratory resources of academic departments along with the intellectual capital of professors and students may result in publications (usually journal papers) or in innovations or inventions (whether patented or not). The learning and expertise acquired by the investigators is a side product. In these cases, external funding acts as a catalyst to speed up the process; it can also implement some large research projects which, in the absence of funding, would not be accomplished. In short, academic research is a production process that begins with human and financial input and ends with the output of papers and patents. The practice of learning-by-doing promotes the quality of the human resources involved. On the input side, researchers and their associates compose the human capital which employs physical capital (equipment, machinery, tools, field/office) and materials (anything consumed in the process, such as chemicals, paper, energy, etc.). The research process itself involves various stages (literature review, method development/prototype design, experiment and data collection, analysis, and report writing/documentation) that, depending on the nature of the R&D, may need a time span of weeks to years in order to be accomplished. The findings of the research are reflected in publications (papers, books, or reports) or realized in inventions; as mentioned, the learning achieved during the process also adds to human capital. Grants, and funding in general, are used to provide input by compensating

for human resources, for buying or renting tools, equipment, and offices, and finally, for providing necessary materials.

Our ABM model consists of certain agents and processes with certain parameters attributed to them. The principal agent in the model is the investigator (researcher) carrying out academic investigation. One of the assumptions of this model is that the investigations are done individually, and no collaboration is taken into account. There are two dependent sub-agents for the investigator: Investigation and Grant. The investigator is always busy with at least one line of investigation that results in academic papers as the output. The investigations and the resulting papers are saved for any investigator. The investigators take part in every granting competition, with some of them winning and some facing rejections. The grants won make feasible more and new investigations that result in more output for the winners. The paper output of the investigators is taken into consideration by the granting agency when it assesses grant proposals in the next rounds.

Various sources and kinds of grants are available for researchers, but they are all obtained through a process. Finding an idea, and gathering some information about it, is the first step. Then comes the writing of an application, which is normally submitted in the form of a proposal. The proposal is reviewed by the funding agency and, if accepted, the grant money is given to the applicant. Grants make it possible to start new investigations, resulting in more output. The agents compete for grants provided by the granting agency in different periods or rounds. In the first round, success is quite random, and provides winners the opportunity to publish more papers: the paper output (and score) is used in subsequent rounds as a criterion to assess grants, which improves the chance for the winners to receive grants in the future. As a result, in spite of the homogeneity of agents in the beginning, some inequality and distinction emerge in the process. As noted above, the agents are assumed to be researching by themselves with no interaction among them. Papers are assumed to be of different qualities, giving rise to some heterogeneity among those having the same number of papers. A random score is considered to account for the quality and pertinence of papers in future competitions.

Some processes are modeled as Statecharts, which make it possible for agents (more accurately, sub-agents) to pass through different states. The Investigation agents are born and go through accomplishment resulting in papers. The Grant agents start with proposals that, if they are approved, are consumed for investigations. The variable values are stored and updated in corresponding variables, dynamic parameters, or charts. Events occur during the simulation period, and the values of attribute and performance variables are recorded in order to be available at the end of the simulation. Based on these values, the performance of the whole system is analyzed and compared for various policy or assumption changes. The overall performance is measured by certain indicators which are described below.

2.2 Output Measures

As for any policy, every granting agency may consider two impacts of their efforts. The first aspect is efficiency associated with the cost-effectiveness of the system. The second aspect is equity concerning the distribution of grant money and papers among investigators. Distribution is important because the public does not want resources dispersed among only a few people; this may also have implications for efficiency. The outcome of the simulation is summarized by measures that address these two aspects and that are used in model verification and scenario comparisons.

The efficiency of the system (or in other words, the productivity of the grants) is measured by papers per grant money, which is simply the whole number of papers divided by the total grant money. It is stated as papers per million dollars (PMD). Equity aspects are measured by two kinds of indices borrowed from social sciences. The first is the Gini index, developed originally in the field of economics, where it is used to measure the distribution of income and wealth. The second measure is the "Matthew effect," theorized in sociology to explain a situation where some academic figures achieve an unfair advantage as a result of some initial fame or chance, resulting in a growing gap among faculty members (or scientists) in the same discipline or field.

Gini index. In economics (and in other fields as well), a Gini coefficient (or index) is used to measure the magnitude of a program's equality (or inequality). This index is based on the Lorenz curve, which shows the percentage of income (or any resource) gained by any percentage of the population. (For details on the curve and the index, see e.g. Sen, 1973.) The population (in our case, the investigators) are ordered by income (here, by grant money or number of papers) ascendingly on the horizontal axis in percent, while the income (here, paper or money) percentage is shown on the vertical axis. The Gini index is theoretically the ratio of the area between the equality line and Lorenz curve and the whole area of the triangle below the equality line. In practice, the population is divided into equal groups (for example, 10 groups or deciles) and their cumulative income percentage is calculated. When placed in a graph, these points give an approximation of the Lorenz curve. To estimate the Gini index, the following formula has been developed, based on the original version proposed by Dixon et al. (1987):

$$G = \frac{2\sum_{i=1}^{n} i x_i}{\sum_{i=1}^{n} x_i} - \frac{n+1}{n}$$

where n is the number of population groups indexed by i, and x_i is the income share of the i^{th} group. In this study, the population will be divided into 10 equal groups (deciles), with their paper or grant money share represented by x_i. This index is computed both for papers as the paper Gini index (PGI) and for grant money as the grant Gini index (GGI).

Matthew effect. Based on interviews of some sociologist with Nobel laureates in the United States and on his other experiences, Robert Merton (1968) developed the idea that famous scientists often get more credit than their comparatively unknown colleagues for performing similar work. He called this phenomenon the Matthew effect, which in his opinion goes beyond mere reputation and extends to the communication system that ultimately affects the allocation of scientific resources. Later (Merton, 1988), he expanded the concept and stated that advantages as well as disadvantages accumulated as a result of the working of this concept. In the context of this study, the implication is that those investigators who initially receive some resources and gain some advantage over others will gradually and continually receive more and more of the resources, leading to an ever-widening gap among the investigators.

Although the presence of the Matthew effect can be described verbally, there are no precise tools to measure its magnitude. However, some measures can be applied to get a rough approximation of this factor. Since the investigator agents start simultaneously and are assumed to be homogeneous, any differences emerging during the simulation horizon may be attributed to

the Matthew effect. Apart from the Gini index described above, there exists the concept of a power law or scaling correlation[136] which states that in some cases, there is a scaling correlation between two variables. Generally, a power law relationship exists between y and x when $y \propto x^{\alpha}$; α is called the scaling factor. To see if there is such a relationship, logarithms of y on x can be graphed against each other to see whether or not the data lie on a line. In practice, a regression is run for *lny* and *lnx* and the statistical significance of the relationship is checked. In the case of this study, it is hypothesized that such a relationship exists for the number of papers and the number of people having those numbers of papers; the same may hold for grant amounts and number of people. Put differently, it is speculated that only a small number of investigators publish many papers (or win large sums of grant money), while there are many others with a small number of papers or grants.

2.3 Parameters and Model Validation

In this simulation, 600 homogeneous university investigators are considered to be researching in different universities across Canada. They simultaneously start their academic investigations, which take two years to be accomplished, at time zero. Any investigation then results in 1 to 5 papers published in a period of 3 to 12 months. The granting agency (GC) starts the grant competitions at the end of year 2 and then holds them every three years. Since there is no output for the investigators at the end of year 2, the grant approval for the first competition depends merely on chance, and some investigators are randomly selected to receive grants.

Table 1: Assumptions of the model and parameter values

Parameter	Value	Considerations
Number of investigator agents	600 people	Scenario analysis
Budget per competition	$50 million	Scenario analysis
Grant size	$120,000-$500,000	Scenario analysis; triangular distribution (120, 500, 240)
Competition gap	3 years	Scenario analysis
Simulation horizon	26 years	Sensitivity analysis
Investigation duration	24 months	Sensitivity analysis
Without grant annual fund	$24,000/year	Sensitivity analysis
Papers per investigation	1-5	Sensitivity analysis; uniform distribution (1, 2, 3, 4, 5)
Publication duration	3-12 months	Triangular distribution (3, 12, 6)
Paper quality score	1-4	
Investigation cost	$2,000/month	
Grant writing time	6 months	
Grant assessment time	1 month	

These grants are used to carry out investigations which yield papers (with differing qualities and scores in later competitions). Those who win grants by chance in the first competition publish more papers, which are then considered in future grant proposal assessment. If the approval of grants from the second competition onward is only based on past paper

[136] Since Alfred J. Lotka was the first to study such a phenomenon, it is called Lotka's law, defined as "the frequency distribution of the number of papers per author follows an inverse power law" (Watts and Gilbert, 2014, p. 138).

performance, then the investigators who did not receive grants through the first competition would not stand a chance to win any grants in the future; this reality justifies adding a random score besides the paper score. From this point onward, the competitions occur in the same way until year 26, with those winning grants producing more papers. In cases where investigators have no grants, they fund one investigation by other sources. Table 1 shows the parameter values assumed.

The coding for the simulation is done in the Java language in AnyLogic. There has been a lot of back-and-forth communication in the programming phase, ultimately resulting in a working program for simulation, with tests run to ensure that the model functions correctly. The granting procedure and criteria were changed a number of times, the model was run with different random seeds to check the robustness of the results against randomness, and the values of some parameters were changed to ensure that the results are consistent with the changes. The validated model was then ready for simulation, with the results being reported below.

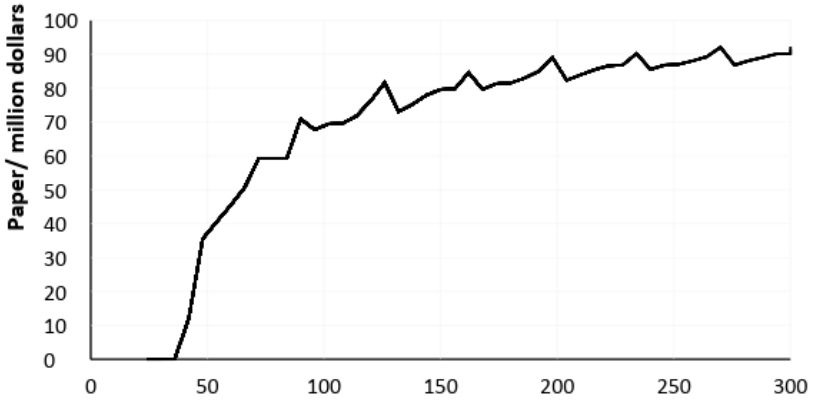
3. Results

Having tested the validity of the model and its behaviour, the simulation results are presented and discussed here, using the values of the parameters discussed in the previous section. The results of the baseline scenario are presented and discussed first, followed by the results of some alternative policy scenarios.

3.1 Baseline Scenario Results

The total paper output of the system is about 37,000, produced over the 26 years of the model simulation. At the end of the simulation horizon, a total of 12,309 investigations have been accomplished, meaning that every investigation leads to an average of almost three papers, as expected.

Figure 1: Trend of PMD

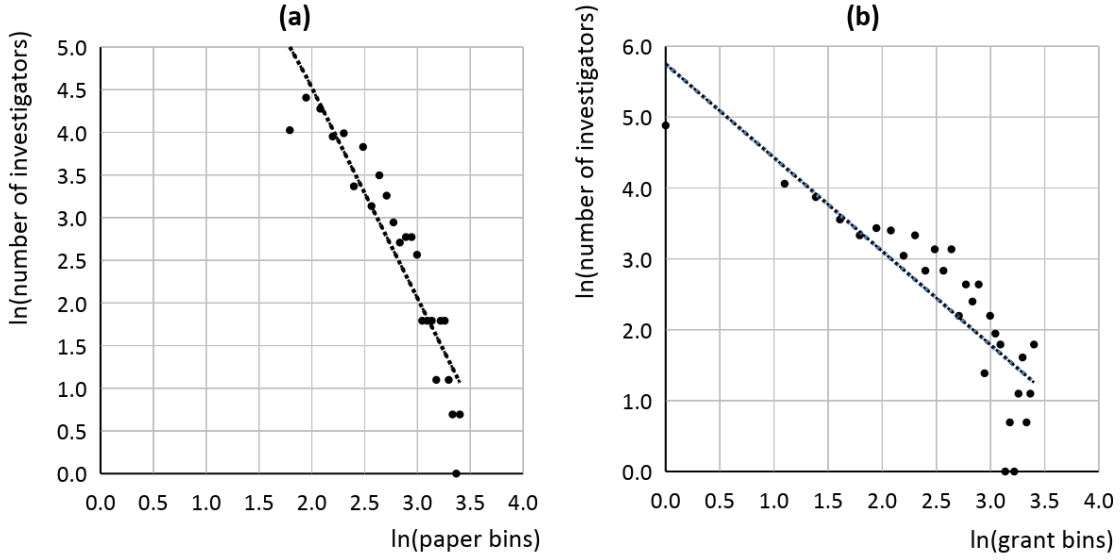


The trend of the efficiency measure (PMD) is shown in Figure 1. Because no papers are produced in the initial years, with publication starting at some point in year 3, the graph rises steeply and then flattens gradually, since the numerator (papers) and denominator (grant dollars) behave as before and the initial delay wears out. However, although the money is spent quickly at any round, the publication process is more gradual (3 to 12 months for a paper); this is the cause of the non-smoothness of the trend. At the end of the simulation horizon (month 312) the

PMD measure reaches 92.2, meaning that every million dollars of grant money results in an average of more than 90 papers. It should be remembered that some of the papers originate from investigations carried out from non-GC grant money. The Gini indices computed for papers (PGI) and grant money (GGI) are 0.346 and 0.606 respectively, meaning that paper publication is more unequal than grant money.

As another measure of equity, power relationships between both the number of papers and grant money on the one hand, and the number of investigators publishing the papers or winning the grants on the other, were used to examine the concentration of the publications among the investigators. The number of papers varied from 24 to 166 and the money granted varied from zero to $2.7 million, categorized into 30 equal bins. The bins were numbered from 1 to 30, which is considered *x*, and their contents (the number of investigators in every bin) were counted to represent *y*. Taking logarithms of these variables and presenting them in a graph resulted in Figure 2 for papers (a) and grant money (b). The dots represent real values and the dotted line is the line fitted on the data; since some of the bins were empty, the number of dots (observations) is less than 30.

Figure 2: Power law relationship for papers (a) and grant money (b)



Obviously, there is a near-linear relationship in both cases in Figure 2. However, to check the statistical significance of the relations and determine the scaling factor (α), a regression had to be run over the data; the results of this are shown in Table 2. The equations are shown in the second column along with the *t* statistics. All the parameters (constants and slope (α) parameters) are significantly different from zero, meaning that there is a significant relationship between the variables. Therefore, the power law holds in both paper and grant money cases.

Table 2: Results of the log-linear regression estimations for power law relationships

	Estimated Relationship	Statistics
Paper analysis	$\ln ln\,(y) = 9.5 - 2.47 \ln ln\,(x)$ *t* values 16.1 11.9	n=25, R^2=0.86, F=141.8
Grant analysis	$\ln ln\,(y) = 5.7 - 1.32 \ln ln\,(x)$ *t* values 14.3 8.7	n=29, R^2=0.74, F=76.5

3.2 Alternative Policy Scenarios

There are some tools that granting agencies can use to influence the outcomes of the model in the long run. However, the outcomes are measured from two perspectives (efficiency and equity) which sometimes do not behave similarly and between which there exists a trade-off. The variables that can be manipulated by a granting agency such as GC are the total sum of money allocated in any competition, the size of the individual grants, the size of the target group, and the gap between the two consequent competitions (or number of competitions). The impact of changes in these variables is explored below, followed by an analysis of their combinations. Table 3 gives a summary of the scenarios that were assessed for single-instrument changes.

Table 3: Summary of the single-instrument policy scenarios

Scenario Variable (Policy Instrument)	Unit	Values
Competition budget	$ million	50, 100, 150
Grant size (min, mode, max)	$ thousand	(120-240-500), (120-360-500) (120-240-1000), (120-480-1000)
Target group size	persons	600, 400, 200
Competition gap	years	3, 4, 5

It was assumed in the benchmark model that the granting body allocates $50 million for every competition. This would result in a PMD of 92.2, and PGI and GGI values of 0.35 and 0.61 respectively. With an increase in the amount of the budget, the efficiency drops and equity improves. However, the magnitude of changes is not the same: a 100 percent increase in the budget results in a 28 percent drop in PMD, a 33 percent decline in GGI, and an only 10 percent drop in PGI. Therefore, increasing the budget does not seem to be a good policy, due not only to the decrease in paper productivity, but also to the small improvement in equity indices.

In analyzing the variable of the budget, some consideration should be given to the administrative costs of any grant program or agency, and also to the opportunity costs of the participants. Part of the cost of handling the competition and granting process is fixed and does not change with the amount of budget allocated, implying that their average per dollar granted declines with an increase in the budget. Similar reasoning governs participant opportunity costs, in that it does not make sense to hold a competition with 600 participants if only a small percentage of applicants are approved. It can be argued that to better manage participant opportunity costs, narrowing the competition and decreasing the size of the target group might be better.

Table 4: Impact of policy parameter changes on outcome measures

Policy Tool	Parameter Values	PMD	PGI	GGI
Baseline Scenario		**92.2**	**0.35**	**0.61**
Budget Allocated for Each Competition (50)*	100	66.7	0.31	0.41
	150	57.9	0.23	0.24
Grant Size (120-240-500)*	120-360-500	93.5	0.38	0.69
	120-240-1000	97.8	0.42	0.74
	120-480-1000	99.7	0.46	0.83
Number of Investigators per Competition (600)*	400	74.6	0.35	0.51
	200	57.4	0.22	0.24
Competition Gap (3)*	4	116.9	0.34	0.65
	5	131.7	0.33	0.67

* Baseline scenario parameter values

The grant size is assumed to vary following a triangular distribution, with a minimum of 120, a maximum of 500, and a mode of 240 thousand dollars. Increasing the mode results in a very small improvement in PMD but a small worsening of equity measures; doubling the maximum results in a worsened distribution of papers and money; doubling both the maximum and the mode of the triangular distribution gives the worst outcome, with a 36 percent rise in the money Gini index. Again, there are administration and opportunity cost issues, making it difficult to decide which range of grant size is best.

One of the assumptions in the model is the openness of competition to the whole population of investigators. However, there are occasions where competitions are open only to specific disciplines or where the focus of the competition itself is on specialized fields. Such situations mean that not everybody is eligible to apply for the grants, leading to a decline in target group size. Although these calculations can be done for a specific subgroup of the population, such as those in specific fields, due to the homogeneity of the investigator agents this amounts to a smaller population size. Therefore, the outcome is expected to be similar to that of changing the budget amount—a budget decrease works in the same way as a population increase—and the results are comparable to those of budget increase discussed above.

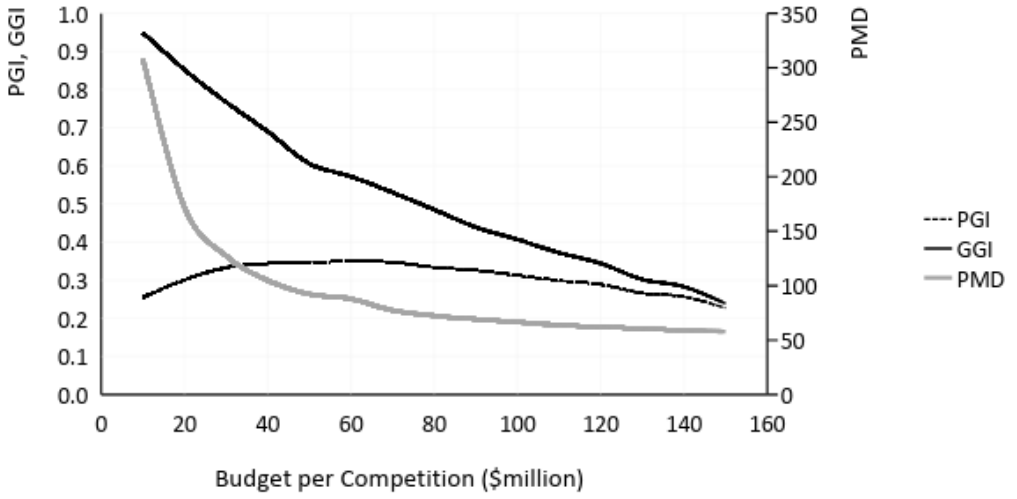
In the baseline model, competitions are held every three years, with a total of 8 competitions and a total budget of $400 million allocated. Raising the gap in time to four years would mean a total of 6 competitions (starting from year 2 and ending in year 22) with a budget of $300 million. If the gap is raised to five years, there would be 4 rounds with a budget of $200 million. Such a policy improves the efficiency, but has a small negative impact on money distribution. Provided that the same grant budget ($400 million) should be allocated, there would be $100 million for every round, resulting in values of 89.3, 0.30, and 0.43 for PMD, PGI, and GGI respectively. When compared with the results of the base scenario reported above, it is evident that with a small loss in efficiency, there would be a large gain in equity.

Because of the presence of two competing criteria for the evaluation of programs (efficiency versus equity), it is difficult to determine the optimal level of policy instruments. A change in a policy variable, such as budget allocated for each round of competition, would change both PMD and GGI in different directions, making it impossible to tell which direction of change is better. However, provided that there is some knowledge of the weight policy-makers

(hence, society) assign to each of the criteria (efficiency and equity), further guidelines can be given regarding the optimal scenario. The weights can be used to combine the two measures in order to produce a single criterion with which the optimal level of a policy tool can be approximated.

As an example, different values of grant budget starting from $10 million and increasing by $10 million to a maximum of $150 million resulted in the outcomes graphed in Figure 3. The outcome measures are graphed with equity measures on the left axis and PMD on the right. It is evident that PMD decreases with a declining slope (like a power function), meaning that its response to budget increases declines. The same kind of response is shown by GGI, but with a smaller change in its slope. The most interesting behaviour is that of PGI, which rises to $60 million and then starts to decline. Smaller budgets are not favourable due to the great inequity in grant money and, since large budgets are impossible to raise, this leaves mid-range budgets for selection. Notably, with lower budgets, a great amount of efficiency must be sacrificed to get a moderate gain in equity. Calculating the percentage changes in PMD and GGI for each increment and taking their ratio provides a measure called elasticity (of changes in PMD with respect to changes in GGI). A unit elasticity means that 10 percent change in PMD coincides with the same percentage change in GGI. According to the results, higher budgets result in smaller improvements in PMD but great gains in equity, making the elasticity very low. Nevertheless, large budgets are not feasible and small budgets are unjustifiable in terms of the administrative costs involved; a budget range in the middle is plausible. The optimal levels should be sought in such a range and if the two criteria are of the same weight, the neighbourhood of an elasticity value of one (unit elasticity) would be optimal. Nevertheless, finding the optimal levels of policy tools requires further information that lies beyond the scope of this study. On the one hand, knowledge of the administrative costs of granting is necessary, and on the other, the comparative values of outcome criteria are needed. The optimal level of any policy instrument would depend on the comparative emphasis society puts on either criterion.

Figure 3: Behaviour of outcome measures in response to increments in grant budget



The policy alternatives discussed above dealt with manipulating single instruments. In practice, policy-makers are able to choose policy combinations consisting of multiple tools.

Although many combinations might be available with various values chosen for every instrument, only a few combinations are analyzed here as examples. Suppose that the long-term budget of the granting body is $400 million, which must be allocated in grants over a period of 20 years. According to our model, granting can begin at year 2 and continue until year 22 in a number of ways, as shown in Table 5. The first row shows the baseline scenario, while the next three rows illustrate different scenarios. Increasing the competition round gap to 5 years improves the equity significantly but causes a small decrease in efficiency; this situation can further be improved by reducing grant size (last row). Of course, there are other issues, such as administrative limitations for the granting agency, which have not been taken into account in our model. Nonetheless, the model gives some basic guidelines which can be utilized to set policy actions on a better course.

Table 5: Outcomes of some policy instrument combinations

Budget	Round Gap	Grant Size	PMD	PGI	GGI
50	**3**	**120-240-500**	**92.2**	**0.35**	**0.61**
100	5	120-240-500	89.3	0.30	0.43
50	3	100-150-300	83.3	0.27	0.45
100	5	100-150-300	81.0	0.19	0.22

Source: Simulation runs

4. Conclusion

The agent-based model developed for this study is a simple one, assuming homogeneous investigators, individual grant application, and grant money spent to carry out investigations and produce papers. We have shown that such a model can be used to analyze the system output in response to policy changes. For a more realistic and complicated model, other factors need to be included in the simulation. In reality, investigators are not homogeneous, differing in their discipline, experience, interest, performance, and so on. The process of investigation may be changed to include various factors used in research (such as equipment, materials, and human services), as well as multiple outputs such as publications, patents, and training. The granting procedure and the mechanisms and expenses within the granting agency can also be included in the model. Regarding the outcome measures, the long-running debate over the importance of efficiency versus equity continues, and the choice of indicators and the preference shown to them remains controversial. Ultimately, the ABM approach can be successfully used in policy simulation to study the long-term impacts of policy designs or changes.

References

Ahrweiler, P., Gilbert, N., Pyka, A. (2011a). Agency and structure: A social simulation of knowledge-intensive industries. *Computational & Mathematical Organization Theory, 17*(1), 59-76.

Ahrweiler, P., Pyka, A., Gilbert, N. (2011b). A new model for university-industry links in knowledge-based economies. *Journal of Product Innovation Management, 28*(2), 218-235.

Ahrweiler, P., Pyka, A., Gilbert, N. (2004). Simulating knowledge dynamics in innovation networks (SKIN). In R. Leombruni & M. Richiardi (Eds.), *Industry and labor dynamics: The agent-based computational economics approach* (pp. 284-296). Proceedings of the Wild@Ace 2003 Conference held at Torino, Italy, 3-4 October 2003. Singapore: World Scientific.

Arvanitis, R. (Ed.). (2003). *Science and technology policy* (Vol. 1, Encyclopedia of Life Support Systems). Oxford, UK: UNESCO/Eolss.

Dixon, P. M., Weiner, J., Mitchell-Olds, T., Woodley, R. (1987). Bootstrapping the Gini coefficient of inequality. *Ecology, 68*(5), 1548-1551.

Doern, G. B., Castle, D., Phillips, P. W. B. (2016). *Canadian science, technology, and innovation policy: The innovation economy and society nexus*. Montreal, Canada: McGill-Queen's University Press.

Genome Canada. (2010). *Perspectives on progress: Annual report 2009-2010*. Ottawa, Canada: Genome Canada.

Genome Canada. (2016). *Corporate plan 2016-2017*. Ottawa, Canada: Genome Canada.

Gilbert, N. (1997). A simulation of the structure of academic science. *Sociological Research Online, 2*(2), 3.

Gilbert, N., Ahrweiler, P., Pyka, A. (2007). Learning in innovation networks: Some simulation experiments. *Physica A: Statistical Mechanics and Its Applications, 378*(1), 100-109.

Gilbert, N., Pyka, A., Ahrweiler, P. (2001). Innovation networks—A simulation approach. *Journal of Artificial Societies and Social Simulation, 4*(3), 8.

Gilbert, N., Troitzsch, K. (2005). *Simulation for the social scientist*. Berkshire, UK: Open University Press.

Grimm, V., Railsback, S. F. (2005). *Individual-based modeling and ecology*. Princeton, NJ: Princeton University Press.

Merton, R. K. (1968). The Matthew effect in science. *Science, 159*(3810), 56-63.

Merton, R. K. (1988). The Matthew effect in science, II: Cumulative advantage and the symbolism of intellectual property. *Isis, 79*(4), 606-623.

Pyka, A., Gilbert, N., Ahrweiler, P. (2007). Simulating knowledge-generation and distribution processes in innovation collaborations and networks. *Cybernetics and Systems, 38*(7), 667-693.

Railsback, S. F., Grimm, V. (2012). *Agent-based and individual-based modeling: A practical introduction*. Princeton, NJ: Princeton University Press.

Sen, A. (1973). *On economic inequality*. New York, NY: Oxford University Press.

Teitelbaum, D., & Dowlatabadi, H. (2000). A computational model of technological innovation at the firm level. *Computational & Mathematical Organization Theory, 6*(3), 227-247.

Triulzi, G., Pyka, A. (2011). Learning-by-modeling: Insights from an agent-based model of university-industry relationships. *Cybernetics and Systems, 42*(7), 484-501.

Urban, J. B., Osgood, N. D., Mabry, P. L. (2011). Developmental systems science: Exploring the application of systems science methods to developmental science questions. *Research in Human Development, 8*(1), 1-25.

Watts, C., Gilbert, N. (2014). *Simulating innovation: Computer-based tools for rethinking innovation*. Cheltenham, UK: Edward Elgar.

Chapter 4

Open versus Closed Innovation:
Genome Canada's ABC Competition

Peter WB Phillips, Bethany Penn, Bill Boland, Aaron Hertes, Yvonne Nyake, Simbo Olobobokun and Andrew Phillips

Abstract:

There is a conflict both in the literature and in practice about whether open innovation or proprietary research efforts generate the optimal technological change and innovation. With the acceleration of research that leads to non-rival and non-excludable ideas, recipes, business processes and design, the issue has taken on a new urgency. Scholars and practitioners line up on both sides of the debate. Some assert that optimal research effort requires an open architecture, where all past knowledge and information are universally and freely available, allowing for the effective and efficient development of new inventions. Others accept that in a world of unlimited resources, this may be true, but they note that instead we are always faced with the challenge of allocating scarce resources among competing ends. One domain of particular interest is the agricultural and food system. Getting the optimal rate of technological change and innovation is vital to global food security, which underpins the larger global economy and society. Genome Canada embodies the tensions arising from the ambiguity of research policy. While in its earlier competitions (2000-2008), it pursued largely an open style strategy, it was pushed by the Conservative Government both in policy and process terms to become more strategic in the Applied Bioproducts and Crops (ABC) Competition in 2008-9. The call for proposals embodies a mix of exhortations to open scientific investigation that generates economic impact, all couched in the language of innovation and impact. This paper applies a qualitative-quantitative approach to examining the balance of open to proprietary interests in the context of constructing the ABC competition (informed by position papers and various external reviews) and the operation of the competition, as they solicited interest from 58 teams who pitched 47 letters of intent which was winnowed down by internal review to 26 full applications which lead to 12 teams with grants. The analysis demonstrates that the process generally drove project proponents to sharpen their commercial pitch and that the decisions differentially rewarded those that privileged commercial impacts rather than open science aspirations.

Key Words: open innovation; property rights; research design

1. Introduction

There is a conflict both in the literature and in practice about whether open innovation or proprietary research efforts generate the optimal technological change and innovation. As long as we were primarily investing in the development of rival and excludable machinery and equipment, the net impact of open versus closed research and commercialization systems was

modest at best. With the acceleration of research that leads to non-rival and non-excludable ideas, recipes, business processes and design, the issue has taken on a new urgency.

Scholars and practitioners line up on both sides of the debate. Some assert that optimal research effort requires an open architecture, where past knowledge and information are universally and freely available, allowing for the effective and efficient development of new inventions (Chesbrough 2003). Moreover, many assert that the optimal economic and social impact can only be realized in a non-proprietary world—any barriers to entry and use, such as patents and other IPRs, simply reduces the market size and welfare effects. Others accept that in a world of unlimited resources, this may be true, but they note that instead we are always faced with the challenge of allocating scare resources among competing research demands (Alston et al. 1985). In this context, we need to incentivize individuals and firms to invest their time, energy and material and financial resources in areas of particular need (Phillips 2000).

While the state could either undertake the research itself (e.g. in universities or public labs) or provide tax credits or direct or indirect subsidies to incentivize private investors to allocate their resources into research, the prevailing view is that providing property rights (intellectual or otherwise) to the research results may in many instances be less expensive and more effective (ibid.).

To that end, states and markets have developed a web of interlocking and overlapping mechanisms to protect and exclude others from using inventions without approval. These include: a mix of explicit IPRs, such as patents, plant breeders rights, pedigrees, copyright, trademarks and trade secrets; regulatory mechanism that protect the rights of inventors and their regulatory compliance; and a host of anti-competitive private strategies such as contracts and vertical and horizontal integration that are underpinned by the courts and legal systems (Phillips 2000).

One domain where this is a particular concern is the agricultural and food system. Getting the optimal rate of technological change and innovation is vital to global food security, which underpins the larger global economy and society. Globally there is about US$70B of research underway annually, about half in the private sector and half funded by governments, universities and not-for-profit organizations (Pardey, Alston and Cahn-Kang 2013). In Canada, government and producers, through industry check-off levies, fund about C$800 million of research, much of which is done in government labs and universities.

In the 1990s, with the advent of new genomics technologies, the government of Canada created Genome Canada as a new funding agency to bridge the gap between public, private and university researchers. This new institution embodies the tensions arising from the ambiguity of research policy. While in its earlier competitions (2000-2008) Genome Canada pursued largely an open style science strategy, requiring all sequencing information to be deposited in global databanks, it was nudged by the newly-elected Conservative Government after 2004 to become more focused on the economic impacts of their investments. The Applied Bioproducts and Crops (ABC) Competition in 2009-9 was the result – the call for proposals embodies the long-standing exhortation to open scientific investigation but with a strong signal that proposals must also demonstrate significant potential for economic impact in Canada and abroad.

This paper undertakes a qualitative analysis of the resulting process. We examine the balance of incentives for both open and proprietary interests in the context of the construction of the ABC competition itself (informed by coding the goals and directions in position papers and various external reviews) and in the actual operation of the competition, which solicited interest from 58 teams who pitched 47 letters of intent, winnowed down by internal review to 26 full

applications which lead to 12 grants. We encoded the documents of each stage of this process to identify the evolution and uptake of open innovation and proprietary structures and strategies.

2. Context

Genome Canada was created in 1999 to accelerate research into genomics in order to ensure Canada shared in the benefits of this emerging, transformative technology. Genome Canada ran three open competitions (I, II, and III) where the field of research was unlimited (besides that the field must be important to Canada), thereby allowing the research community to submit projects of scientific merit on any topic. While teams were invited to show the potential impact of their work, the primary focus was on the quality and novelty of the science.

In 2006, Industry Canada recommended that Genome Canada pursue a different style of funding competition. Based on Industry Canada's recommendations, the ABC Competition asked the scientific community to identify strategic research themes in order to fund more targeted research objectives. This fell in line with the federal government's new policy, Mobilizing Science and Technology to Canada's Advantage, and its focus on targeted research. The ABC themes were determined using a position paper process, which took time, effort, and money. Once themes were identified, Genome Canada received a grant of $140 million in the February 2008 federal budget, $53 million of which was dedicated to the ABC competition. The competition proceeded through a series of steps, delivering 12 projects awarded $114 million.

The ABC competition was qualitatively different than the other competitions (Phillips and Warren 2022). The overriding scientific objectives for the first three competitions remained relatively stable but, in Competitions II and III, a section on economic, social, and industrial benefits for Canadians, was added, representing the first sign of a focus on projects with commercial potential. The ABC competition objectives, based on the new funding agreement signed with Industry Canada in 2008, were markedly different. The list included a number of objectives melded together from previous competitions, with both deletions and additions, resulting in a list of five rather than nine objectives. Particularly interesting is the addition of, "the development and establishment of a coordinated national strategy for genomics research to enable Canada to become a world leader in areas such as health, agriculture, environment, forestry and fisheries" listed as the first objective. This reflected Industry Canada's desire to support more targeted research effort. The ABC competition further developed the scholarly focus on genomics-related ethical, economic, environmental, legal and social issues (GE3LS). In past competitions GE3LS work generally explored impediments (ethical, economic, legal, or otherwise) to the success of the project. The ABC competition directed project proposals to specifically explore how GE3LS work could help the scientific research realize maximum benefits. The guidelines instructed applicants to integrate GE3LS issues into the scientific components of their proposals, a concept absent from previous competitions.

In past competitions there were separate sections discussing benefits for Canadians and commercialization; in the ABC competition these were melded into one section, implying that benefits would be delivered by commercialization. The ABC competition guidelines were more precisely worded, exchanging words like "economic growth and social benefits" for "product and service development." The instructions explicitly directed proponents to consider impacts via product and service development, the start-up of spin off companies and related licensing opportunities. The program guide stipulated that the identified benefits should be realized within

five years of the completion of the science activities in the project. Applicants were instructed to seek out expertise on the commercialization process, including market analysis and marketing.

Nevertheless, the ABC Competition sustained the long-standing focus on open science. The program guide instructed applicants to show how they would comply with Genome Canada's Data Release and Resource Sharing Policy, created in July of 2005 to formalize data management. The policy stated Genome Canada funded projects were a "community resource project, defined as a research project specifically devised and implemented to create a set of data, reagents or other material whose primary utility will be as a resource for the broad scientific community." The stated objective in this section of the guide was to ensure "the timely development of projects that will benefit humankind."

Both Genome Canada, as the manager of the competition, and the academics and their partners as project proponents had to navigate these diverse and in some ways conflicting goals.

The process started with a call for letters of intent (LOIs), which had been dropped in earlier competitions. LOIs involved a one-page executive summary of the project was followed by a five-page detailed proposal (outlining the goals of the research and the plans to achieve those goals), a two-page section on GE3LS that required applicants demonstrate how these issues were integrated into the overall structure of the project and a one-page summary of the expected benefits of the projects research. This summary was to identify the expected outcomes of the research and their potential benefits for Canadians, as well as identify any team members with expertise in commercialization, IP rights, or other relevant fields who could help the project realize those benefits. Additionally the LOI included the roster of investigators and the rationale for their participation, a management structure and a preliminary financial plan that included cost estimates and a list of secured or potential funding sources. One additional criteria was that applicants were to document any previous Genome Canada funded projects that any team members were involved with, which was to be used to assess the applicants' experience in managing a large-scale project. By rewarding past success, this consideration worked to concentrate funding to those who had previous Genome Canada experience, making it more difficult for new actors to get involved.

The ABC competition added an additional review process in response to a high volume of LOIs (48) that were accepted and then developed into full proposals. To make the face-to-face meetings with project investigators feasible, the international peer review panel worked to eliminate some of the applications. A streamlined review process was put in place by Genome Canada and announced on August 1, 2008. Prior to the reverse site visits by project investigators, each proposal was given a full scientific review by selected members of the international review panel. Those deemed non-fundable (i.e. "non-competitive") by the majority of reviewers were dropped from the competition. In the first week of December, unsuccessful applicants were informed that they did not pass the streamlining process, and were sent copies of the panels review. Out of 48 full proposals, 27 were sent to full peer review. In the end 12 projects were funded.

3. Theory

Intellectual capital is very important in the production process. While much of the economic literature assumes that knowledge transfers that generate economic returns are most effectively moderated by private claims to their useful applications (i.e. patents), over time,

terms such as open innovation, openness, open access, and open source have been used to describe an alternate path by which many organizations obtain and use intellectual capital. Chesbrough (2003) defined open innovation as a "distributed innovation process based on purposively managed knowledge flows across organizational boundaries". Chesbrough and Bogers (2014) refined the definition to assert it involves an intentionally-managed process for knowledge flows across these boundaries, using both pecuniary and non-pecuniary mechanisms consistent with the objectives of the organization. de Beer (2015) generated data from journals that focus on intellectual property (IP) to conduct a literature review of how some related words to openness and 'open innovation', including 'user innovation', 'open access' and 'open S\source' were used alongside 'innovation', within various legal contexts and intellectual property strategies.

One posited benefit of open innovation is that it enables access to prior information and knowledge that can facilitate the effective and efficient development of new inventions. But at the same time, economic theory suggests that for-profit investors would not spend (or at least not spend enough) on the research and development to create knowledge that would be freely used, as they would not have any opportunity to generate any returns on their outlays. This is usually categorized as a public good problem. A range of solutions are implemented, including providing private property rights such as patents, trademarks and copyrights (essentially the right to exclude others from using one's idea), public subsidies for research (including tax credits, concessionary finance and program or project grants) and sometimes direct public provision (through publicly funded research in universities and public labs). While most knowledge from the proprietary system eventually becomes available, the right to use it often comes with a cost.

The increased evidence of the co-existence of open innovation and proprietary strategies within organizations has influenced studies on strategic duality and ambidextrous organizations. Figeli and Biloslavo (2015) conducted a literature review to investigate the dualities that exist in different areas of organizational policy. The paper identified 21 organizational dualities within different areas of organizational policy that could promote competitive advantage. He & Wong (2004) found evidence consistent with the ambidexterity hypothesis in a study of 206 manufacturing firms. The survey revealed that balanced explorative and exploitative innovation strategies were positively related to sales growth and that a relative imbalance between explorative and exploitative innovation strategies was negatively related to the sales growth rate. Oorschot et al. (2018) investigated the Chinese shipbuilding industry to systematically model the long-term effects of sharing versus exploitive strategies, finding that overreliance on a protection strategy reduced innovation.

While there are benefits of open innovation, there are also challenges in obtaining the innovation resources needed for any organization. West and Gallagher (2006) identified that firms pursuing an open innovation strategy need to find creative ways to exploit internal innovation, to incorporate external innovation into internal development, and to motivate outsiders to supply an ongoing stream of external innovations. The study identified that firms variously employ pooled R&D/product development, engage in spinouts, sell complements and seek to attract donated complements. Other studies (e.g. Dahlander and Gann 2010) investigated the forms of relationships firms enter into, finding that organizations use a mix of contractual arrangements or licenses and engage in collaborations and research networks as knowledge sharing strategies. At the extreme, enterprises can enter 'Open Innovation Communities' (OIC) which moderate the sharing or trading of knowledge for a specific technology or market (West & Marcel Bogers 2013).

Our look at the requirements of Genome Canada for the 2009 ABC competition reveals the directions to proponents were to define a dual strategy for open innovation and proprietary benefits from each project. The earlier 2000-2008 competitions concentrated on collaboration and sharing of knowledge, including system wide annual meetings to share and learn about other activities in the portfolio of projects. The goal seemed to be to generate an open innovation community. With the changes initiated by the new federal government, there was an explicit push to raise the profile of economic and social benefits for Canada and the world. This proprietary objective was more consistent with the profit maximizing objectives of the private-sector partners and not the altruistic objective of conventional public researchers.

This study investigates the tensions between the two strategic foci to see if and how they influenced the processes and outcomes of the ABC Competition.

4. Objectives, method and data

This paper is designed to test to see how program design, project development and the adjudication process balanced the open and proprietary objectives. To do this we encode and test for correlations between the two objectives in the design and structure of the program itself, in the initiation and evolution of the project proposals and in the results of the adjudication process.

Ultimately openness is a function of how projects are designed, managed and then what they seek to deliver in terms of outputs and outcomes. We break the process into four phases: assembling inputs, including financial, human, material and information resources, that are used to produce outputs through activities; activities, the actions taken or work performed through which inputs are mobilized to produce outputs; outputs, which are direct products or services stemming from the activities of the project; and outcomes, which are the changes directly or indirectly but logically expected to flow from the project, laid out as proximal or distal. Evaluation rubrics suggest investigating the interaction between inputs, activities and outputs can identity process efficiencies while one can explore the effectiveness of a measure by exploring the flow of external outputs from the assigned inputs, activities and their derived outputs.

Methodologically, we assembled all of the program artifacts, including program design documents, all of the project applications, all of the adjudication reports and the final decisions and then encoded them using NVivo for their alignment of specific tasks and activities with the open and proprietary approaches. Two researchers independently encoded each document using a common coding rubric. We then assessed the relative balance of open and proprietary design in each stage of the process, testing for statistical significance of the relative balance.

Two types of documents were reviewed: first, the background documents designed by Genome Canada that constructed the ABC competition and then the project proposals and the management documents that assessed their fit. The program design set of documents provides the background and structure for the resulting competition (table 1). As best we can tell, teams were invited to submit notices of intent and while no culling was done some matchmaking was undertake to encourage complementary or competing projects to investigate making larger ventures.

Table 1: Program design for the ABC Competition

	Key sections of report that were coded	# pages	# Docs
Request for Position Papers	Background; Process; Scope	6	1
Guidelines and evaluation criteria for position papers	Objectives; Background; Submission and Evaluation Procedures; Evaluation; Funding; Lessons Learned; Evaluation Criteria	14	1
Two position papers: Plants and Bioproducts	Relevance to Canada's Future; Areas of Impact Capacity; Stakeholder interest and support Socio-Economic Outcomes; Budget Request (esp. leveraging options)	~16	2
KPMG Evaluation	Findings on impacts	82	1
Guidelines for Evaluation	Objectives; Background; Request; Competition Evaluation Procedures; Project Management; Interim review; Funding and cofounding; Administration; Evaluation criteria; Data policy		
Data Release, Resource Sharing Policy	Policy Principle; Mechanism for Sharing Plans; Uses; Examples of repositories	3	1
Corporate Privacy Policy	Protection of personal information; Privacy principles; Safeguards; Openness	3	1
Intellectual Property	Objectives; Ownership of IP; Protection of IP	2	1
Risk Management	Policy objectives; Definitions; Components; Responsibilities; Assurance	10	1
Review Committee list	Commercial orientation of reviewers	3	1

The program generated a series of project documents which were also encoded. Table 2 shows the key documents and sections that were reviewed and encoded.

Table 2: Project documents for the ABC Competition

	Key sections of report that were coded	# pages	# Docs
LOIs	Executive summary (1 pp); Project proposal (5 pp) Project team (1-2 pp); Management org chart (1 pp); GE3LS (2 pp); Benefits for Canada (1 pp); Financial information including co-funding strategy (1 pp)	~16	47
Applications (APPs)	Keywords; Research team; Participating organizations; Lay summary (1 pp); Scientific summary (2 pp); Research proposal (30 pp) including services from others, training; Milestones maps; Handling of data and resources (2 pp); Management (4 pp), incl. SAB and experience; Communication and outreach (2 pp); Benefits for Canada (4 pp); Financial information; Co-funding strategy (3 pp)	~70	44
Appendix IX	Data and resource sharing	1-2	44
Desk Reviews	Look for commercial orientation or economic impact	15-25	46
Summary of peer review	Strengths and weakness of the science, research team, GE3LS, benefits for Canada section, management and financing; Final rating; Co-funding		27
Notice of Award	Standard wording for all projects	3	12
Public descript.	Paragraphs	1	12

The program launched in 2008 generated significant interest (table 3). In all, 58 notices of intent (NOI) were submitted, which generated 48 letters of intent (LOI). All LOIs were approved to proceed: 48 groups submitted full proposals that were put through a desk review. At this stage 21 applications were culled and 27 were sent for face-to-face international peer review. In all 12 applications were approved and provided grants, communicated through a formal notice of award (NOA).

Table 3: The ABC Competition program activities

Categorized by last stage achieved	NOI	LOI	APP	Desk review	Peer review	NOA Summary
NOI	58					
LOI		48				
APP			48			
Desk reviewed APP				48		
Peer Reviewed APPs					27	
Awarded: NOA, summary						12
Total documents	Na	48	48	48	27	12
Missing		1	4	2	0	0
Documents reviewed	0	47	44	46	27	12

Each document was read and encoded based on the key words and concepts in Table 4.

Table 4: Key words and concepts used to encode program and project documents

Stage	**Proprietary**	**Open Innovation**
Inputs	Co-funding from private company; Co-funding from commodity group; Prior patenting or start-up activities; technology transfer; Mention of commercial suggest/efforts by team members	Co-funding from university or government; University based scientists; Public sector scientist
Activities	Contract research; Public-private exchanges; MTAs; Licenses; Ownership ; GE3LS stand alone	Integrated teams; Training; Open access; GELS integrated to management team
Outputs	Patents/patent filings; Trademark; Trade secret; Copyright; GE3LS focused on market access or commercialization; Genes; Intellectual property; Variety; Start-up; Invention disclosures	Publication; Trainees; Cutting edge, world class science; knowledge generation; GE3LS focused on ethics or research processes; Sequences; Deposits/repositories; Basic science
Outcomes	Value; Market size; Economic; New products and/or services; Commercialization; Job creation and economic growth; Measurable benefits for Canada; Commercial licenses; Commercial potential	Repository; Policy; benefit sharing; Standards and guidelines; Measureable benefits to the poor

Once the files were coded, estimates of the number of references to the various concepts and metrics in each section of the reports as noted above were used to data citation estimates that were normalized by project to reflect the relative use of each concept in each project. We then calculated standardized means (and standard deviations) for the two subpopulations, the awarded projects (n = 12) and the rejected proposals (n varied between 32 and 35 deepening on the available files as noted in table 3). Much of the analysis uses the difference of means test to assess for significant focus and intent at each stage of the competition. The online calculator at https://www.medcalc.org/calc/comparison_of_means.php was used to test for significance.

5. Analysis and Results

Using the NVivo program the initial evaluation was to conduct a text search of the applications in the ABC Competition for words that were considered to distinguish a research as open innovation or proprietary. Text searches were conducted to determine word frequencies for a range of key concepts related to the proprietary approach, including economic, co-funding, prior patent, technology transfer, data, contract research, trademark and intellectual property (IP).

The statistical analysis that follows uses the mean word frequencies obtained for "economic" and "intellectual property" and "proprietary tools" to test for a proprietary orientation of the proposals and frequencies for 'open innovation' and "data" as the logical counterfactual to represent the open concept of innovation.

First we assess the how the different foci were managed in the project development and adjudication stages, comparing and contrasting the two populations, and then we compare and contrast between the different approaches. .

5.1. Proprietary approaches

Starting with the more general encoding for economic claims in the projects reveals some interesting points (table 5). When looked as longitudinal activities, moving from the LOI to the NOA, we found a set of trends worth noting. In the first instance, we can see that there is not a lot to distinguish those projects that got funded from those that didn't in terms of their claims; none of the means are statistically different between the approved and not-approved projects. While the rejected projects appeared to a bit more enthusiastic than those not approved about their economic impact at the LOI stage, their claims converged to a much more modest (possibly nuanced?) set of claims at the full application stage. One might assume that the clash of wills tempered the enthusiastic claims.

Table 5: Economic focus in project proposals

	Approved projects			Not approved proposals			
	N	Mean	SD	N	Mean	SD	p =
LOI	12	0.1008	0.117	35	0.1328	0.139	.4788
Application	12	0.0425	0.026	32	0.0452	0.043	.8400
Desk Review	12	0.0383	0.028	34	0.0511	0.068	.5321
Peer reviews	12	0.0725	0.059	15	0.0426	0.088	.3232
NOA/summary	12	0.1742	0.194	na	na	na	Na

What is perhaps more interesting is that the desk and peer reviewers and the decision documents differentially accentuated the economic claims (table 5.1). The desk reviews tended to downplay the economic claims relative to the LOI and the in-person peer reviewers for the approved projects (90% confidence), while the LOIs were the only stage of the process overly focused on the economic motive. But when the NOA and public announcements were made, the decision and announcement documents heavily weighted their messaging on the economic prospects for the projects (at over 95% % confidence). One might interpret this as more of a signaling exercise to alert the granting agency that their process was aligned with the renewed and strengthened economic goals of the renewed funding.

Table 5.1: Significance tests for the economic focus between stages in the process

	Approved projects				Not approved proposals		
	LOI	APP	Desk Review	Peer reviews	LOI	APP	Desk Review
Application	.1061				.0488 **		
Desk Review	.0856 *	.7070			.0810 *	.8018	
Peer reviews	.4623	.1213	.0833 *		.0707 *	.9276	.7937
NOA/summary	.2738	.0293 **	.0252 **	.2204			

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

The explicit focus on creating and exploiting intellectual property from the research projects is also revealing (table 6). Projects that were rejected for funding started in their LOIs with high hopes that they would deliver valuable IP, but their enthusiasm waned in the full applications and both the desk and peer reviews were singularly unimpressed by the IP strategies in those proposals. In contrast, the successful proposals started with a more modest focus on IP that was then bolstered in the applications. While the desk reviews discounted the IP focus moderately (not statistically significantly), the peer reviews massively accentuated the value and importance of IP in the project proposals (at 90% confidence). The peer review focus on IP for successful projects was significantly higher (at 99% confidence) than for the rejected proposals.

Table 6: Focus on intellectual property in project proposals

	Approved projects			Not approved proposals			
	N	Mean	SD	N	Mean	Standard Deviation	p =
LOI	12	0.0233	0.06	35	0.0498	0.067	.2318
Application	12	0.0358	0.034	32	0.0228	0.02	.1238
Desk Review	12	0.0317	0.036	34	0.0149	0.018	.0414**
Peer reviews	12	0.1575	0.144	15	0.0112	0.037	.0008 ***
NOA/summary	12	0.0642	0.222	na	na	na	na

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

There was no obvious change in the focus on IP between the LOIs and full applications but the peer reviews we much more focused on intellectual property (at 95% confidence) (table 6.1). Again, NOA and public summaries were more focused on IP than the applicants presented in their full proposals, albeit less bullish than the peer reviews. Interestingly the project

proponents developing a rejected projects significantly downgraded their focus on IP between the LOI and the full application. While the desk reviews confirmed that evolution in the projects (90% confident), the peer review judged the IP plans as relatively less compelling than asserted in the LOIs (significant at the 95% confidence) but, while signaling relatively low prospects, their analysis did not differ significantly from the weight in the application.

Table 6.1: Significance tests for the IP focus between stages in the process

	Approved projects				Not approved proposals		
p stats	LOI	APP	Desk Review	Peer reviews	LOI	APP	Desk Review
Application	.5365				.0321 **		
Desk Review	.6815	.7769			.1103	.0962 *	
Peer reviews	.0069 ***	.0093 ***	.0078 ***		.0419 **	.1685	.6380
NOA/summary	.5442	.6656	.6216	.2349			

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

Last, we explored references to proprietary tools, such as patents, licenses, tech transfer and start-ups (Table 7). The occurrence of proprietary words was not significantly different for any the stage except peer review, where the proprietary claims of the successful projects were significantly higher than for the rejected proposals.

Table 7: Focus on proprietary claims in project proposals

	Approved projects			Not approved proposals			p =
	N	Mean	SD	n	Mean	SD	
LOI	12	0.0179	0.0251	35	0.0223	0.02	.5411
Application	12	0.0044	0.0047	32	0.0054	0.0068	.6425
Desk review	12	0.0168	0.0114	34	0.0117	0.0122	.2125
Peer review	12	0.0461	0.01989	15	0.152	0.0256	<.0001 ***

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

Interestingly, while the proponents relatively downgraded their proprietary claims between the LOI and application stages (at 90% and 99% confidence for the granted/rejected projects), the desk and peer reviewers were significantly more focused in proprietary claims than the proponents (all at 90% or higher confidence) (Table 7.1).

Table 7.1: Significance tests for the proprietary claims between stages in the process

	Approved projects			Not approved proposals		
p stats	LOI	APP	Desk Review	LOI	APP	Desk Review
Application	.0806 *			<.0001 ***		
Desk Review	.8913	.0021 **		.0101 **	.0125 **	
Peer reviews	.0059 *	<.0001 ***	.0002 ***	<.0001 ***	<.0001 ***	<.0001 ***

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

5.2. Open Innovation orientation

When we tested a bundle of measures that captured the open innovation concept (table 8). Generally speaking, there was not statistically significant difference in how often the proponents of successful and unsuccessful projects made references to the bundle of open innovation ideas, but the desk and peer reviewers were unambiguously more likely to cite OI elements in support of their recommendations for awarding approvals.

Table 8: Focus on open innovation in project proposals

	Approved projects			Not approved proposals			p =
	N	Mean	SD	N	Mean	SD	
LOI	12	0.0234	0.0261	35	0.0298	0.0247	.2476
APP	12	0.0124	0.0117	32	0.0098	0.0115	.5098
Desk	12	0.0323	0.0228	34	0.0213	0.0182	.0992 *
PEER	12	0.0567	0.0278	15	0.0144	0.0275	.0006 ***

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

While there was some downgrading of OI form the LOI to the application among both the successful and unsuccessful projects, the change was only significant for the failing proposals (table 8.1). Nevertheless, the reviewers at both the desk and peer review stage focused heavily on these signals, citing them significant more than either the approved or failing proposals. This does suggest that perhaps the proponents missed the cues to keep the open innovation focus in balance with the proprietary objectives.

Table 8.1: Significance tests for the OI focus between stages in the process

	Approved projects			Not approved proposals		
p stats	LOI	APP	Desk Review	LOI	APP	Desk Review
Application	.1964			.0001 ***		
Desk Review	.3833	0.0134 **		.1092	.0034 **	
Peer reviews	.0062 ***	<0.0001 ***	0.0281 **	.0566 *	.4201	.3035

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

Next we assessed how the projects, proposals and reviews dealt with data, which is a proxy for a focus on open innovation (table 9). As a reminder, we already demonstrated that the applications made absolutely more references to data than either of the proprietary elements. The most notable result is that the successful applications may absolutely more reference to data (aka scientific rather than commercial outcomes) but that didn't seem to differentially affect the adjudication of the projects at the desk or peer review stage.

Table 9: Focus on data in project proposals

	Approved projects			Not approved proposals			
	N	Mean	Standard Deviation	N	Mean	Standard Deviation	p =
LOI	12	0.03	0.0388	35	0.0451	0.0464	.1478
Application	12	0.0808	0.0131	32	0.0228	0.0553	.0009 ***
Desk Review	12	0.0433	0.0296	34	0.0533	0.419	.9350
Peer reviews	12	0.0523	0.0869	15	0.014	0.0297	.1320

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

During the development phase, the focus on data rose between the LOI and applications for successful projects (at 99% confidence) but fell for unsuccessful ones (90% confidence) (Table 9.1). The peer reviews for the unsuccessful projects were much less likely to note the data plans in the applications (95% confidence).

Table 9.1: Significance tests for the data focus between stages in the process

	Approved projects			Not approved proposals		
p stats	LOI	APP	Desk Review	LOI	APP	Desk Review
Application	.0003 ***			.0776 *		
Desk Review	.3554	.0006 ***		.9087	.8007	
Peer reviews	.4257	.2734	.9726	.0210 **	.9514	.7199

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

5.3 Comparative influence of proprietary and open innovation on success

Using an in-sample analysis of the 12 successful proposals, we tested for the relative influence of the five tested concepts during the development of the proposal and at the desk and peer review stages (table 10).

The first observation is that proponents of the successful proposals at the LOI stage differentially promoted economic impacts and proprietary claims over open innovation concepts (at above 90% significance). Given that there was no organized feedback on the LOIs to the proponents, this rebalancing is more likely to be the result of the compromises needed to get scholars to commit to the effort and partners to contribute funding.

The more interesting comparison is between how the applications were adjudicated. The desk review, which generally involved three arm's length, anonymous reviews, focused less on the proprietary claims (at 99%) and marginally but not statistically less on the economic and IP aspects of the proposals than were in the proposals, but were significantly more focused on the open innovation aspects of the pitches. Moving to the peer review stage, which involved committees of up to 12 reviewers that met face to face with the management team of the project, reviewers were much more focused than the desk reviewers on the economic impact and intellectual property aspects of the project (at 90% and 99% significance) and more interested than the applicants on the open innovation and data aspects of the proposals (at 99% confidence).

Table 10: Mean citations of concepts at the four stages for the 12 successful ABC Competition projects

		LOI	Application	Desk Review	Peer Review
Economics	Mean	0.1008	0.0425	0.0383	0.0725 *
	SD	0.117	0.026	0.028	0.059
Intellectual Property	Mean	0.0233	0.0358	0.0317	0.1575 ***
	SD	0.06	0.034	0.036	0.1440
Proprietary Rights	Mean	0.1079	0.0808	0.0433 *	0.0523
	SD	0.0251	0.0131	0.0296	0.0869
Open Innovation	Mean	0.0234	0.0124	0.0323 **	0.0567 ***
	SD	0.0261	0.0117	0.0228	0.0278
Data	Mean	0.03	0.0044	0.0168 ***	0.0461 ***
	SD	0.0388	0.0047	0.0114	0.01989

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

Looking across the application and review stages, we can see the unweighting and down weighting that went on. The proponents presented applications with clear delineation between areas of focus, with each of the mean citation rates being statistically significantly different. At the application stage, proprietary rights were more heavily cited, while open innovation artifacts were less significantly cited. At the desk review stage, the only notable outlier was the up weighting of data in their analysis. At the peer review stage, the most notable outlier was the focus on intellectual property in their reviews, which was cited two to three times more frequently than other key variables (at 99% confidence).

Table 10.1: Significance of difference of means at stages for the 12 successful ABC Competition projects

	Economics	Intellectual property	Proprietary Rights	Open Innovation
Applications				
Intellectual Property	.5931			
Proprietary Rights	.0002 ***	.0003 ***		
Open Innovation	.0014 ***	.0345 **	<.0001 ***	
Data	.0001 ***	.0044 ***	<.0001 ***	.0388 **
Desk Review				
Intellectual Property	.6211			
Proprietary Rights	.6749	.3979		
Open Innovation	.5707	.9615	.3189	
Data	.0220 **	.1855	.0084 ***	.0468 **
Peer Review				
Intellectual Property	.0717 *			
Proprietary Rights	.5122	.0145 **		
Open Innovation	.4104	.0414 **	.8689	
Data	.1560	.0145 **	.8118	.2944

Significance: * 90% confidence; ** 95% confidence; *** 99% confidence

6. Conclusions

The Applied Bioproducts and Crops Competition managed by Genome Canada in 2008-9 offers key insights into the challenge of balancing the conflict between open and proprietary innovation styles. Genome Canada originally focused primarily on cutting edge, large scale research, regardless of its economic or commercial import. With a change in government policy in the mid 2000s, Genome Canada created a novel competition that attempted to embody both open science and proprietary goals. The call for proposals embodies this mixed exhortation to open scientific investigation that generates economic impact, all couched in the language of innovation and impact.

This paper has assessed the update and impact of that dual objective, using a mixed qualitative-quantitative approach to examining the balance of open to proprietary effort in the context of constructing the ABC competition (informed by position papers and various external reviews) and the operation of the competition, which solicited interest from 58 teams who pitched 47 letters of intent which was winnowed down by internal review to 26 full applications which lead to 12 grants.

The analysis demonstrates a number of elements. First, proponents, both successful and unsuccessful made significant claims of the economic impact and their ability to generate intellectual property that they would be able to exploit through propriety rights. It is interesting to note the proponents in their letters of intent initially overshot in their enthusiasm to pitch their work as generating economic value that can be commercialized. Both the successful and unsuccessful applicants rebalanced their pitches as they developed their full applications. While the means of the citation of the five tested elements that reflected the open-proprietary divide looked somewhat different between the successful and rejected proposals, the only statistically significant difference between those two groups what the greater focus on data management in the successful teams.

Moving into adjudication process, at the desk review tended to down weight the economic factors in their assessments and up weight the open innovation factors. The only significant difference in focus between the successful and rejected proposals was intellectual property, which the desk reviewers cited more heavily than for the rejected projects (albeit at a lower rate than the proponents).

The peer review process, which ended up ranking the projects for consideration and decision by the Board of Genome Canada, was the penultimate step in the adjudication. The review documents general up weighted intellectual property, proprietary claims and open innovation, but the citation rate for IP was double or more the other two factors and more than four times the projects they were assessing.

While the proposals and reviews generally conformed to the mission of covering both open and proprietary goals, the differential way they did so offers some insights into the efficacy of melding two divergent strategies into the same project. First, we can see that the proponents found it hard to calibrate the divergent goals, overshooting in their enthusiasm to show an economic bent in the letters of intent. The unsuccessful teams swung the other way and downgraded the economic focus so much that the reviewers downgraded them for that. Second, the proponents presented applications with clear delineation between areas of focus, with each of the mean citation rates shown in table 10 being statistically significantly different from each other. So one can say that the template did not drive to homogeneity. This may be transitory, as

applicants may learn from the first round and more closely align with the signals they received from the portfolio of approved projects. Third, the peer reviewers pulled in multiple directions, which may have materially changed the outcome. The desk reviewers, who ended up culling 27 of the full applications were much less focused on the economic variables than the peer reviewers, which suggests that some of the culled projects might have fit the somewhat different frame of the peer reviewers.

References

Alston, Julian M.; Norton, George, W.; and Pardey, Philip G. 1995. Science under scarcity: Principles and practice for agricultural research evaluation and priority setting. London UK and Ithaca, NY: Cornell University Press for the International Service for National Agricultural Research (ISNAR)

Chesbrough, H., 2003. Open Innovation: The New Imperative for Creating and Profiting from Technology, Boston, MA: Harvard Business School.

Chesbrough, H. and M. Bogers. 2014. Explicating Open Innovation: Clarifying an Emerging Paradigm for Understanding Innovation. In New Frontiers in Open Innovation, Henry Chesbrough, Wim Vanhaverbeke, and Joel West, eds. Oxford: Oxford University Press, pp. 3-28.

Dahlander, L and D Gann. 2010. How open is innovation? Research Policy 39, 699-709.

de Beer, J. 2015. "Open" Innovation Policy Frameworks: Intellectual Property, Competition, Investment & Other Market Governance Issues. Prepared for Industry Canada: Ottawa. https://jeremydebeer.ca/wp-content/uploads/2017/08/Open-Innovation-Policy-Frameworks.pdf.

Figelj, RR and R Biloslavo. 2015. Organizational dualities: an integrated review. International Journal of Business and Systems Research 9(3), 235-254. https://doi.org/10.1504/IJBSR.2015.071828

He, Z. and Wong, P. (2004) Exploration and Exploitation: An Empirical Test of the Ambidexterity Hypothesis. Organization Science, 15, 481-494. https://doi.org/10.1287/orsc.1040.0078

Oorschot, J. E. Hofman, J. Halman. 2018. A bibliometric review of the innovation adoption literature. Technological Forecasting and Social Change 134, 1-21.

Pardey, P., J. Alston and C. Chan-Kang. 2013. Public agricultural R&D over the past half century: an emerging new world order. Agricultural Economics 44(1), 103-113.

Phillips, P. 2000. Intellectual Property Rights and Public Research in Canada. In V. Santaniello et al. (eds.), Agriculture and Intellectual Property Rights: Economic Institutional and Implementation Issues in Biotechnology. CAB International, pp. 223-248.

Phillips, P. and E. Warren. 2022. Managing Large-Scale Science Research Programs: The Genome Canada Experience 2000-2010. JSGS-CSIP Working Paper 2022-4, https://www.schoolofpublicpolicy.sk.ca/csip/documents/research-paper-summaries/2022_managing-large-scale-science-research-programs-genome-canada.pdf.

West, Joel and Bogers, Marcel. 2013. Leveraging External Sources of Innovation: A Review of Research on Open Innovation. Journal of Product Innovation Management. http://ssrn.com/abstract=2195675

Chapter 5

Social Capital in Large-Scale Competitions

The structure of the Genome Canada research network

Puja Sharma and Peter WB Phillips

Abstract

The contemporary era is witnessing a global systemic transition in the science and innovation paradigm. The research world is rapidly shrinking in response to the challenges brought forth by integration of commercial and regulatory systems, faster communications, proactive science management and development of contemporary technology and innovation policy frameworks. It is increasingly becoming more challenging to compete and gain global leadership in science and in innovation. As one of the response to these challenges, the network oriented large-scale model has evolved as one means to realize national innovation goals and pursue international competitiveness. To keep pace with these network-based global developments, the Canadian government has aligned its research policy frameworks, strategic programs, and tactical initiatives, backed with significant financial resources, towards network focussed large-scale innovation projects. The federal science policy framework is one of the areas streamlined with the contemporary research and innovation developments. This paper examines Genome Canada's large-scale innovation projects, in specific their social capital outcome and their downstream residual results to assess the evidence to support policy and program realignment to large-scale innovation projects. A group of 139 investigators, who raised financial capital in Genome Canada's Applied Bioproducts and Crops (ABC) Competition held in 2009, are assessed in the context of their network engagement through 2000-2009. The investigation reveals that maximum social capital benefits accrue in large-scale innovation projects that have minimal requirements for project actors' real-time interactions and that encourage hybridization with cross-disciplinary exchanges through personnel mobility. Public funding for projects supporting co-publication opportunities and partnered research awards appear to positively sustain national innovation competitiveness and progress agendas.

Key words: Large-scale projects, Social Capital, Innovation, Centrality, Networks.

1. Introduction

Today's economies are increasingly dependent upon their innovation competencies to compete on the global technology front. Canada is a strong contender in this innovation race and has proactively advanced its science and innovation policies to parallel developments globally. One of the many contemporary and landmark transitions in management of science has been the gradual move to large-scale networked grants from the traditional 'single investigator research model. These large-scale research projects address complex, but focused, science problems and have dedicated infrastructure and human resources requirements (Nass & Stillman, 2003, pp. 17-18).

Large-scale projects permit network of heterogeneous actors, with different institutional and sectoral affiliations, to interact, access, and exchange experiences/knowledge and to advance a bigger agenda. This structural shift, with pronounced collaboration and interaction opportunities, produces opportune environment for generation of social capital — a collective benefit derived from cooperation between individuals.

There has been significant interest, at the global level, to exploit these 'assumed' benefits of social capital in order to advance national innovation mandates. Social Network Analysis (SNA) provides a functional method to identify and characterize these complex interactions and exchanges within networks and quantify them to track outcomes.

This paper summarizes the results of a recent thesis. The paper reviews the role of networks in Canada's innovation system, explores the theory of social capital and then applies social network analysis tools to the ABC competition of Genome Canada.

2. Networking Canadian innovation and research

Between 1997 and 2012, more than C$3 billion federal funds in Canada have been channeled into key research organizations that pursue large-scale network based innovation models. A significant portion of these funds have been allocated to genomics research. The large-scale efforts have been widespread, including in organizations and programs such as the International Science and Technology Partnerships Program (ISTPP) of Industry Canada, Tri-council network and partnership grants (E.g. CIHR, NSERC and SSHRC), the Canadian Foundation for Innovation (CFI), and Genome Canada (Sharma, 2012). Also, there is a network of 200 plus federal laboratories and science facilities across Canada with networked research in place (Government of Canada, 2009, p. 31). Canada's latest science strategy – Mobilizing Science and Technology to Canada's Advantage (Industry Canada, 2007; OECD-Canada, 2010) emphasized application of large-scale networking fundamentals to pursue "entrepreneurial advantage, knowledge advantage, and people advantage" for global leadership in innovation (Government of Canada, 2009, p. 9). The policy asserts that innovation is increasingly multi-disciplinary, collaborative, and network based (Government of Canada, 2009, p. 30). The strategy to foster the partnership doctrine pushes for innovation through large-scale participatory networks between the "federal agencies, other levels of government, the private sector, the academic community, and international partners" (Government of Canada, 2010, p. 1; OECD-Canada, 2010). The progress report on Mobilizing Science and Technology to Canada's Advantage, 2009, underlines the networked approach to science management as key catalyst in realizing Canada's vision of global leadership in innovation. It places the development of large-scale research networks at the heart of the plan to facilitate access to novel information and advice (Government of Canada, 2009, p. 41; Schwab, 2010).

Canada's national innovation strategy 2002, mentions that R&D focussed clusters comprising "universities, technical institutes, research hospitals, government laboratories or private sector facilities" are a key source of competitive innovation. Successful clusters have a strong and vibrant entrepreneurial base of networked and interdependent firms, which ultimately accelerates the pace of innovation, attracts investment, stimulates job creation and generates wealth.[137]

[137] http://publications.gc.ca/collections/Collection/Iu4-5-2002E.pdf (pg 13)

Networked science is on the rise internationally. An OECD review in 2010 identified the key S7T policy frameworks for member countries and how they have strategically placed networking elements around large-scale partnerships, integrated and synergized innovations, and domestic-foreign innovation linkages (Table 1).

Table 1: GLOBAL SCIENCE AND TECHNOLOGY POLICY FRAMEWORKS

Country	S&T policy frameworks	Network elements
Australia	Powering Ideas, 2009	Strengthen integrated approach to innovation and improve Australia's linkages with global innovation systems
Canada	Mobilizing S&T to Canada's Advantage, 2007	One of the core strategic focus is to foster research partnership
Denmark	Globalization Strategy, 2012	Focus on efforts that contribute to networking and collaboration with worldwide research initiatives
Finland	Innovation Strategy, 2008	Encourage stakeholder involvement in the development of collaborative alliances amongst domestic firms
France	National Research and Innovation Strategy, 2008	Prioritize synergized innovation efforts amongst stakeholders present in competing innovation clusters
Germany	High-Tech Strategy, 2020	Encourage innovation based linkages
Netherland	R&D Promotion Act (WBSO)	Add funds to strengthen domestic and foreign innovation linkages
Sweden	Research and Innovation Bill, 2008	Renew funding to promote sustained research relationships
UK	Science & Innovation Investment Framework	Focus research and innovation activities on large innovative firms and strong internal/foreign linkages
USA	American Recovery and Reinvestment Act, 2009	Allocate financial backing to large-scale partnership oriented innovation models

Source: (Industry Canada, 2010; OECD various, 2010; Publishing and Depository Services, 2007)

The shift towards large-scale networked research ventures assumes that formal innovation networks can mobilize these human resources to interact and exchange in ways that positively impacts latent innovation capacities.

3. Theory

The move towards large-scale research systems has stimulated a global debate about its significance and impact. One arguments is that execution of large-scale research enables formal and informal methodical interactions and relationship building, which generates value to researchers, funders, and the economy. In sociological terms, this value is referred as "social capital" (Hanifan, 1916), which generates downstream productive residual outcomes in terms of research capacity and commercial results that can positively affect national innovation agendas. This justifies continual public funding. This is a compelling theory but there is limited evidence to connect large scale innovation research, social capital, and residual beneficial outcomes. There is not enough empirical substantiation to identify or quantify the social capital harbored in large-scale projects or to relate that capital with downstream benefits. This paper assess the relationship between large-scale research ventures, social capital, and its downstream productive outcomes by examining a case of federally supported large-scale research project — Genome Canada's Applied Bioproducts and Crops (ABC) Competition.

Large-scale innovation projects are examined through the theoretical lenses of Mode 2 knowledge (Gibbons et al., 1994), National Systems of Innovation (Lundvall, 1992), Triple Helix Model (Etzkowitz & Leydesdorff, 1998; Leydesdorff, 2000, 2003) and social capital (Hanifan, 1916). One school of thought posits innovation is an outcome of 'special processes', with their theoretical base in the systems literature. The contemporary research policy framework is also embedded within the systems theory that makes it plausible to explain both innovation and research policy elements through systems-based theoretical and practical underpinnings (Leydesdorff, 2003, p. 446). Contemporary knowledge in these systems tends to be context-driven, reflexive, heterogeneous, problem-focused, and trans-disciplinary. The Mode-2 world is inherently full of network interactions of talented human resources (Gibbons et al., 1994; Shinn, 2002). In this context, collaborative networks involve state, academia, and industry in public interactions are that effect production and transfer of mode-2 knowledge – an essential input to contemporary innovation and research (Etzkowitz, 1983; Gibbons et al., 1994, 1-17; Shinn, 2002).

Contemporary innovation performance also depends on the attributes of interactions (joint research, personnel exchanges, cross-patenting, etc.) between institutions (private enterprises, universities, public research institutes, and employees). Innovation under National Systems of Innovation (NSI) combines "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (C. Freeman, 1995). In the NSI model, complex connections and feedback loops amongst relevant actors set agendas, determine research priorities, and engaging in contemporary knowledge production (Lundvall, 1992). The NSI model views research and innovation performance as a variable that depends on decoding actor interaction complexities (Lundvall, 1992; OECD, 1997). The Triple Helix approach models innovation as triage convergence, association, and cross-functional intricacies of exchange and cooperation amongst actors, regulations, and institutions (Benner & Sandstrom, 2000; Etzkowitz, 2008, p. 7; Etzkowitz & Leydesdorff, 1998; Viale & Ghiglione, 1998, p. 3). Fraternal innovation networks, under the TH model, generate transformational effects on global and national innovation environment (Gibbons et al., 1994). The spiral arrangement in the Triple Helix model captures the standalone status and intricacies of multiple reciprocal relationships among public, private, and academic institutional settings and postulates institutional orders and re-structuralizations of organizational fields (Benner & Sandstrom, 2000). Universities, industry and government, the three functionally and schematically distinct institutions that underpin the triple helix world involving large-scale projects, develop networks, expand capacities, and augment outputs. The Triple Helix configuration, with rearrangements, mobility, and integration functions as a stimulant to innovation by inspiring creativity and generating dynamic network of proactive exchange relationships (Etzkowitz, 2008, pp. 12-18; Leydesdorff & Etzkowitz, 2000).

Similar to the NSI approach and Triple Helix model, social capital conceptualizes innovation as a result of the complexities of human interaction. Social capital has no undisputed definition due to substantive and ideological complexities (Adler & Kwon, 2002). Table 2 classifies a range of frequently used definitions of social capital into four main typologies based primarily on network actors and their action/behaviors, structural placement, psychological placement and resource utilization.

Social capital typologies conform or contradict each other based on source, relations, affects, or tie types (Adler & Kwon, 2002; R. D. Putnam, 2000; Robison et al., 2002). Social capital is supposed to exist in relations of trust, social exchange, embeddedness, relational

contracts, and social networks (Adler & Kwon, 2002, p. 18). An actor's location and their connections to others in the innovation network generates a personal advantage (Burton, Wu, & Prybutok, 2010). The NSI and Triple Helix pinpoint collaborative structures as seats of contemporary innovation. These networked structures, exchange relationships, social structures, and personal network are also assumed to be breeding ground for social capital. Social capital produces tangible effects (physical or financial resources) or intangible benefits (prestige, power, influence, trustworthiness) for the related actors (Coleman, 1988, pp. S98-101). Though an elusive concept, the presence and levels of social capital are deducible via the amount of benefits drawn or resources accessed during participation in social relations (Savboda, 2010, p. 83).

TABLE 2: TYPOLOGY OF SOCIAL CAPITAL BASED ON COMMON DEFINITIONS

Authors	**What is social capital?**	**Where does social capital reside?**	**What are benefits/outcomes of Social capital?**
Action based view on social capital			
Coleman (1990)	Entity with social structure	Social structure	Facilitates actions from structure stakeholders
Portes and Sensenbrenner (1993)	An expectation for action within collectivity	In collectivity	Affect the economic goals and goal-seeking behavior of its members
Putnam (1993)	--	• Networks • Norms • Social trust	• Improves the efficiency of society by facilitating coordinated actions • Facilitate cooperation for mutual benefit
Fukuyama (1995,1997)	Ability of people to work together in groups, certain informal values or norms shared by group members	Among group members	Permits cooperation amongst group members
Narayan and Pritchett (1997)	--	--	• Community cooperative action • Strengthened communal harmony that speeds diffusion of innovations, improves quantity/quality of information flows and reduces transactions costs • Splits risk, allowing for higher risk/ higher return activities
Kwon (2002)	Fabric of social relations	In social relations	Can be activated to facilitate action
Social Capital as outcome of positional placement of individual in a network			
Baker (1990)	Resource driven by actors from social structures	In social structures	Used to pursue actors individual interests
Schiff (1992)	Set of elements of the social structure	In social structure	Affects relations among people, inputs of production and utility function
Burt (1992, 2000)	-	In network structures	Give opportunity to network individuals to use other forms of capital

TABLE 2: TYPOLOGY OF SOCIAL CAPITAL BASED ON COMMON DEFINITIONS			
Authors	**What is social capital?**	**Where does social capital reside?**	**What are benefits/outcomes of Social capital?**
Portes (1995)	Capacity of individuals to command scarce resources	In networks or broader social structures	-
Kwon (2002)	Resource available to actors as a function of their location	In the structure of their social relations	-
Social Capital as outcome of psychological placement of the individual in a network			
Bourdieu (1985, 2006)	Social obligations or connections	-	Convertible into economic capital under certain conditions
Robinson (2002)	Is sympathy	In exchange relationship	Generates potential benefit, advantage, and preferential treatment for network members
Resource-based view on Social Capital			
Boxman (1991)	• Property of network • Network-as-resources	Personal networks	Where people benefit in a social network through exchange of social resources
Bourdieu (1985, 2006)	Aggregate of actual or potential resources	-	Creates network of institutionalized relationships
Nahapiet & Ghoshal (1998)	Sum of actual & potential network resources	Network of Relationships	
Knoke (1999)	Social actors create and mobilize their network connections	Network connections	Gain access to other social actors' resources

Different concepts are used to conceptualize social capital. Bonding or bridging concepts track an actor's social network position and identify their access to social capital in innovation networks. In an innovation collective, where internal network exchanges can generate bonding social capital, actor relations with external networks can procure bridging equivalent and its advantages (Adler & Kwon, 2002, p. 19; R. D. Putnam, 2000). Similarly, bonding social capital can positively impact innovation performance by reinforcing group cohesion and trust that minimizes task and relational conflicts. Bridging ties can encourage novelty and diversity in ideas —essential inputs to contemporary knowledge production – which in turn are crucial constituents to innovation (R. S. Burt, 1997, p. 340; Yuan & Gay, 2006). Similarly, the closure model (R. S. Burt, 2005) explains the benefits of internal versus external relations to networks engaged in innovation. Dense, closed, and highly cohesive innovation networks — with excessive closure – assist internal information exchange of resources, whereas bridging with external actors or networks permits access to novel information. Burt (2005) asserts systems requires structural holes to allow for new ideas to emerge; tightly bonded systems are often antagonistic to external stimulus. Ties with the external environment improves innovation performance as they broadens knowledge conception, ensures diversity of opinion, and procures resources which align and legitimizes internal organizational practices with external competitors

(Argote & Ophir, 2002; R. S. Burt, 2004). In an innovation guided and knowledge-based economy, the diversity of information and resources improve intellectual exchange of ideas and the national competitive edge (Mollica, Gray, & Trevino, 2003).

4. Methodology and conceptual framework

This paper examines Genome Canada's large-scale research project operations, in specific its social capital outcome, with the downstream residual results. Genome Canada's large-scale funding initiatives into the Canadian agri-food research, spanning 2000-2009, forms the network of interest. Genome Canada is a not-for-profit organization established in 2000 (Brzustowski, 2010). The organization has sponsored projects of multi-disciplinary teams of experts from national and international research communities to associate in peer-reviewed research projects. Genome Canada range four main competitions in the 2000-2009 period (see chapter 1 in this report) — I and II with CAD $136 million and CAD $155.5 million invested respectively (both held in 2001), III with $346 million investment (held in 2004), and the Applied Genomics in Bio-products and Crops (ABC) Competition with $112 million invested (held in 2009).

To frame this analysis, we focused on the social capital underpinning the ABC competition, which funded 139 investigators in 12 successful projects. These investigators are assigned with unique numerical identifier to reflect their project association but conceal their identity. Binary data is collected from publically available artifacts on four network relations, namely: (i) Disciplinary affiliations capturing disciplinary ties based on ISI categorization of peer-reviewed publications (2000-2009); (ii) Institutional connections extracting physical co-location ties based on location of primary employment from 2000-2009; (iii) other Research Grants from peer-reviewed grants, based on a review of 2000-2009 years of grants awarded by CIHR, NSERC, SSHRC, CFI, and Genome Canada; and (iv) Co-publications network recording prior co-publication links based on ISI search of all published works.

Social Network Analysis (SNA) tools and algorithms, embedded in Analytical Technologies –UCINET and Netdraw software, are utilized for data analysis and to construct sociograms (Borgatti, 2002). The key SNA descriptive statistics describe, predict, and test for the presence or absence of relationships and help to identify core network actors (Angehrn & Gibbert, 2005, p. 526). It is often challenging to quantify or estimate outcomes of network based exchanges (trust, goodwill, or social capital, etc.) due to their intangible and complex nature. However, SNA can "make the invisible visible" and reveal concealed patterns within relations (Mead, 2001; Wasserman & Faust, 1994). SNA provides a functional method to identify and characterize complex interactions and exchanges occurring within networks. SNA has two main focuses – "the actors and the relationships between them in a specific social context" (Serrat, 2009, p. 1). It can identify "top leadership networks," "boundary spanners, gatekeepers, knowledge bottlenecks …. under and over-utilized individuals or organizations," ….and "opportunities or constraints on individual action" (Cross, Borgatti, & Parker, 2002 in; Ryan, 2007, pp. 46-47). Social network position (SNP) offers differential access of network resources (goods, financial capital, information) and gives economic meaning to social capital (product of social exchanges) (Clark, pp. 4-5). Network characteristics such as "contacts, ties, connections, group attachments…..as means to relate one actor to another" are most probable predictors of trust and goodwill and can be taken as indicators of social capital (Putnam, 1995: 67). SNA

technique makes it feasible to identify groups, pinpoint isolates, and decipher core-periphery network structure where core actors have dense internal ties while periphery actors have more ties with core actors than amongst themselves (Hanneman & Riddle, 2010a). In addition to generating a qualitative pictorial representation of network in question, SNA software generates quantitative measures to depict network structure. These quantitative outcomes offer statistically verifiable representations to the network (Borgatti, 2002).

The current analysis employs network measures of density, centrality, and correlation algorithms to collect evidence. Network density outcomes confirm overall interactions and the ratio of interconnections within innovation networks (Hanneman & Riddle, 2010b; Knoke & Kuklinski, 1982, p. 45). Network density is analogous to the mean number of ties per group member where a high number of in and out ties indicate high network exchanges, higher density, and more social capital, with its attendant positive impacts (Belliveau, O'Reilly, & Wade, 1996, p. 1572; Sparrowe, Liden, Wayne, & Kraimer, 2001, p. 317). Network centrality measures identify dominant actors, institutions, or research teams within the broader innovation network. They also signal the core actors that control resources and have better choice of alternatives (Sparrowe et al., 2001, pp. 316-317). Relative to the tangential actors, central nodes develop more competencies due to superior resource access. High impact positions, assigned to complex tasks, are posited to positively link with individual performance and network outcomes (Baldwin, Bedell, & Johnson, 1997; Molm, 1994; Sparrowe et al., 2001).

The network centrality measure is delineated into three sub-measures. Betweenness centrality identifies how often an individual is positioned on the shortest paths between two other actors. An actor with a high betweenness score is on the geodesic paths between pairs of other actors in the network. In Equation 1, *gij* represents the number of ties linking *i* and *j* and *gij(pk)* is the number of these ties that contain individual *k* (L. C. Freeman, Borgatti, & White, 1991, pp. 141-154).

$$CentralityBetweenness = 2\sum_i \sum_j \frac{\frac{g_{ij}(p_k)}{g_{ij}}}{n2-3n+2} \quad \text{..... Equation (1)}$$

Degree centrality (DC) is “the number of ties incident upon a node” or the “number of paths of length one that emanate from a node”(Borgatti, 2005, p. 62). DC of node i is the sum of In Degree (IDC) and Out Degree (ODC) (Haiyu & Yoong, 2010, p. 233).

$$\boxed{DC(i) = IDC(i) + ODC(i)} \quad \text{..... Equation (2)}$$

The eigenvector approach identifies the most central actors as those with the smallest distance from the other actors in the network (Hanneman & Riddle, 2010c). Eigenvector centrality measures the aggregate prominence of an actor by calculating centrality as a function of centrality of others to whom an actor is connected via direct or indirect ties (Bonacich, 1987, pp. 1172-1173; Ibarra, 1993, p. 480).

$\lambda v = Av$..... Equation (3)

Here v is the eigenvector of A and λ is the associated eigenvalue (constant). Eigenvector measures assumes that when an actor influences other nodes, they subsequently influence many other nodes, and the chain continues, so that the chain originator actor is highly influential (Bonacich, 1987, p. 1172; Borgatti, 2005, p. 61). Table 3 details the affects of social network position, depicted via centrality scores, on the innovation outcomes at an actor's level.

TABLE 3: IMPACT OF SOCIAL NETWORK POSITION ON ACTOR LEVEL AND NETWORK LEVEL OUTCOMES

	Betweeness Centrality (BC)	**Degree Centrality (DC)**	**Eigenvector Centrality (EC)**
Implications	A network actor with high BC is positioned on the geodesic paths between pairs of other actors in the network and functions as a bridge or broker of flow of information and communication between these actors.	A network actor with high DC is positioned in the center of the network and functions as a hub or core in decisions, communications, and information flows.	A network actor with high EC has direct or indirect ties with other actors who themselves have high centrality.
Actor level outcomes (centrality)	Identifies network actor(s) that : -control information flows -link the network -are potentially influential	Identifies network actor(s) that are: -central in location and/or activity (in-degree and out-degree assessment) -highly connected, signified with high number of links, to other actors	Identifies network actor(s) that are: -central or prominent -connected to other central or influential actors

Source: (Baldwin et al., 1997; Hanneman & Riddle, 2010c; Ibarra, 1993; Molm, 1994; Sparrowe et al., 2001)

Finally a correlation analysis is performed to test the symmetric association between social network position and social capital's latent outcomes. Equation 4 generates value of correlation coefficient (r) for observation ranging from (x1, y1), (x2, y2) ... (xn, yn).

$$r = \frac{1}{n-1}\sum\left(\frac{x-\bar{x}}{s_x}\right)\left(\frac{y-\bar{y}}{s_y}\right)$$

……..... .Equation (4)

Value of (r) is between -1 and 1, respectively indicating perfect negative and positive correlation (O'Connor, 2011; Yale University, 1998).

A correlation matrix tests social network positions (SNPs) as artefacts of social capital in the large-scale innovation environment. A proxy for social capitals' latent or downstream effects is devised to address unavailability of actual residual artefacts. Proxy employed in the analysis is the dollar amounts value awards in each of the 12 successful ABC competition projects. The analysis correlates social network position (the social capital artefact) using different centrality measures (degree, betweenness, and eigenvector) and the dollar amount of allocations to 12 successful project. This analysis is performed for all of the 139 sample investigators.

5. Results

The centrality counts in Table 4 identify a number of high impact social network individuals. High density scores indicate excessive network closure with restrictive inflow of novel information into the system. On that basis, the area of expertise analysis suggests that the investigators were highly linked, most with other high linkers; there were few structural holes in this space and only a small number of bridgers. In contrast, there is low network density using institutional connections, research grants and co-publications. Moreover there were only a few central actors that ranked as significant using the eigenvector measure and conversely, a little more relative reliance on bridging actors.

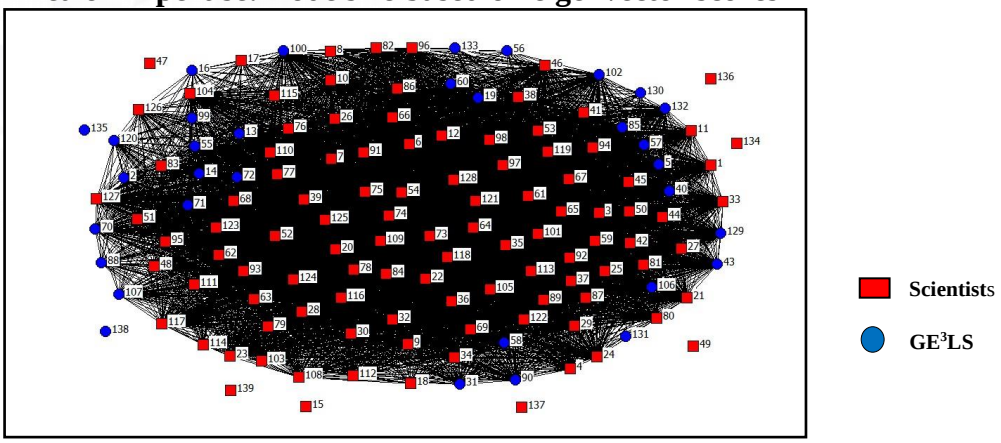
TABLE 4: SUMMARY OF HIGH IMPACT ACTORS (N=139)

Networks of interest	Number of active nodes	Network Density (without isolates)	Number of central network actors*		
			Betweenness	Degree	Eigenvector
Area of Expertise	130	0.7471	9	44	122
Institutional Connections	105	0.0689	5	4	14
Research Grants	50	0.1075	2	2	11
Co-publications	100	0.0225	14	7	4

* Threshold of 2 standard deviations to access central/high impact actors

Looking explicitly at the areas of expertise (aka disciplinary strengths), we can see bridging social capital is sparse and mediator advantage is significantly reduced in this dense environment, as there are adequate alternate channels to ensure resource exchange (Sociogram 1). None of the 139 actors, via expertise, assert leadership or prominence that could affect innovation oriented decisions. Equal power and influence fails to identify central network actor (N=122).

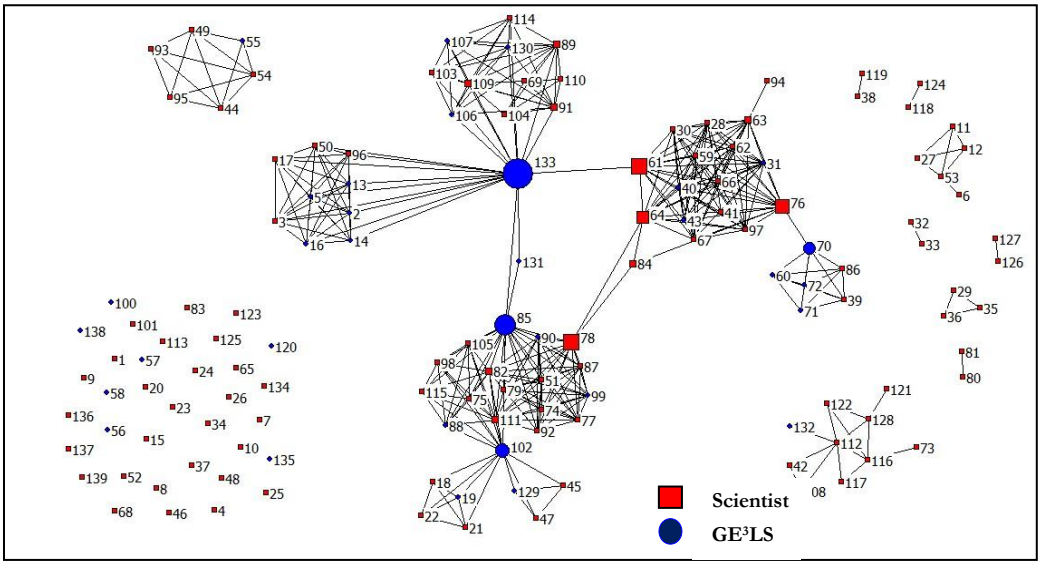
Sociogram 1: Area of Expertise: Node size based on eigenvector scores



* Active nodes= 130 ** Node color and shape indicates affiliation

Genome Canada competitions from 2000-2009 have successfully constructed project teams with significant cross-affiliated, multi-institutional ties. The incidence of dense intra-institutional linkages with sparse inter-institutional connections leads to a pronounced brokerage role for a core group of individuals (Sociogram 2). The presence of bridging social capital broadens the functional space, facilitating access to external resources, and contributing to more diverse opinions in the innovation process (N=5). Institutional homophily – where a contact between similar people occurs at a higher rate than among dissimilar people – is balanced with a few critically placed inter-institutional connections, making available high quality first-hand information and resources to relevant actors. The structure of co-location ties facilitates identification of core actors (N=4) with high degree scores. Their core social network position can accelerate communications, resource exchange, and joint decision making between affiliates. Prominence and power for high eigenvector scorers is assured through connectivity with other prominent actors in the cluster (N=12).

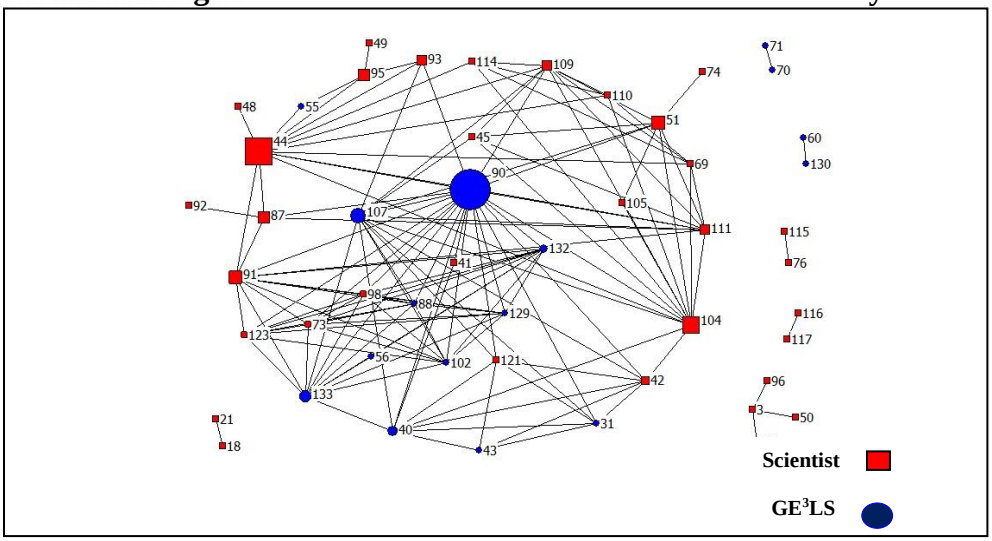
Sociogram 2: Institutional Connection: Node size based on betweenness scores



* Active nodes= 105 ** Node color and shape indicates affiliation

Network partnerships have developed amongst 35 percent of 139 actors (N=50) through research grants. Bridging advantage is shared amongst two core actors who also have equal access to bonding social capital (Sociogram 3). Their social network position strengthens their role in communication and negotiations essential to accessing research funds or awards. Prominent network actors influence decisions impacting research grant acquisition (N=11).

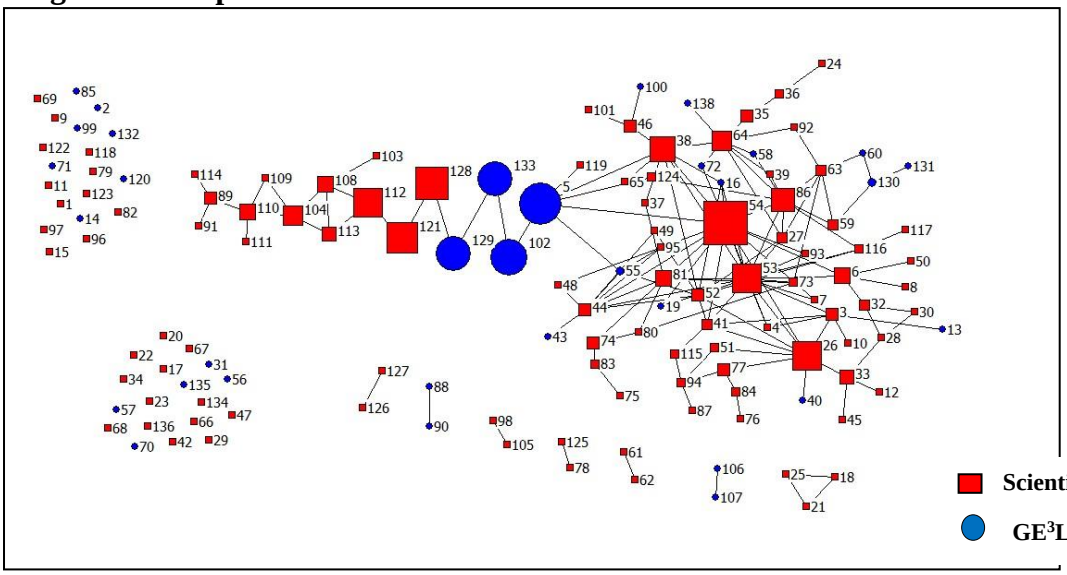
Sociogram 3: Research grants: Nodes size based on betweenness centrality



* Active nodes= 50 ** Node color and shape indicates affiliation

Knowledge production through co-publication exhibits the lowest relative density among the four domains, with approximately 18 percent of the total 139 actors displaying some aspect of centrality (Sociogram 4).

Sociogram 4: Co-publications network: Node size based on betweenness centrality



* Active nodes= 100 ** Node color and shape indicates affiliation

The gatekeeper or bridge position in the large-scale co-publications environment generates operational independence for relevant actors (N=14). High impact actors with multiple connections demonstrate bonding social capital which is critical in co-publication related decision-making and information exchange (N=7). These actors with hub functionality are assigned high social status. Informal network leadership is identified for four actors that have access to novel resources, influence co-publication related decisions, and set future directions.

Now lets move on to the impact of social capital on innovation outcomes. Table 5 records the results of correlation performed between 139 actor centralities depicting social network positions and their impact on downstream research capital in Genome Canada ABC competition (identified through the proxy of the dollar amount allocation to 12 ABC competition projects). The correlation takes the premise that in large-scale networked project, the core actors have access to social capital, which positively impacts projects downstream latent outcomes.

TABLE 5: CORRELATION BETWEEN CENTRALITY AND ACTOR-WISE $ AMOUNT (N=139, df=137)

Relations	Centrality Outcomes	Actor-wise $ amount	r	Probability
Area of Expertise (AOE)	AOE Betweenness Centrality(Nrm)	$ amount	-0.234	0.002**
	AOE Degree Centrality	$ amount	-0.163	0.027*
	AOE Eigenvector Centrality(Nrm)	$ amount	-0.186	0.01*
Institutional Connections (IC)	IC Betweenness Centrality (Nrm)	$ amount	-0.010	-
	IC Degree Centrality	$ amount	0.056	-
	IC Eigenvector Centrality (Nrm)	$ amount	-0.053	-
Research Grants (RG)	RG Betweenness Centrality(Nrm)	$ amount	0.178	0.01*
	RG Degree Centrality	$ amount	0.049	-
	RG Eigenvector Centrality(Nrm)	$ amount	0.073	-
Co-publication (CP)	CP Betweenness Centrality (Nrm)	$ amount	0.029	-
	CP Degree Centrality	$ amount	0.147	0.04*
	CP Eigenvector Centrality (Nrm)	$ amount	0.079	-

* p<0.05, **p < 0.01, ***p < 0.001,

Expertise did not seem to deliver positive returns. The correlation and probability statistics in expertise based relation show a negative relationship between actor centralities and their potential to procure investments for future projects. Bridging centrality in this system imposed the highest penalty, perhaps because the densely packed system did not need the bridging function. Correspondingly, both high degree scorers and those with links to other prominent and influential network actors were impaired, but somewhat less than for bridgers. In total, social capital produced via disciplinary ties is found to negatively impact future financing in this space. Rather, large-scale project environment favours cross-disciplinary ties more than in-field relationships and rewards those engaging in such efforts relatively more. All three, expertise-based correlations were statistically significant (p<0.05) at 95 percent confidence or higher.

Contrary to a common view, institutional linkages or real time interactions add little or no incremental value to future returns. The relation between the number of network linkages between actors and their ability to procure research capital is weak and statistically insignificant. Overall, co-location oriented correlations are probably neutral and insignificant.

In the grants based network, a positive and significant ($p<0.05$) linear relationship is ascertained between network spanners and their likelihood to gain in future research awards ($r=0.178$). In contrast, those with a high number of financial tie-ups have weak and insignificant association to downstream fund raising possibilities. These results are replicated for investigators that share close associations with other prominent network actors (eigenvectors). In some ways this suggests that that Matthew Effect discussed in Chapter 3 is not as strong as many fear. We see some evidence that the large-scale granting space does actually reward people looking to explore recombination more than those seeking to pursue iterative research.

Using knowledge co-production ties, the correlation between actor degree centrality scores and funding in ABC competition are positive, but weak (within 0 - 0.2 range), but statistically significant ($p<0.05$) at 95 percent confidence level. On the contrary, there is positive but very weak and non-significant relation between spanner and eigenvalue social network positions and research awards in the ABC competition. In other words, the likelihood of past co-publication ties generating future monetary benefits is more likely for core actors with multiple ties than for actors with spanner or eigenvector functionalities.

6. Conclusions

The national S&T agendas have incorporated networks based models to execute science innovation and research. Contemporary research networks are constructed through amalgamation of people, institutions, and resources that adds up into a large-scale configuration.

The personal and institutional exchanges in large-scale project interactions produce a networked environment or broader social structure for generation of social capital. Large-scale research and innovation projects: create conditions of collectivity; increase communities' cooperative action; generates social obligation; augments group cohesion; and sustains communal harmony that minimizes task and relational conflicts. Such circumstances produces relationships of trust and goodwill — the base conditions for generation of social capital. The involvement of cross-disciplinary and multi-institutional stakeholders in large-scale project setting augment the exchange process, produce social capital and expose the affiliates to benefits of social capital. The generation of social capital in large-scale research positively affect the economic goals and the goal-seeking behavior of individuals, facilitates cooperation for mutual benefit, improves efficiency by facilitating coordinated actions, assists in preferential treatments to network members, aids in splitting of risk and persuasion of riskier high return activities and facilitates further networking opportunities to use other forms of capital.

Our analysis suggests that the maximum benefits of social capital appear to accrue in large-scale innovation projects that: have minimal requirements for co-location or real time interactions; encourage hybridization across disciplines; and facilitate cross-disciplinary exchanges through personnel mobility, knowledge production, and partner research grants. Public funding for projects supporting co-publication opportunities and partnered research awards, appear to offer a positive way to sustain research and innovation.

Government efforts to include network frameworks in science and technology policy works stimulates the allocation of public and private funds to large-scale innovation projects. The current research confirms greater success for publically funded large-scale research on inclusion of: cross disciplinary teams; opportunities for knowledge production and research grants partnerships; and minimal requirements for project teams to co-locate. The identification of positive downstream impact of social capital in large-scale projects provides a strong rationale for the federal government (and other funding organisations) to financially back research of scale. Policy frameworks reinforcing integration of people, disciplines, and institutions has the potential to generate social capital that not only has present day benefits but long term returns. Policy and monetary support for large-scale innovation ventures, such as Genome Canada programming, emerge to positively impact and sustain research and innovation and presents a strong case for support to large-scale innovation ventures.

Bibliography

Adler, P.S., & Kwon, S.W. 2002. Social Capital: Prospects for a New Concept The Academy of Management Review, 27(1), 17-40.

Angehrn, A. A., & Gibbert, M. 2005. Learning Networks.

Argote, L., & Ophir, R. (Eds.). 2002. Intraorganizational learning. Malden: MA: Blackwell.

Baldwin, T. T., Bedell, M. D., & Johnson, J. L. 1997. The social fabric of a team-based M.B.A. program: Net-work effects on student satisfaction and performance. Academy of Management Journal, 40(6), 1369-1397.

Belliveau, M. A., O'Reilly, C. A., & Wade, J. B. 1996. Social capital at the top: Effects of social similarity and status on CEO compensation. Academy of Management Journal, 39(6), 1568-1593.

Benner, M., & Sandstrom, U. 2000. Institutionalizing the triple helix: research funding and norms in the academic system. Research Policy, 29(2), 291–301

Bonacich, P. 1987. Power and centrality: A family of measures. . American Journal of Sociology,, 92(5), 1170-1182.

Borgatti, S.P. 2002. NetDraw: Network visualization. Harvard, MA: Analytic Technologies.

Borgatti, S.P. 2005. Centrality and network flow. Social Networks, 27, 55–71. doi: 10.1016/j.socnet.2004.11.008

Bourdieu, P. (Ed.). 1985. The forms of capital New York: Greenwood.

Bourdieu, P. (Ed.). 2006. The Forms of Capital- Education, Globalization, and Social Change. New York: Oxford University Press.

Boxman, E. A. W., De Graaf, P. M., & Flap, H. D. 1991. The impact of social and human capital on the income attainment of Dutch managers. Social Networks, 13, 51-73.

Brzustowski, T. 2010. Budget 2010 and Canadian S&T. The Canadian Science Policy Centre. from http://sciencepolicy.ca/news/budget-2010-and-canadian-st

Burt, G. 1992. Structural Holes. Cambridge: Harvard University Press.

Burt, R.S. 1997. The Contingent Value of Social Capital Administrative Science Quarterly, 42(2), 339-365.

Burt, R.S. 2004. Structural holes and good ideas. American Journal of Sociology, 110(2), 349-399. doi: 10.1086/421787
Burt, R.S. 2005. Brokerage and Closure: An introduction to social capital
Burton, P., Wu, Y. A. & Prybutok, V. R. 2010. Social Network Position and Its Relationship to Performance of IT Professionals Informing Science: the International Journal of an Emerging Transdiscipline, 13, 1.
Clark, L. 2006, 15, November, 2010. Network Mapping as a Diagnostic Tool. from http://www.mande.co.uk/docs/networkmapping_LC06.pdf
Coleman, J. S. 1988. Social capital in the creation of human capital. The American Journal of Sociology, 94, S95-S120.
Coleman, J. S. 1990. Foundations of social theory: The Belknap Press of Harvard University Press.
Cross, R., Borgatti, S.P., & Parker, A. 2002. Making Invisible Work Visible: Using Social Network Analysis to Support Strategic Collaboration. California Management Review, 23.
Etzkowitz, H. 1983. Entrepreneurial scientists and entrepreneurial universities in American academic science. Minerva, 21(2), 198-233. doi: 10.1007/bf01097964
Etzkowitz, H. 2008. The Triple Helix: University Industry Government Innovation in Action (First ed.). New York: Routledge.
Etzkowitz, H., & Leydesdorff, L. 1998. The triple helix as a model for innovation studies. Science and Public Policy, 25(3), 195-203.
Freeman, C. 1995. The National System of Innovation in Historical Perspective. Cambridge Journal of Economics 19, 5-24.
Freeman, L. C., Borgatti, S. P., & White, D. R. 1991. Centrality in valued graphs: A measure of betweenness based on network flow. Social Networks, 13, 141-154.
Genome Canada. 2010. Welcome to Genome Canada's GE3LS Page. Retrieved 5 June 2011, 2010, from http://genomecanada.ca/en/ge3ls/
Genome Canada. 2011. About Genome Canada. Retrieved 21 October 2011, from http://www.genomecanada.ca/en/about/
Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. 1994. The new production of knowledge: The dynamics of science and research in contemporary societies. London: SAGE Publications Ltd.
Government of Canada. 2009. Mobilizing Science and Technology to Canada's Advantage - Progress Report 2009. Ottawa: Publishing and Depository Services Retrieved from http://www.ic.gc.ca/eic/site/ic1.nsf/vwapj/STProgressReport2009.pdf/$file/STProgressReport2009.pdf.
Government of Canada. 2010. Overview of the Federal S&T Map of Outcomes and Activities: Federal S&T Community Secretariat.
Haiyu, Jin, & Yoong, W. K. 2010. A Network Analysis of Concept Maps of Triangle Concepts. Paper presented at the Shaping the future of mathematics education: Proceedings of the 33rd annual conference of the Mathematics Education Research Group of Australasia, Fremantle. http://www.merga.net.au/documents/MERGA33_Haiyue&Wong.pdf
Hanifan, L. J. 1916. The Rural School Community Center. Annals of the American Academy of Political and Social Science, 67, 130-138.
Hanneman, A. R., & Riddle, M. 2010a. Chapter 4. Working with NetDraw to visualize graphs. Riverside: University of California.

Hanneman, A. R., & Riddle, M. 2010b. Chapter 7. Connection and Distance. Riverside: University of California.
Hanneman, A. R., & Riddle, M. 2010c. Chapter 10. Centrality. Riverside: University of California.
Ibarra, H. 1993. Network centrality, power, and innovation involvement: Determinants of technical and administrative roles. Academy of Management Journal, 36, 471-501.
Industry Canada. 2007. Prime Minister releases national science and technology strategy to strengthen Canada's economy. Retrieved 4/10, 2010, from http://pm.gc.ca/eng/media.asp?id=1656
Industry Canada. 2010. Mobilizing Science and Technology to Canada's Advantage, 2007: Chapter 3: Entrepreneurial Advantage. Retrieved 5 November, 2010, from http://www.ic.gc.ca/eic/site/ic1.nsf/eng/00864.html#box57
Knoke, D., & Kuklinski, J.H. 1982. Network Analysis. Series: Quantitative Applications in the Social Sciences. CA: Thousand Oaks: Sage.
Leydesdorff, L. 2000. The triple helix: an evolutionary model of innovations. Research Policy, 29, 243-255.
Leydesdorff, L. 2003. The mutual information of university-industry-government relations: An indicator of the Triple Helix dynamics. Scientometrics, 58(2), 445-467.
Leydesdorff, L., & Etzkowitz, H. 2000. The dynamics of innovation: from National Systems and ‘‘Mode 2’’ to a Triple Helix of university–industry–government relations. 29, 109–123.
Lundvall, B. A. 1992. National Systems of Innovation. Towards a Theory of Innovation and Interactive Learning London: Pinter Publishers.
Mead, S. 2001. Using social network analysis to visualize project teams. Project Management Journal 32(4), 32-38.
Mollica, K. A., Gray, B., & Trevino, L. K. 2003. Racial homophily and its persistence in newcomers' social networks. Organization Science, 14(2), 14.
Molm, L.D. 1994. Dependence and Risk: Transforming the Structure of Social Exchange Social Psychology Quarterly, 573 (Conceptualizing Structure in Social Psychology), 163-176.
Nass, J.S., & Stillman, W.B. 2003. Large Scale Biomedical Science- Exploring Strategies for Future research Stillman W.Bruce Nass J.Sharyl (Ed.) Retrieved from http://www.nap.edu/openbook.php?record_id=10718&page=R2
O'Connor, T. 2011. MegaLinks in Criminal Justice. Retrieved 15 December, 2011, from http://www.drtomoconnor.com/3760/3760lect07.htm
OECD-Australia. 2010. OECD Science, Technology and Industry Outlook: Country Profiles: Australia (Country notes-Reports). Retrieved 1 January 2011 http://www.oecd.org/dataoecd/31/0/46663563.pdf
OECD-Canada. 2010. OECD Science, Technology and Industry Outlook: Country Profiles: Canada (Country notes-Report). Retrieved 1 January 2011 http://www.oecd.org/dataoecd/30/60/46663788.pdf
OECD-Denmark. 2010. OECD Science, Technology and Industry Outlook: Country Profiles: Denmark (Country notes-Report). Retrieved 1 January 2011 http://www.oecd.org/dataoecd/42/13/46664002.pdf
OECD-Finland. 2010. OECD Science, Technology and Industry Outlook: Country Profiles: Finland (Country notes-Report). Retrieved 1 January 2011 http://www.oecd.org/dataoecd/42/11/46664029.pdf

OECD-France. 2010. OECD Science, Technology and Industry Outlook: Country Profiles: France. Retrieved 7 January 2011, from OECD http://www.oecd.org/dataoecd/42/10/46664196.pdf
OECD-Netherland. 2010. OECD Science, Technology and Industry Outlook: Country Profiles:Netherland (Country notes-Report). Retrieved 1 February 2011 http://www.oecd.org/dataoecd/40/58/46665447.pdf
OECD-Sweden. 2010. OECD Science, Technology and Industry Outlook: Country Profiles:Sweden (Country notes-Report). Retrieved 7 February 2011 http://www.oecd.org/dataoecd/41/6/46665928.pdf
OECD-UK. 2010. OECD Science, Technology and Industry Outlook: Country Profiles:United Kingdom (OECD Country notes-Report). Retrieved 7 February 2011 http://www.oecd.org/dataoecd/40/28/46666019.pdf
OECD-USA. 2010. OECD Science, Technology and Industry Outlook: Country Profiles: United States (Country notes-Report). Retrieved 8 February 2011 http://www.oecd.org/dataoecd/40/27/46666029.pdf
OECD. 1997. National Innovation Systems. In OECD (Ed.), (1997 ed., pp. 48). Paris: OECD.
Portes, A. (Ed.). 1995. Economic Sociology and the Sociology of Immigration: A Conceptual Overview. New York: Russell Sage Foundation.
Portes, A., & Sensenbrenner, J. 1993. Embeddedness and Immigration: Notes on the Social Determinants of Economic Action. The American Journal of Sociology, 98(6), 1320-1350.
Publishing and Depository Services. 2007. Mobilizing Science and Technology to Canada's Advantage-2007. Ottawa: Retrieved from http://www.ic.gc.ca/eic/site/ic1.nsf/vwapj/SandTstrategy.pdf/$file/SandTstrategy.pdf.
Putnam, R. D. 2000. Bowling Alone: The Collapse and Revival of American Communities. New York: Simon & Schuster.
Putnam, R.D. 1995. Bowling alone: America's declining social capital Journal of Democracy, 6(1), 65-78.
Robison, L. J., Schmid, A. A., & Siles, M. E. 2002. Is social capital really capital? Review of Social Economy, 60(1), 1-21.
Ryan, C.D. 2007. Performance of Public-private Collaborations in Advanced technology Research networks: Network analyses of Genome Canada projects. (Doctor of Philosophy), University of Saskatchewan, Saskatoon.
Savboda, S. 2010. Network possibilities: Using network inquiry to investigate processes of social capital acquisition and mobility in an educational context. (Doctor of Philosophy Doctoral thesis), University of Saskatchewan Library, Saskatoon. (URN No. etd-05132010-113904)
Schwab, P. 2010. Canada's Budget – what does it mean for Canada's R & D and biotech firms. Retrieved 18/10/2010, from http://sciencepolicy.ca/news/canada%E2%80%99s-budget-%E2%80%93-what-does-it-mean-canada%E2%80%99s-r-d-and-biotech-firms
Serrat, O. 2009. Social Network Analysis. Knowledge Solutions, 28, 4. http://www.adb.org/Documents/Information/Knowledge-Solutions/Social-Network-Analysis.pdf
Sharma, P. 2012. Social Capital in Large-scale Projects and their Impact on Innovation: An SNA of Genome Canada (2000-2009). (Masters in Public Policy Masters), University of Saskatchewan, Sasktoon.

Shinn, T. 2002. The Triple Helix and new production of knowledge: prepackaged thinking on science and technology. Social Studies of Science, 32(4), 599–614. doi: 10.1177/0306312702032004004

Sparrowe, R. T., Liden, R. C., Wayne, S. J., & Kraimer, M.L. 2001. Social Networks and the Performance of Individuals and Groups. The Academy of Management Journal, 44(2), 316-325.

Viale, R., & Ghiglione, B. 1998. The Triple Helix model: a tool for the study of european regional socio-economic systems (Vol. 29): The IPTS Report.

Wasserman, S., & Faust, K. 1994. Social Network Analysis. Cambridge: Cambridge University Press.

Yale University. 1998. Course list for 1997-98 (Ph.D and M.A), Yale University, Connecticut. Retrieved from http://www.stat.yale.edu/Courses/1997-98/101/correl.htm

Yuan, Y. C., & Gay, G. 2006. Homophily of network ties and bonding and bridging social capital in computer-mediated distributed teams. . Journal of Computer-Mediated Communication, 11(4).