SOCIAL CAPITAL IN LARGE-SCALE PROJECTS AND IT'S IMPACT ON INNOVATION:

SOCIAL NETWORK ANALYSIS OF GENOME CANADA (2000-2009)

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ABSTRACT

The contemporary era is witnessing a systemic transition in the Canadian science and research paradigm. The research world is shrinking rapidly in response to modern technological developments, commercial and regulatory integration, faster communications and transportation and proactive science, technology and innovation policy. It is increasingly challenging to make competitive progress in world-class innovation or to gain global leadership in science. Big-science is now proposed as one of the means to realize national innovation goals and international competitiveness. As a result, government support for large-scale innovation projects has increased multifold.

This dissertation examines a range of hypotheses large-scale research projects enhance investigator exchanges and generate social capital that has significant downstream benefits, which would provide a reason to support big science beyond the instrumental goals of the projects themselves. Taking Genome Canada as an example, this dissertation examines the production and role of social capital generated through large-scale research projects to assess the evidence base for funding big science research. A group of 139 investigators who raised capital in the Genome Canada Applied Bioproducts and Crops (ABC) Competition in 2009 are examined in the context of their engagements and networks in 2000-2009 in four relational arenas, namely their area of expertise, institutional connections, research grants, and co-publications.

The investigation reveals three main findings. First, large-scale innovation projects as delivered through Genome Canada, comply with the fundamentals of contemporary innovation network theory. Second, the ties amongst investigators generate social capital, which offers positional advantage and differential superior access to networked resources. Third, the social capital generated in actor relations has pronounced long term impacts on downstream research success. Inter-disciplinary and cross-institutional large-scale research projects that have strong elements of knowledge production and financial exchange are found to assist the federal government in advancing research and innovation objectives. The results of the current investigation provide a strong rationale for the integration of people, disciplines, and institutions under the umbrella of large-scale genomics and proteomics research, and possible lessons for other research fields.

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I want to thank my parents for where I am today – my late father always instilled in me the importance of dedicated diligence and education, while my mother always encouraged me to tread on the less treaded paths and to find my own way(s) in life.

Above all I want to thank my loving husband who has been with me in every step. He has been my support system all the way. I feel obligated for his perpetual belief in my abilities and for motivating me to achieve higher heights whenever I would go a bit 'off-steam.' I want to thank my newborn son for being a fragrance of fresh air in my life (and I am NOT referring to diaper duties and sleepless night!!!). He has given me moments of immeasurable joys and happiness during the hectic work days. It is amazing to actually experience the stress-busting abilities of a baby's simple smile.

Last but not the least I want to thank God, for answering my prayers and for giving me the strength to strive continuously and to accomplish this task.

<u>DEDICATION</u>

I want to dedicate this dissertation to *my loving husband*

for

always encouraging and motivating me to reach for my dreams

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GLOSSARY OF ACRONYMS

ACOA	Atlantic Canada Opportunities Agency
ABC	Applied genomic research on Bio-products and Crops
BERD	Business Expenditure on Research and Development
CIHR	Canadian Institute of Health Research
CFI	Canadian Foundation for Innovation
GC	Genome Canada
GDP	Gross Domestic Product
GE^3LS	Genomics, Ethical, Environmental, Economic, Legal and Social
GERD	Total Gross Expenditure on Research and Development
GHI	Genome and Health Initiative
GOVERD	Gross Expenditure on Research and Development
HRST	Human Resources in Science and Technology ratio
IBM	International Business Machines
IPR	Intellectual Property Rights
ISTPP	International Science and Technology Partnerships Program
ISTC	Industry Science and Technology Canada
IT	Information Technology
NABST	National Advisory Board on Science and Technology
NCE	Networks of Centres of Excellence
NRC	National Research Council
NSERC	Natural Sciences and Engineering Research Council
NSI	National System of Innovation
OECD	Organization for Economic Cooperation and Development
R&D	Research & Development
SC	Social Capital
SNA	Social Network Analysis
S&T	Science and Technology
SSHRC	Social Sciences and Humanities Research Council
TH	Triple Helix

C h a p t e r 1

INTRODUCTION

"To raise new questions, new possibilities, and to regard old problems from a new angle requires creative imagination and marks real advance in science." *(Einstein and Leopold 1966)*

Economies today are increasingly dependent on their innovation competencies to stay ahead on the global technological curve. To fulfill the aspiration of surpassing other competitor economies in the innovation race, the Canadian government has continually refined and adjusted its research and innovation policies. In the last decade, large public investments have been made in Canada towards world-class science and innovation oriented research programs. These strategic and timely actions by the Canadian government have been indispensable in coping with the enhanced information processing requirements of the twenty-first century. The new age needs novel practices and systems which are more efficient, more productive, more risk bearing, and more flexible. The rigid, conventional, and path dependent systems, structures and practices that tolerated low productivity, and had low coordination requirements, no longer fit with changing time.

One of the contemporary landmark transitions in research and innovation has been the revolutionization in management of science. There is a progressive shift towards the phenomena of *big science* or projects with *economies of scale*. The term big science denotes a sequence of changes in science organization that specifically occurred in the industrial nations during and after World War II. This model is now embedded in most national science strategies, in many cases without any compelling evidence that the model is appropriate or effective. The thesis investigates this through a case study of one specific big science model, Genome Canada's support for genomics and proteomics. To set up the case study, this chapter examines the phenomena of big science in theory and practice in Canada and abroad.

[1.1] Big Science - A Post War Phenomenon

The global progress and success in science and technology has always been driven by warfare, however, the scale of funds allocated to science in wake of World War II was totally unprecedented. Science was recognized as a global venture. One of the first serious attempts at real life application of big science fundamentals was the *Manhattan Project* in 1942. The project led to the development of the first atomic bomb during World War II. This project was led by the United States with active participation from the United Kingdom and Canada. The Manhattan Project, which initially began as a small research program eventually employed more than 130,000 people at a cost of nearly US$2.4 billion. Research and production for the project took place at more than 30 sites, including universities across the United States, the United Kingdom, and Canada (Frisch 1970). In the shadow of the Manhattan project and the first atomic weapons, the importance of a strong scientific research establishment was apparent to any country that wished to play a major role in international politics. After the success of the Manhattan Project, government(s) became the chief patron of science and the character of the scientific establishment underwent several significant changes.

The landmark report titled *Science: The Endless Frontier* by Vannevar Bush, Director of the Office of Scientific Research and Development to President Roosevelt in 1942, was a novel and visionary attempt at: post war strengthening of basic research centre's such as colleges, universities, and research institutes to expand frontiers of knowledge; developing comprehensive research activities; and harnessing science talents to apply science towards practical purposes. Though, widely accepted for its high performance outcomes, the contemporary idea of big science generated some criticisms, namely that it: undermines the basic principles of the scientific method; leads to elitism; subverts the enlightenment-era ideal of science as a pure quest for knowledge; requires intensive time commitment from scientists on grant requests as well as other budgetary bureaucratic activity; and compromises objectivity whenever research outcomes contradict benefactors interest (Bush 1945).

Weinberg (1961) observed on the advent of big science into the contemporary scientific sphere and had offered big-science and large-scale science as synonyms. His definition of big or large-scale science encompassed massive scale of operations and excessive expenditures (e.g. space exploration and high-flux research reactors). He identified a number of problems related to big or large-scale research, including its potential to change the role and functionality of universities and ability to move the focus in research from pressing issues that impact human life with clear practical applications (e.g. molecular biology, nuclear energy) to the study of topics without any practical applications (e.g. the study of biology in space). Nevertheless, Weinberg (1961) asserted that "molecular biology" was one of the key research areas with a strong potential to affect human welfare that could benefit tremendously from application of the principles of big science (Weinberg 1961).

[1.2] Global Trends in Science Research and Innovation

In order to ascertain a country's performance in research and innovation, a range of globally acknowledged indicators are used including: total Gross Expenditure on Research and Development (GERD); Business Expenditure on Research and Development (BERD); the number of acquired triadic patents (i.e. patents in the US, EU, and Japan); the number of scientific publications and their citation rates; the Human Resources in Science and Technology (HRST) ratio; the number of projects with sustained internal and foreign linkages or collaborations; and public-private partnerships on research and development. A country-wise comparison, based on these research and innovation based performance indicators showed following respective trends for Canada and rest of the OECD partners.

Table 1.2-1: Comparatives: State-wise GERD allocations above and below OECD avg. (2008)

Year	OECD	Country	GERD allocations (as % of GDP)
2008	Countries with GERD allocations above OECD	Sweden	3.75%
		Finland	3.7%
		Switzerland	3%
		United States	2.8%
		Japan	2.7%
		Germany	2.6%
		Denmark	2.7%
	OECD Average allocation		2.3%
	Countries with GERD allocations below OECD	Netherland	1.8%
		Canada	1.8%
		United Kingdom	1.8%

Source: (OECD-Netherland 2010, 205)

Table 1.2-1 shows 2008 country-wise ranking based on GERD allocations across some of the world's leading nations where Canada's share fall below OECD average. On similar lines, a descending comparison of state-wise ranking across OECD countries based on number of acquired triadic patent in year 2008 and comparison of number of scientific publications in the same year are given in *Table 1.2-2* and *Table 1.2-3* respectively.

Table 1.2-2 indicates that similar to GERD allocation trends, Canada ranks below the OECD average allocations triadic patents too. On the contrary, Canada outperforms most of the other OECD countries and produces well above the OECD average number of scientific publications per million people. This suggests that the upstream basic research system is alive and well but Canada lacks some capacity to convert that effort to downstream commercial applications (as reflected in patents).

Table 1.2-2: Comparatives: State-wise Triadic Patents above and below OECD average in 2008			
Year	OECD	Country	Triadic Patents (per million population)
2008	Countries with triadic patents above OECD	Switzerland	186
		Japan	111
		Sweden	88
		Germany	73
		Netherland	66
		Finland	64
		Denmark	60
		Austria	52
		United States	49
	OECD Average allocation		40
	Countries with triadic patents below OECD	France	38
		United Kingdom	27
		Canada	19
		Australia	14.6

Source:(OECD-Germany 2010, 179)

Table 1.2-3: Comparatives: Scientific Publications above and below OECD average in 2008			
Year	OECD	Country	Scientific publications (per million population)
2008	Countries with number of scientific publications produced above OECD average	Switzerland	1770
		Australia	1448
		Canada	1356
		New Zealand	1330
		United Kingdom	1480
		Austria	973
		United States	900
	OECD Average allocation		635
	Countries with number of scientific publications produced below OECD	Japan	620
		Korea	260

Source: (OECD-Australia 2010, 155)

Further, the availability, recognition, and inclusion of competent, well trained, and innovative manpower is crucial for national performance in science and innovation. All these factors, for success, are reflected in the HRST ratio (expressed as total S&T personnel employed as a percentage of nation's total employment). *Table 1.2-4* indicates that the occupations under the realm of HRST are well represented within the total employment ratio for Canada though an accurate percentage for the nation is unavailable. A brief comparison of the S&T policy frameworks of some of the leading innovation economies of the world can shed crucial light on the research and innovation based global policy agenda of the government. In an attempt to decipher the presence or absence of some common strategic elements, the following is a brief review of existing or future policy mandates of nations that have assumed the role of global leaders on the S&T innovation forefront. The main message from this review is that governments have targeted to increase partnerships and collaborations, partly to create larger scientific enterprises and partly to link to global leaders and collaborators. For example, the Australian government has outlined a ten-year reform agenda entitled *Powering Ideas-2009* to strengthen an integrated approach to innovation and improve Australia's linkages with global innovation systems (OECD-Australia 2010).

Table 1.2-4: Comparatives: State-wise HRST rankings in 2008		
Year	**Country**	**HRST ratio** (as % of national total employment)
2008	Sweden	39%
	Denmark	38%
	Norway	37%
	Netherland	37%
	Belgium	33%
	United States	33%
	France	33%
	United Kingdom	28%
	Canada	*HRST occupations are well represented in total employment, accurate percentage unavailable*

Source: (OECD-Canada 2010, 162; OECD-Denmark 2010, 171).

Table 1.2-5: National Science and Technology Policy frameworks		
Country	**S&T policy frameworks**	**Common network encouraging strategic elements across national science policy frameworks**
Australia	Powering Ideas-2009	Strengthen integrated approach to innovation and improve Australia's linkages with global innovation systems
Denmark	Globalization Strategy-2012	Focus on efforts that contribute to networking and collaboration with worldwide research initiatives
Finland	Innovation Strategy-2008	Encourage key stakeholder involvement in the innovation process and in the development of collaborative alliances amongst domestic firms involved in innovation activities
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
United Kingdom	Science and Innovation Investment Framework (SIIF)	Focus research and innovation activities on large innovative firms and strong internal/foreign linkages
United States of America	American Recovery and Reinvestment Act 2009	Allocate financial backing to large-scale partnership oriented innovation models
Canada	Mobilizing Science and Technology to Canada's Advantage	One of the core strategic principles is *fostering partnership*

Source: (OECD-Australia 2010; OECD-Denmark 2010; OECD-Finland 2010; OECD-France 2010; OECD-Netherland 2010; OECD-Sweden 2010; OECD-UK 2010; OECD-USA 2010; Industry Canada 2010; Publishing and Depository Services 2007)

Similarly, Denmark's *Globalization Strategy-2012* has focused on efforts that contribute to networking and collaborations with worldwide research initiatives (OECD-Denmark 2010). On the same lines, the Finnish government's *Innovation Strategy-2008* has strongly encouraged key stakeholder involvement in the innovation process and in the development of collaborative alliances amongst domestic firms involved in the innovation activities (OECD-Finland 2010). The French *National Research and Innovation Strategy-2008* has also prioritized synergized innovation efforts amongst stakeholders present in competing innovation clusters (France-OECD, 2010). Germany's recently restructured *High-Tech Strategy 2020* also encourages innovation based linkages (OECD-Germany 2010). Moreover, to strengthen domestic and foreign innovation linkages, the Dutch government plans adding more funds under its R&D Promotion Act (WBSO) (Netherland-OECD, 2010). Sweden is in the forefront for seeking domestic and foreign alliances for better outcomes. The country's five-year *Research and Innovation Bill-2008,* stipulates renewed funding to promote sustained research relationships (OECD-Sweden 2010). The research and innovation activities in UK are chiefly centered on large innovative firms and on strengthening internal and foreign linkages (OECD-UK 2010). The US, similar to United Kingdom, under the *American Recovery and Reinvestment Act 2009,* has allocated financial backing towards large-scale partnership oriented innovation models (OECD-USA 2010). Lastly, in league with these developed countries, Canada also strongly advocates *fostering partnership* as one of the core principles in its latest Federal S&T Strategy, entitled *Mobilizing Science and Technology to Canada's Advantage* released in 2007 (OECD-Canada 2010, 162).

Overall, networking and partnership seeking strategies are key guiding principle for all nations that aspire to lead in global research and innovation. Countries worldwide are employing formal networking and partnership to achieve progressive innovation outcomes. In fact, there is a continual global expansion of government programs and policies worldwide that encourage networks as a means to organize public funded research and innovation and conduct research activities that address specific emerging public policy issues (Wixted and Holbrook 2008, 3).

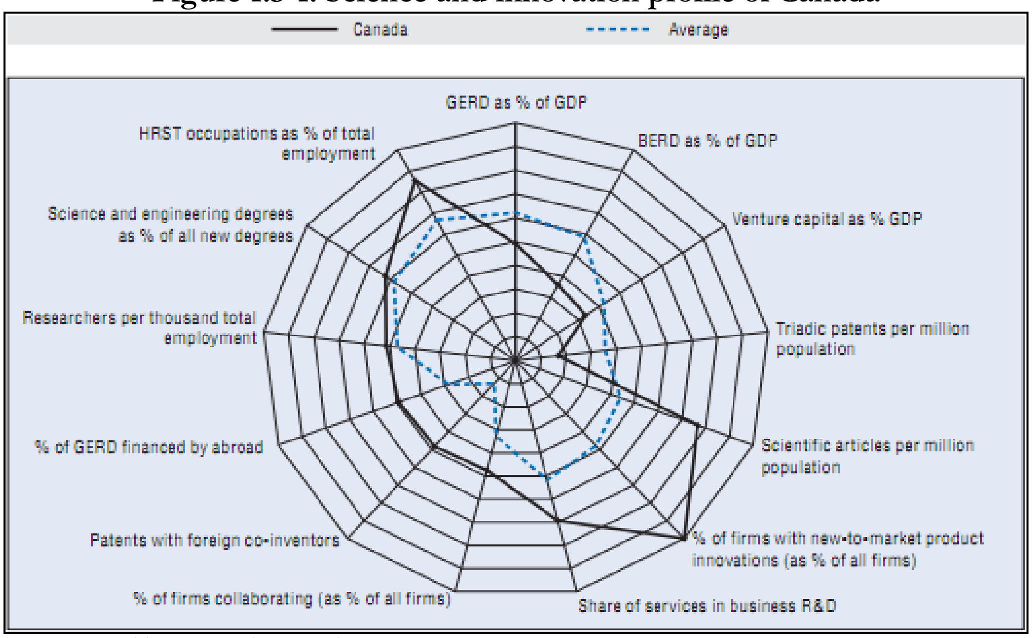
At a glance Canada's federal S&T policy seems well aligned with current global developments. However, in order to ensure a deeper understanding of how networking, partnership, and collaboration based ideas extend through Canadian public policy, the following section reviews the contemporary and historical Canadian S&T policy structures.

[1.3] Policy Frameworks for Innovation in Canada

The review of global innovation state-of-the-art has revealed that Canada's innovation profile has elements of notable strengths and weakness. Canada, as a developed nation and as an active member of OECD, has been an ally to the global developments and policy changes in S&T research and innovation. *Figure 1.3-1* demonstrates the Canadian research and innovation profile, clearly depicting the economy's areas of strength and weakness. The notable features of strength have been: (i) the ratio of proficient, knowledgeable, and well represented Canadian HRST professionals in the country's total employment; (ii) an education system that is synergized with the needs of the industry; (iii) the high number of Canadian scientific publications in 2008 that made up 2.7 percent of the world's total scientific publications; and (iv) Canada's strong inclination for development of intra- or inter-institutional linkages, reflected in the fact that 30 percent of total patents were an outcome of networking with foreign co-inventors.

In sharp contrast, Canadian innovation indicators reveal the following shortcomings: (i) the GERD allocations in Canada have been significantly lower than Sweden, Finland, Switzerland, United States, Germany, Denmark and the OECD average; and (ii) Canada fell short in terms of total triadic patents allotted in 2008. The Canadian performance of 19 triadic patents was significantly lower than the OECD average of 40 triadic patents per million population (OECD-Canada 2010).

Figure 1.3-1: Science and innovation profile of Canada



Source: http://dx.doi.org/10.1787/888932333291

On May 17th 2007, the Canadian government launched its latest S&T Strategy – *Mobilizing Science and Technology to Canada's Advantage* (OECD-Canada 2010; Industry Canada 2007). The new strategy was an effort to synergize Canada's science policy framework with the latest global developments. This strategy currently drives the contemporary Canadian science, technology, and innovation landscape and gives focus and direction to government's future innovation related investments. The strategy reiterates Canadian government's vision of global leadership in S&T (Government of Canada 2009). Such vision's realization requires clear steps that chart executable agenda items. Such federal agenda strives to: create high quality jobs in S&T; build a stronger economy; attract or retain world class talent; support world-leading research; transform discoveries into commercial successes; improve quality of life for Canadians; and uphold regulatory, public policy, and operational mandates (Government of Canada 2009, 20-28).

Further, the 2007 strategy is using network or partnership fundamentals in pursuit of "entrepreneurial advantage, knowledge advantage, and people advantage" to gain global innovation leadership (Government of Canada 2009, 9). The principle of an entrepreneurial advantage reinforces public-private research partnerships and network associations. These partnerships or networks exceedingly facilitate competitive advantage by allowing researchers and entrepreneurs to access world class knowledge networks and novel information. Partnerships also enable research outcomes to deal effectively with market driven challenges and opportunities (Government of Canada 2009, 17-18). The principle of knowledge advantage mandates creation of *next generation* research networks. This mandate is further elucidated in the 2007 S&T strategy document with acknowledgement from the federal government that science is increasingly becoming multidisciplinary, collaborative, and network based (Government of Canada 2009, 30). By exploring new possibilities of network science the federal government is diligently investigating opportunities to create large-scale networks that can leverage Canada's competitive edge in knowledge creation. For the competitive edge the Canadian government strongly depends on research outcomes of a network of about 200 federal laboratories and science facilities across the country (Government of Canada 2009, 31). Similarly, the people advantage doctrine warrants support for those programs or projects that attract or retain a talented, skilled, and creative workforce into Canadian S&T sector. The Canadian government has introduced a range of measures, for example, competitive immigration system, increased accessibility to grants and loans, world-best scholarships, and research chairs that can attract top international S&T talent(s) into Canada. This manpower influx and enhanced opportunity to collaborate can expand Canadian(s) prospects for networking, partnerships, and new skill training (Government of Canada 2009, 33-39).

The above mentioned principles of entrepreneurial, knowledge, and people advantage are based on four core doctrines: to promote world class excellence; to focus on priorities; to enhance accountability; and to foster domestic and foreign partnerships. The *fostering partnership* doctrine guides network expansion between business, academics, government, and the public. It also mandates networking of Canadian entrepreneurs with scientist communities to fuel uptake and use of Canada's technological advancements (OECD-Canada 2010). A detailed examination of the policy documents revealed that the *fostering partnership* principle is at the core of the Canadian STI strategy and its impact is evident at different levels of policy framing. For example, the principle advocates development of collaborative ties amongst the "federal agencies, other levels of government, the private sector, the academic community, and international partners" (Government of Canada 2010, 1). Throughout the 2007 policy document there is a recurring theme of developing effective partnerships and networking.

The networking elements were highlighted in the 2009-S&T Progress Report which outlines a "modern approach to S&T management" (Government of Canada 2009). In this report, the networking approach to S&T management is mentioned as the key catalyst in realizing Canada's vision for S&T global leadership. The progress report states that partnerships are a launch pad for: revitalizing and connecting to the global supply of ideas, talent, and technology; accessing novel external S&T advice; actively engaging in federal, provincial, or territorial working groups on innovation; exploring options on the international scene for contribution to and benefitting from international S&T developments; and committing to mutually beneficial research and innovation agreements. The report charts a range of action plans that target to open access to global and domestic innovation advice. It also strategizes development of large-scale innovation and research networks that rely upon elements of association and partnership (Government of Canada 2009, 41; Schwab 2010).

In summary, the major contemporary strategic S&T documents that guide the Canadian government in its pursuit for global leadership strongly acknowledge collaboration, partnerships, or networking as paramount factors in its vision realization. The review of these documents indicate that terms such as cross-sectoral partnership, networking associations, and inter-departmental cooperation are all intertwined within the 2007- S&T strategy and also in the subsequent 2009 progress report. Apparently, in order to achieve world class innovation goals through partnerships and cooperation, the federal government aspires to link Canada with the global research and innovation networks and create an environment that is enabling for both Canadian researchers and entrepreneurs (Government of Canada 2009, 42). The following section will examine historical Canadian S&T policies (1867 to 2006) with an aim to identify collective, partnership, and network oriented inclinations within them.

[1.4] Review of Historical S&T Policies in Canada: The Big Science Element in Traditional Policies

There are many events in the evolution of science and technology policy in Canada, however for the purpose of the current research only those events that have close affinity to the purpose of this project and those that support the notion of collaboration, networking, and partnership in framing of National Science Policy are discussed. The progression of science policy in Canada has been very similar to its development in other parts of the world. This is primarily due to the fact that trial and error and "remarkable historical evolution" began with the second World War in Canada — as did in rest of the world (Whyte 1997, 346).

The Canadian federal government began functioning in 1867. At that time a low priority was assigned to science or to production of integrated science policy for Canada. However, between the years 1890-1914 science in Canada expanded, responding to wheat boom and to influx of immigrants. The year 1913 was crucial in the events as *Royal Commission in Industrial Training and Technical Education* recommended promotion of science as means to make Canadian industry more competitive internationally. This was a powerful recommendation and led the federal government to allocate and spend almost 4 percent of that year's budget on activities focused on innovation and promotion of science (Whyte 1997, 347). In 1916, with the launch of National Research Council (NRC), the Canadian research model notably changed from a single institution executing a project, to a multi-institutional setup performing multiple S&T projects with united goals. In 1915, NRC was the honorary Advisory Council for Scientific and Industrial Research (Whyte, 1997, p. 344). During the five decade period, spanning 1940-1990, the Canadian government increased its involvement in S&T oriented innovation and launched a set of specific science polices to that effect. The post war period witnessed a sudden spurt in efforts to create networks between the universities, government laboratories, and private firms. These collaboration efforts in Canada were particularly pronounced amongst thirty research universities, about a hundred and fifty government laboratories, and dozens of government departments. All these institutions shared the common intention to nurture innovation in private firms, academia, and the government organizations (Niosi, Godin, and Manseau 2000, 193-196).

The establishment of the NRC was the first time when federal government applied a collective and network based approach to institutional management. This development was conjoined with some key modifications to the research funding priorities in Canada, some of which are still evident today. Establishment of the NRC was perceived as a promising move in a series of attempts to synergize research with the demands of new era; it initiated a trend for managing projects at a large-scale (Grosjean 2006). However, despite its revolutionary setup and associated high expectations, the NRC could not coordinate the national research committees that were spread across Canada. This led the government to constitute a plethora of *quasi-coordinating bodies*[1] directed to achieve where NRC had failed. Many thinkers are of the opinion that these quasi-coordinating bodies strongly supported the government's efforts to coordinate science. However, Whyte (1997) challenges the efficacy of quasi-coordinating bodies. He states that rather

[1] The quasi-coordinating bodies, in an ascending order of timeline are: Science Secretariat of Privy Council (1964), the Science Council (1966), the Economic Council of Canada (1964), the Ministry of Science and Technology (1970), The Natural Science and Engineering Research Council(1979), The House of Commons Select Committee on Research, Science and Technology (1986), the Social science and Humanities Research Council (1977), The Council of Science and Technology Ministers (CSTM), the National Advisory Board on Science and Technology (1987), and the Network of Centers of Excellence (1990) (Whyte 1997, 340).

than optimizing coordination, the quasi-coordinating bodies "led to a greater lack of coordination and cooperation amongst the national research committees" (Whyte 1997, 340).

Another notable initiative to develop an integrated science policy for Canada was triggered by the Glassco Commission Report (1963). The commission noted that governmental science activities were progressing in a piecemeal fashion, with a total lack of operational synchronization and with a surplus of functional redundancy. These observations from the Glassco Commission report served as tactical inputs for a report by the NRC's president C.J. McKenzie. The recommendations from Mackenzie's report led to the establishment of the Science Secretariat within the Privy Council Office. On November 8, 1967 the Senate Special Committee on Science Policy was constituted under the Chairmanship of Senator Maurice Lamontagne. The committee suggested constituting a Ministry of Science in Canada and recommended an overarching need for development of an integrated structural framework. The recommendations of the committee were landmark recognition of the importance that public interest, multi-stakeholder processes, and collaborative public forums had in framing of national science policy. In response to the recommendations from both the Glassco and Lamontagne Commissions, a Minister of State for Science and Technology was appointed for Canada in August 1971 (Wilks 2004, 7-8; Brassard 1996).

In 1985 the federal government issued a background paper titled — National Science and Technology Policy. This paper led to creation of Council of Science and Technology Ministers, which included science ministers from the federal, provincial, and the territorial levels of the government. A series of important events after 1985 led to an integrated science policy. In 1987 the National Advisory Board on Science and Technology (NABST) was inaugurated. The board provided advice to the Prime Minister on application of national research and innovation policies to the Canadian economy that was very similar to the advice given by the Glassco Commission in 1963 (Brassard 1996). In the same year, the federal government applied an integrated approach to departmental construction and consolidated federal S&T activities into a single department named Industry, Science, and Technology Canada (ISTC), which in 1993 was restructured and renamed Industry Canada (Wilks 2004, 8-9). One of the fundamental goals of ISTC was to create an environment that facilitated partnerships for excellence in the Canadian S&T paradigm (Brassard 1996).

With the creation of the Networks of Centres of Excellence (NCE) program in 1988, the quantifiable network oriented changes were apparent in the Canadian science policy. The NCE program was jointly administered by Canada's three federal granting agencies (tri-council): the Canadian Institutes for Health Research (CIHR); the Natural Sciences and Engineering Research Council (NSERC); and the Social

Sciences and Humanities Research Council (SSHRC), in partnership with Industry Canada (NCE, 2002-2003, p. 8). The NCE program was different from its predecessors as it was the first initiative to focus on intensive cross-collaborations between different fields, disciplines, and institutions to produce better outcomes. The establishment of the NCEs was in direct support of the Canadian government's vision to launch a web of national research networks that shared strong affiliations with the academic institutions. The Canadian government envisioned *research institutes without walls* and NCE was in line with this vision. NCE was mandated with the task to improve interdisciplinary communication through creating networks, direct collaborations, and partnerships amongst the universities, industry, government, and not-for-profit organizations (Bergeron and Taylor 2004, 742; Grosjean 2006). The NCE program in 1988 was similar to the contemporary 2007 S&T strategy as both shared the goals of "mobilizing Canada's research talent in the academic, private and public sectors and applying it to achieving economic growth, sustaining job creation, advancing knowledge and improving the quality of life of Canadians" (Network of Centres of Excellence 2003, 6; Industry Canada 2010).

The NCE visionaries aimed to achieve these goals through national and international partnerships and through coordination across disciplines. One of the most important contributions of the NCE program was in terms of landmark changes it brought to the Canadian research funding model. The establishment of NCEs demonstrated that international competitiveness could be realized by large-scale, cross-collaborative, and multi-institutional research teams. The NCE model exemplified the process of harnessing research programs with national goals. The success of the NCE program pushed the federal government to commence supporting other multi-disciplinary and large-scale projects in addition to supporting traditional investigator-initiated small research projects. The NCE Annual Report 2002-2003 revealed that the networking model of NCEs made significant contribution towards acceptance of: multi-disciplinary or cross-collaborative research; partnerships with users; knowledge and technology transfer; and development of local or national critical mass of intellectual capacity to address problems of great complexity and scale. This report was instrumental in outlining the relationship between network-based project management and its effectiveness in procuring solutions for large-scale problems. The report underlined that the NCE model achieved real and effective outcomes as it brought people together and led to effective partnerships between leaders from business, industry, university, and government. Overall, the NCE program affirmed that efforts to solve large-scale issues could be an effective way to develop the economy and improve citizenry quality of life (Network of Centres of Excellence 2003, 3). The NCE model later went on to become the central theme for the science policy restatements of 1996 and 2007. In 1996 the release of federal government report — Science and Technology for the New Century —

launched Technological Partnerships Canada that provided additional funds to NCEs. In 1997 NCE was established as a permanent program (Fast 2007, Appendix A- i).

From these series of successes and pitfalls in the quest for developing a national science policy for Canada, the federal government, on March 11th 1996, finally proclaimed an innovative S&T policy entitled *Science and Technology for the New Century: A Federal Strategy* (Industry Canada 1996). The 1996 federal science strategy, similar to the recent 2007-S&T strategy, emphasized the alignment of S&T goals with the national competitiveness goals and signaled the need for enhanced coordination between the government, business, finance, and academic institutions. The strategy strongly advocated a *Team Canada* approach for dealing with S&T research in Canada. The Team Canada focus introduced a shift from dealing with single-issues to a line of enquiry that cuts across disciplines and demands greater interdepartmental collaborations. This approach promoted creation of networks between research factions in the "provinces and territories, labor organizations, and the universities" (Whyte 1997, 338-339).

To summarize, Whyte (1997, p. 346) asserts that Canada's science and innovation policy has evolved in a series of distinct, iterative stages: a *Naive Decade* spanning 1945-1955, characterized by science policy fundamentally supporting basic research; an *Age of Pragmatism* spanning 1955-1970 characterized by increased resource allocation to basic science; a period of *Taking the Technology Cure* spanning 1970-1975 characterized by increased investments towards industry-university linkages; *Science as Strategic Opportunity* spanning 1975-1988 characterized by the strategic move towards networking and coordination exercises; and *Science as Marketplace* spanning 1985-1995 characterized by multidisciplinary and multi-stakeholder consultation. Since then a focus on large-scale partnerships and commercialization has dominated.

Nearly all historical attempts at generation of a Canadian national science policy have repetitively insisted on network strategies for achieving success, including: establishment of intergovernmental cooperation and coordination; development of mechanisms to capture benefits of partnerships; creation of information-oriented networks; building collaborative networks with domestic or international stakeholders; and promotion of cross-sectoral and multidisciplinary collaborations. The support for science, the phenomena of *big science* — in spirit, and the execution of research and innovation through large-scale collaborative projects has matured over time. Large-scale projects have become the leading applications of network-based science policy. Yet, questions that require further investigation are: why, out of all possible strategies, has the Canadian government pursued and adopted network based S&T strategies implementable through large-scale projects? Is the adoption of the *big science* approach to research and innovation actually a good means to attain success now? These crucial questions will be investigated in subsequent sections.

[1.5] Inclination towards Big Science: Advent of Large-Scale Research and Innovation Projects in Canada

Research and innovation projects can be termed *large-scale* if they utilize large-scale infrastructure and/or address problem that are large and complex but focused (2003, 17-18). Often large-scale research efforts require management of diverse and complementary resources and are conducted by multiple institutions in a multi-disciplinary setting. Large-scale projects are manifestations of the federal government's vision to support inter-disciplinary, cross-collaborative, team-based research projects with pronounced elements of partnership and networking. They are assumed to benefit from economies of scale and scope and produce outcomes that have the potential to make significant contributions to multiple fields and disciplines.

In recent years many remarkable shifts have been witnessed in the way research and innovation is conducted in Canada. The review of historical science and research policies in *section 1.1* of this chapter revealed that the Canadian government has continually revised their research models in order to embed elements of partnerships and networking. In 1996 and 2007, the focus was sharpened to increase the scale and scope of federal innovation efforts. The first notable change in the design of contemporary federal S&T policy frameworks has been the support of unconventional research and innovation practices where inter-disciplinary research teams with common goal and such projects that generate extensive pools of data are sustained. The second key shift in the Canadian research model after 1996 is that federally-funded research and innovation projects are significantly outsourced to the universities, non-government organization(s), and to the private research organizations. In the past, federally-funded research has largely been performed by federal laboratories, research centers, and intramural research branches of the government. New sub-contracting institutions have emerged as key partners in Canadian research and innovation efforts. Towards the end of the 20th century, the longstanding life science focus in Canadian science policy has expanded with projects from basic physics and astronomy now included in the realm of big science.

To align with these contemporary developments, the Canadian government made significant budgetary adjustments to extend financial support to external research partners and agencies. The heavy investments from the government and the industry into the academic sciences, where funding support for entire academic departments and public universities came from the private companies, blurred the line between public and private research (Phillipson 2008). Some key global events have helped the Canadian large-scale research and innovation landscape to develop into its present form. The global experience with organizing the large-scale Human Genome Project in late 1980s has changed the modalities of performing research. In order for this project to be effectively implemented and to have a high production capacity, a consortium of genome centers around the world was needed (2003, 29-30; Cambell et al. 2009, 3). While research facilities worldwide committed to the success of this project, Canada was unable to participate in the Human Genome project as the country lacked in high-throughput genome centers. The inability to participate in the global experience, and thereby missing the opportunity to compete for global leadership in genomics research, prodded the federal government to take up new measures. Deliberations by the federal government in 2000 led to the establishment of Genome Canada (GC), a not-for-profit research organization. The federal government strategically selected Genome Canada to develop and implement a national strategy that strengthens application of large-scale genomics and proteomics research (Cambell et al. 2009, 3-4; Department of Finance 2010). Genome Canada has emerged as a primary funding agency and an information resource on genomics and proteomics research in Canada. The organization has gone on to vest the country with the ability to execute large-scale, multi-stakeholder, and peer reviewed projects in genomics and proteomics research (Genome Canada 2011).

As a model organization, Genome Canada partners with government agencies, industry, venture philanthropist organizations, and other institutions both in Canada and abroad. Some of its key federal partners are: National Research Council (NRC)[2], Atlantic Canada Opportunities Agency (ACOA)[3], Western Economic Diversification[4], Agriculture and Agri-Food Canada (AAFC), Natural Resources Canada, and Canada Foundation for Innovation (CFI). The main industrial partners comprise: Ag-West Bio, SUN Microsystems, IBM, and a range of other pharmaceutical and biotechnology companies. Institutional partners includes universities, hospital foundations, and other private foundations (Genome Canada 2011). Genome Canada has also signed scientific collaboration agreements with other countries, including Sweden, the Netherlands, Spain, Estonia, Denmark, United States, United Kingdom, Norway, New Zealand, and Australia. Notable international partners include: Karolinska Institute in Sweden; Johns Hopkins University, Albert Einstein College of Medicine, National Institutes of Health in USA; and Genome España, and Wellcome Trust in the United Kingdom. These partnerships have provided access to leading-edge technology for researchers. In partnership with six regional Genome Centre's across Canada, GC has enhanced research opportunities for Canadian scientists in areas such as crops, human proteins, bovine, environment, fish, and forestry products (Genome Canada 2011). Besides genomics the Canadian

[2] The NRC's Biotechnology Program is a founding member of Genome Canada and contributes to Canadian innovation in genomics through the NRC Genome and Health Initiative (GHI) — a unique horizontal program that involves several NRC biotechnology institutes located across Canada.
[3] Atlantic Canada Opportunities Agency had contributed funds to Genome Atlantic through Atlantic Innovation Fund (2002).
[4] Western Economic Diversification has funding linkages to Genome BC, Genome Alberta, and Genome Prairie (2009).

government is also financially supporting large-scale projects in other sectors, such as national or regional infrastructure development[5] funded by the Canada Strategic Infrastructure Fund, renewable energy projects, and information systems projects such as e-government (Ezz, Furlong, and Papazadeiropoulou 2006; Canada-Manitoba Infrastructure Secretariat 2010).

Genome Canada is one of the pioneer institutes to apply the partnership model whereby it allocates partner contributed funds to support genomics and proteomics based large-scale research projects. Overall, Genome Canada has assumed the role of catalyst in bringing industry, government departments or agencies, universities, and research hospitals together in synergistic and well-linked partnerships. The organization has indeed facilitated Canadian scientists and GE^3LS researchers to access research frontiers, both nationally and internationally, and to gain respect and credibility for their research efforts. The term GE^3LS stands for genomics and its related ethical, economic, environmental, legal and social aspects. GE^3LS research complements genomics research by addressing questions that lie at the interface between science and society (Genome Canada 2011).

In summary, Genome Canada is a key example of Canadian government's inclination towards managing science and innovation with projects of scope and scale. From this preliminary review of documentation it emerges that large-scale projects are increasingly gaining acceptance in the innovation and research world. An examination of the budgetary allocations towards large-scale projects can generate facts to corroborate this claim.

[1.6] Budgetary Trends: Federal support for Large-Scale Research Projects in Canada

Increasingly, public funds are being distributed to projects or initiatives that match with the government's innovation goals and aspirations. During the budget process, a government's decision to spend on any program area depends on the priority ranking of that specific program in the overall governance agenda. This review of federal budgetary allocations from 2000-2009 can be used to test the argument that large-scale scientific investigation or research is one of the prime focus of the S&T agenda of the Canadian government.

The federal S&T spending is classified under two subheadings: intramural and extramural. Intramural spending is the S&T related expenditure by federal departments or agencies. Extramural spending is the classification of the funding for S&T activities by non-federal organizations. As per 2009-2010 strategic document entitled *Federal Government Expenditures on Scientific Activities*, S&T related federal spending has

[5] Highway and Railway Infrastructure, Local Transportation Infrastructure, Tourism or Urban Development Infrastructure, Water or Sewage Infrastructure, and Broadband (Canada-Manitoba Infrastructure Secretariat 2010).

reached approx. CAD$10.7 billion, with projected R&D spending of CAD$6.9 billion and Related Scientific Activities expenditure of CAD$3.7 billion (Minister of Industry 2009, 5). In 2008, GERD statistics from the federal document on Science and Technology Data revealed federal government to be the 2nd largest research and innovation funding entity in Canada, only marginally behind the industrial sector (Industry Canada 2010). Federal S&T allocations have continually declined from 1995 to 1999 as part of the national fiscal restraint program, but spending accelerated from 1999 to 2002. Federal S&T expenditure total budgetary allocations rose from 3.5 percent in 1995 to 5 percent by 2001 and stayed steady at 4.8 percent from 2002 to 2005.

A specific investigation of federal allocations made towards large-scale network projects[6] revealed that allocations towards large-scale research endeavors have been rising, partly at the expense of more traditional funding approaches. In recent years, new funds for the three Canadian granting councils (NSERC, SSHRC, and CIHR) have generally been directed towards large-scale, directed or networked, research and collaborative ventures.[7] This has included extensions and expansions of the NCE program, development of the Canada Research Chairs program, extensions of the Industrial Research Chairs programs, and targeted partnership or sectoral research funds in the councils to spur specific research effort, to name but a few. Meanwhile, federal intramural funding for research in line departments and the NRC has largely been restructured, requiring larger-scale, matching industrial or university partnerships. In addition, new funds have been directed towards an array of research organizations pursuing partnership models. The Canadian Foundation for Innovation (CFI) and Genome Canada in particular exemplified the large-scale research model. In total, since their establishment, federal allocations have totaled about $5 billion in the CFI (since 1997) and $915 million in Genome Canada (since 2000), which has then leveraged at least an equivalent amount of matching funding in the context of the infrastructure, projects, and programs funded. This is the single largest flow of S&T funds to any single source over the period.

In summary, the available statistics indicate that over the last decade (2000-2009), where overall research allocations have been intermittent or static, the federal research funding for large-scale projects, particularly network based genomics research has invariantly increased. It is not that *small science* or small team research has turned obsolete, but it has certainly been marginalized. Irrefutably, theoretical results from small research are significant but, often the empirical verifications of scientific results necessitate setting up costly

[6] International Science and Technology Partnerships Program (ISTPP) is one of the key thematic programs with CAD$8 million assigned over a span of two operational years to foster large-scale strategic international partnerships (2010).
[7] The breakdown is: $16-million for CIHR, $13-million for NSERC, and $3-million for SSHRC. The NSERC money is divided between $8-million for advanced research support and $5-million to foster collaborations between academia and industry.

experiments that require big budgets and massive infrastructure, thus there is mounting need for large-scale projects.

[1.7] Problem Statement

The international advent of *big science* and the assumption that this global prevalence can generate and mobilize latent innovation capacity in a network environment has largely favored intensification of large-scale science innovation projects in Canada. The research focus is gradually shifting from a single scientist's curiosity-led research towards a more team-based, inter-disciplinary, networked-oriented research. It appears that network oriented research strategies that are well depicted and embedded in large-scale research projects are gaining importance.

As a result, significant federal resources in Canada and globally have been channeled to support large-scale projects and their allocations have, in recent years, gained momentum. In fact, large-scale projects are being taken as complete innovation systems in themselves based on their display of reflexivity, trans-disciplinarity, and heterogeneity (Gibbons et al. 1994). However, sociologists and economists around the world are questioning what this systemic change really accomplishes. Both the fields of economics and sociology are gradually embracing the view that execution of large-scale research project enables formal and informal methodical interactions and relationship building, which can generate network *value* in and of itself — in sociological terms, this *value* is most commonly referred to as *network capital* or *social capital*.

Current research will assess whether large-scale research projects are innovation systems that produce social capital which in turn generates downstream productive residual outcomes in terms of research capacity and commercial outcomes. Currently, there is not enough evidence to identify or quantify the *social capital* harbored in large-scale S&T projects or to relate that capital with innovation outcomes. Given such lack of evidence, the federal government's shift towards large-scale research appears presumptuous. An in-depth examination of a federally supported large-scale research project in Canada — in this case the Genome Canada Applied Bioproducts and Crops (ABC) Competition — is one way to probe the theories of innovation systems and the impact of social capital on enhanced innovation outcomes.

[1.8] Research Hypothesis

This dissertation rests on the following assumptions derived from social network theory that there are positive relationships between networks exchanges in large-scale project and social capital, and between social capital and latent productive outcomes. Building upon these assumptions, this dissertation will test the following conditional hypothesis — *Contemporary innovation network systems create social capital which generates downstream productive residual outcomes*. The hypothesis has been further divided into three sub-hypothesis:

(i) Sub-hypothesis#1: Fundamentals of contemporary innovation networks and systems theory are replicated in large-scale research projects.

(ii) Sub-hypothesis#2: Large-scale project exchanges produce a network environment for generation of social capital.

(iii) Sub-hypothesis#3: Social capital produces latent or residual innovation outcomes.

[1.9] Thesis organization

The dissertation is structured in four additional chapters. Chapter two outlines the supporting and related literature for this topic, including more traditional and contemporary theories of knowledge production, NSI, the triple helix model, network analysis tools, and social capital perspectives. Chapter three details the network of interest, lists and clarifies the research objectives, and introduces the methodology. Chapter four includes the data analysis framework which employs the social network analysis measures and tool to illustrate both static and evolutionary aspects of the large-scale networks. A combination of descriptive statistics, output measures, and correlation analysis is utilized to examine the hypothesis, sub-hypothesis, and research assumptions. Chapter five offers research conclusions, examines the limitations, assesses the implications, and makes suggestions for future research.

Chapter 2

REVIEW OF LITERATURE

Introduction

Canadian research agendas are rapidly changing to conform to the emerging knowledge-based global economy. The pressures of globalization and the quest for research-based competitive advantage are creating new connectedness and new challenges. The rapidly evolving technological and scientific challenges are intensifying the need to optimize the use of expertise in Canada and abroad. New knowledge dynamics are surfacing that challenge approaches, theories, and notions previously held in traditional economies. In this revolutionary phase one of the key developments has been the mounting acceptance of both formal and informal collaborative activity that cuts across geographical and institutional boundaries. This has become crucial in accessing suitable resources, creating new scientific knowledge, and adequately disseminating novel technology.

These new developments in global science and technology culture have led to new research into the overlap of governmental, educational, and industrial sectors and within the cross-national boundaries and inter-organizational projects. The emerging field faces difficulty accurately evaluating outcomes of these collaborative research projects and partnerships. In such settings the traditional analytical approaches seem deficient. The problem is aggravated by the fact that the concepts of partnership or collaborative activity are not well understood and fluctuate from case to case. Despite lack in understanding of such arrangements, it is evident that one of the stimuli behind the push towards collaborative activity in research and development is better research outcomes that can facilitate fulfillment of long terms goals for innovative products or processes. The inputs and outputs for complex innovation and research systems are not yet clear and need further examination from both theoretical and empirical standpoints.

Gaps identified in Preliminary Literature Review in Chapter 1 of the Dissertation

The literature reviewed in Chapter 1 of the dissertation creates a backdrop for identifying and defining the problem statement and facilitates in framing an unambiguous research question. The introductory literature review had offered a chronological account of federal government's support for large-scale research initiatives and was limited to recounting the policy problem. It did not however present the system underlying large-scale research projects. The current research requires a much more elaborate understanding of the systemic *push* for operationalizing projects of scale or scope and on the subject of social capital that is posited to reside in the very structure of large-scale collaborative programs. The current research endeavors to replicate and extend past research that has examined the relationship between networking projects, social capital, and latent value generated as the end product.

The research strategies used in this study, in accordance with that of Garfield (1991), involves examining journal articles, text books, government reports, documentations, working papers, and relevant online information (Garfield 1991). The validity of reviewed journals is ensured by accessing articles with high citation index rates from the ISI Science Citation Index (SCI), Social Science Citation Index (SSCI) and Google Scholar. This process also facilitates in understanding connections amidst the reviewed work.

[2.1] Theoretical perspectives

Innovation is a result of special processes and can be dealt with as a systems concept. The notion of special processes finds its theoretical roots in the systems approach to the innovation literature. The innovation literature can provide theoretical and practical underpinning to traditional vs. contemporary research policy applied in Canada and in other parts of the world. *Table 2.1-1* gives a summary of the theoretical frameworks that will be examined for the purpose of current research.

Table 2.1-1: Summary of relevant theoretical perspectives			
Innovation Paradigm	**Theoretical underpinnings**	**Federal Governments Mission Directives**	**Current Research Assumptions** *(from preliminary research)*
SPECIAL PROCESSES	Gibbons et. al. (1994)- Production of Mode 2 knowledge	Effectively manage mode 2 knowledge Creation of Mode 2 knowledge entails different funding pattern relative to traditional knowledge creation	The knowledge outcome of contemporary systems of innovation is distinct from traditional systems of research and innovation
	Lundvall (1992)-National System of Innovation Etzkowitz & Leydesdorff (1998, 2000, 2003)- Triple Helix Model	OECD and Canadian Science Policy (1996, 2007) encourage cross-collaborative and networking based S&T research Principles of *partnerships* incorporated in Canadian S&T policy framework Global innovation policies modified to improve *triage* linkages Increase involvement of universities into national innovation efforts	- Transition from traditional to contemporary innovation system - Stress on joint ventures, partnerships, and cross-collaboration - Human perspective to innovation - Federally/provincially supported funding agencies adopt frameworks to support new institutional order - The patterns of funding altered to support network based research - Increased financial allocations to S&T research - Networking amongst three pillars of contemporary research society - Universities participation critical in contemporary research paradigm

	Concept of Social Capital – An examination of diverse perspectives	Large-scale projects generate social capital Social capital facilitates accomplishment of project milestones Social capital generates latent/ residual outcomes or value	Social capital is a network based concept Large-scale research networks are assumed to be more productive than their small scale equivalents Social capital affects future benefits and productive outcomes

Source: (Lundvall 1992; Etzkowitz and Leydesdorff 1998; Leydesdorff 2000, 2003; Gibbons et al. 1994; Coleman 1990; Putnam 2000; Publishing and Depository Services 2007)

As indicated in *Table 2.1-1, Mode 1* and *Mode 2 knowledge* (Gibbons et al. 1994), *National Systems of Innovation* (Lundvall 1992), and *Triple Helix Model* (Etzkowitz and Leydesdorff 1998; Leydesdorff 2000, 2003) align with the concept of special processes and explain the transition and extend understanding of traditional and contemporary science and research based innovation systems (Leydesdorff 2003, 446).

The advent of the systems based approach to innovation necessitated a fundamental change in the mechanism of scientific knowledge production. Besides facilitating knowledge dissemination, innovation systems are breeding grounds for *social capital* — a network oriented phenomenon. In research networks, social capital is supposedly an outcome of the systems approach to managing science and it presumably has downstream outcomes. The futuristic and dynamic theorizing of social capital can add to our understanding of network based research projects. Elevated outcome is a common policy argument offered in support of transitioning to contemporary science policy and network research models. The contemporary knowledge systems, National System of Innovation, the Triple helix model, and the concept of social capital will be scrutinized to further understanding.

[2.2] Mode 1 Vs Mode 2 Knowledge

Traditional research systems are marked by a lack of theoretical models that offer compelling explanations for knowledge production and innovation processes. Conventional knowledge — termed as *mode 1* knowledge — is primarily discipline-based, academic, and investigator-initiated but offers little theoretical basis to explain innovation. With the advent of the twentieth century, a scientific revolution modernized science research systems. The process triggered interest in the knowledge-based economy and led Gibbons et al (1994) to identify mode-2 knowledge. This form of knowledge differed from mode 1 in being context-driven, reflexive, heterogeneous, problem-focused, diffusible, and inter- or trans-disciplinary. Mode 2 knowledge is organized in the context of its application and employs multi-disciplinary teams that work on specific problem in the real world. Rising social awareness regarding the impact of innovation outcomes on public interests supported production of mode-2 knowledge. As a result, an environment is created where research is open and flexible, human resources are positioned in networks, and there is no pressure to institutionalize the processes (Gibbons et al. 1994; Shinn 2002).

Evolution of research and knowledge has generated a new organizational field that is characterized by a broader innovation triage. The development of this new field of study identified an institutional order that integrates political, industrial, and academic interests while regulating research, political, and economic activities. With contemporary knowledge production, innovation processes become systems, and hence are amenable to systems theory and analysis. State, academia, and industry emerges as key partners in the knowledge production and transfer processes. The knowledge-based economy mandates a new organizational field where collaborative projects are facilitated by resolute norm systems. University researchers and entrepreneurial scientists play a key part in the evolution of new institutional order and bridge the gap between academia and the market (Gibbons et al. 1994, 1-17; Shinn 2002; Etzkowitz 1983).

In a knowledge-based economy innovation is both recursive and interactive. New knowledge is inextricably linked with applications in the overall system, which drives changes in the federal government policy directives on scientific research. The transition to a knowledge-based economy is aligned to knowledge mobilization, which is unattainable in absence of facilitative sponsors (Leydesdorff and Etzkowitz 1997; Benner and Sandstrom 2000)).

[2.3] National Systems of Innovation (NSI)

System-based approaches give a fresh insight into the economic performance of nations that are performing local, national, or global level research. Traditionally, national innovation potency was based solely on research inputs (research spending) and research outputs (product patents). However, in contemporary times national innovation performance depends on additional attributes of interactions (joint research, personnel exchanges, cross-patenting, etc.) between institutions (private enterprises, universities, public research institutes, and employees). In this context, new actors are a crucial component of national research capacity and are central to the technological improvement process (OECD 1997). The NSI framework directs attention towards partnership, linkages, and interaction in innovation system. The approach treats national technological performance as a variable dependent on decoding the complexity of the link between system actors. These actors produce, distribute, and apply different types of knowledge and partner in the innovation process.

The concept of national systems of innovation has no universal definition. While a NSI constitutes "elements that interact during the production, diffusion, and use of new and economically useful knowledge" (Lundvall 1992), it is taken as a system that combines "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman 1995). A National System of Innovation is complex and dynamic and is characterized by feedback loops and re-production processes. It is a social system that includes learning as one of the core activity and involves actor interaction — both being the central attributes of collaboration-oriented systems. Innovation under NSI is a sustained process rather than a single one-time event. The vital inputs into the process of innovation emanate not only from science but also from the everyday experiences of workers, production engineers, and sales representatives. These individuals influence innovation by setting the agenda, determining the innovation direction, and engaging in the production of knowledge. The notion of *learning-by-doing* and *learning-by-using* fits well into the paradigm of interactive learning and collective entrepreneurship and are deemed to influence the process of innovation positively (Lundvall 1992). Under the concept of new combinations and creative destruction, Schumpeter has labeled innovation as an ubiquitous phenomenon that is gradual, cumulative, and can make accumulated knowledge obsolete by radically breaking away from the path dependency (Lundvall 1992).

The NSI concept helps to place large-scale innovation projects in terms of both economy and modern capitalism. In economic terms, innovation is often conceptualized as a process that comes from outside, creates in-equilibrium and after adjustment re-instates equilibrium. In modern policy terms, innovation can now be conceptualized as a phenomenon that is ubiquitous, gradual, and cumulative. The network of relationships generated in national and regional innovation systems, such as industrial relations, technical or scientific institutions, government policies, and cultural traditions are indispensable for the optimum opertionalisation of NSI (Freeman 1995).

Three factors contribute to the application of NSI for investigating on technological innovation outcomes. First, the recognition of the economic importance of knowledge in the knowledge-based economy generates a new set of metrics — a nation based on the production, distribution, and use of knowledge or information engages in flows of knowledge and invests into knowledge amplification processes such as R&D, training, and education. The knowledge flow and investment indicators became important for assessment of national economic growth. The process of decoding knowledge flow, which is codified in publications and in patents, has become easier to track due to the enhancement in IT sophistication. This analysis of knowledge flux can be used to identify major channels and bottlenecks to knowledge flow and to suggest policies to improve knowledge fluidity. Also, such an analysis can provide insights into the power distribution by examining the links between the industry, government, and the academia. Second, NSI's focus on special processes amplifies the scope of study. In the linear model of innovation, science is an initiator of innovation, such that an increase in scientific inputs into the pipeline will directly increase the number of new innovations and technologies flowing downstream. In the linear model knowledge flows are modeled quite simply. Here NSI, in contrast, takes innovation as an outcome of complex connections and feedback loops amongst the concerned actors or institutions that interact at any one of the stages of research, development, marketing, and/or diffusion. NSI visualizes the innovative firm as a complex bundle of competencies that draws on their connections with both competing and allied institutions through joint ventures and close linkages with suppliers and customers. Thus, NSI effectively extends the essential understanding of the contemporary innovation systems to the economy as a whole. Third, the growth in the number of specialized institutions that participate in knowledge production and diffusion processes broadens the application of NSI approach. NSI categorizes the knowledge flows between expert institutions as exchanges among private projects or exchanges among private research organizations, academics, and public research laboratories or movement of workforce amongst different institutions (Leydesdorff 2003, 446; Lundvall 1992; OECD 1997; Hicks and Katz 1996).

Besides its operational applications, the NSI paradigm offers new insights into policy making. Policy makers use the NSI model to identify leverage points that can enhance national innovative performance and overall competitiveness. The NSI approach is useful in identifying variances in the system which if not addressed can prevent progressive research and innovation in a country. It confers unique meaning to institutions, linkages, and/or actors in accordance with their respective roles in the production systems and effectively matches them with policy frameworks (on tax structures, financing schemes, regulations restrictions, and IPRs). If this process is not managed well, it can limit interactions and knowledge flows amidst relevant institutions and actors.

NSI, as an instrument of national technology policy formulation, has had important policy implications. Traditionally, governments have interceded in research and technology to correct market failures which leads to under-investment in research by the private sector because firms are unable to capture all of the benefits from such investments. In response, in an effort to optimize the benefit of technology, governments have offered numerous tax credits and subsidies to compensate for the market failure. The use of NSI approach in policy making reveals and addresses systemic failures that conventionally obstructed industrial innovation performance. Some of systemic failures that negatively impacted research and innovation capacity of a nation include: lack of productive interactions among actors in the system; lack of synergy between publicly-owned basic research and industrial applied research; discrepancies in technology transfer; and deficiency in firms' information recognition and usage systems. Therefore, the application of NSI approach highlights the need for continuous designing and renewal of policies that can suitably increase knowledge flow capacities and address lack of institution-actor exchanges in network environments.

The concept of NSI is increasingly relevant to the global contemporary policy framework. As a product of employing NSI principles to global S&T policy frameworks, importance is being given to decoding formal and informal knowledge flows and facilitating technical network access. Research and innovation clusters are being encouraged for utilization of partnerships and linkages in the most efficient manner. Updated intellectual property rules, labor market policies, and exchange programs are being implemented across nations to facilitate global research and innovation partnerships. Moreover global research and innovation policies are being modified so that they can improve the potential of enterprises, governments, and universities to access appropriate local, national, or international networks and also identify and use pertinent novel information and technology. An increase in the interaction amongst NSI actors is crucial for national innovation performance. Networking amongst the three pillars of the contemporary innovation system is vital and as a consequence, facilitative initiatives are being incorporated in most national S&T policy frameworks. The policies are examined and assessed through indices of public-private partnerships, mapping knowledge clusters, and deciphering inter-institutional technical human resource flows.

The NSI *institution-actor* interactions and knowledge flows can be explained in four broad ways. First, the interactions, collaborations, and partnerships are realized through joint industry activity. Here knowledge flows are assessed through a number of existing technical collaborations among enterprises and also through the imminent informal interactions, which are more difficult to measure. Enterprises work in partnership to access technical expertise, achieve economies of scale, and generate or capture synergies from networked personnel and technical resources. NSI collaborative activities, such as technical cooperation projects, especially in the biotechnology and information technology fields, can enhance firm innovative performance (OECD 1997, 7-8). Second, the assessment of the quality of linkages between public and private research sectors can decode the efficacy of interactions between institutions and actors. The public research sector comprises government supported research institutes and universities, while the private research sector comprises of privately-owned research facilities or infrastructure. The quality of links between national public-private research sectors is a crucial national asset for supporting innovation. These can intensify joint technology research projects and provide a platform for collaboration among project staff and researchers. Public research institutes and universities produce and stockpile new scientific and technical knowledge, which is shared with the industry through patents, published scientific information in the form of new instruments or methods, through training platforms, and during interactions in scientific networks. Public and private sector knowledge flows or spillovers are measured through: assessment of joint research activities; estimation of number of co-patents or co-publications ventures between enterprises, universities, and research institutions (compiled from patent records and publication indices); citation analysis to estimate the amount of information accessed by enterprises from universities and research institutes patents and publications; and firm surveys that reveal the extent to which the industry uses universities or public research institutions as sources of innovation facilitating knowledge (Lundvall 1992; OECD 1997, 1997; Hicks and Katz 1996). Third, the process of technology diffusion allows adoption of cross-sectoral innovations and knowledge crossovers through the institution-actor alliances. The novel technology can come from anywhere including the supplier — the competitor to the public institutions. In such an arrangement the government can operationalize a policy framework to optimize technical diffusion and knowledge flows. The intensity of the knowledge diffusion process is often determined by surveying firms. Lack of information, financing, or technical expertise can obstruct effective knowledge diffusion (OECD 1997). Fourth, the measurement of tacit knowledge flows transmitted through personnel mobility is elemental to estimating *institution-actor* interaction. The statistics on personnel mobility are available through labor market surveys. The formal or informal and one-to-one or close group interactions are all decisive conduits for explaining knowledge transfer and interaction between relevant institutions (industry, government, university) and the actors (the institutional workforce). The scope and quality of employee interactions in the institutions depends largely on their mobility, qualifications, and accumulated tacit knowledge. Their ability to recognize information and access researcher networking skills are linked positively to improved levels of innovation. "High level of personnel mobility contributes positively to national innovation performance" (OECD 1997, 20).

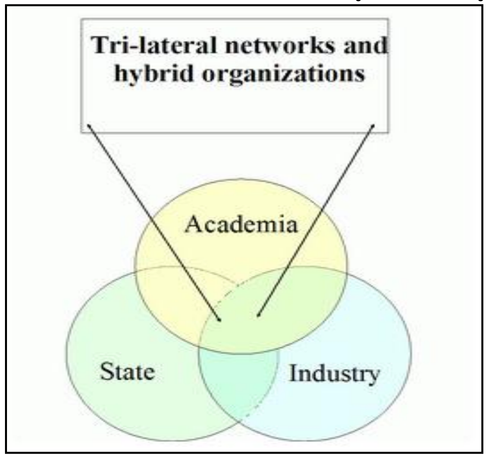
Knowledge flows can also be examined through cluster analysis. Clusters of knowledge flows are identifiable through: "embodied technology flows" where inter-sectoral products purchase and producer-user interactions are analyzed; "technical interactions" where number of patents, their citations, inter-sectoral scientific publications, and joint research activities are inspected; and "personnel mobility" where inter or intra flow of skilled workforce is examined (OECD 1997, 27).

Assessment of certain NSI dimensions is highly problematic. First, under the NSI regime, nation states have two dimensions — national cultural and etatist political. These two dimensions seldom merge to produce homogenous nations — they blur the edge or boundary of every NSI. This makes NSI boundary specification particularly challenging (Lundvall 1992). Second, in normative dimensions, contemporary innovation can exist at three levels: global, international, and national. While the NSI inspires public policy at both the national and international levels, it often fails to have much effect at the global level. This global level gap can be traced to the lack of global norms. In fact globalization and regionalization often weaken the coherence of national systems. Global efforts to synergize standards or models and enhance knowledge sharing practices can be functional remedies (Grosjean 2006). Third, NSI institutional arrangements compete in deciphering innovations outcomes. The various sub-dynamics of NSI, under selection pressure, operate one upon another without any guarantee of harmonization. Order can only be expected to emerge over time as the system matures. These *lock-ins* remains conditioned and constrained by the historical configurations (Arthur 1989). Fourth, NSI generates externalities that can only be interpreted *ex-post* and not *ex-ante*. Socially interacting subsystems, such as technologies, markets, and institutions, are constructed discursively and reconstructed continuously. It is this superimposition of reciprocal expectations and exchange relationships that allows one to break down complex dynamic interactions amid different sub-dynamics, as every sub-dynamic operates recursively based on its previous state. A system with dynamic and sub-dynamic stakeholders can be defined and further redefined in the process of an investigated project (Leydesdorff 2005). The next section examines the contemporary innovation system and its constituents in light of triple helix dynamics.

[2.4] Anatomy of a Triple Helix Model

Of late there has been an increase in the involvement of universities and academic institutions in national innovation agendas. This escalation of academic participation in research processes is primarily a post-war phenomenon and is the foundation for conceptualization of the triple helix model. The triple helix field was developed primarily to explain how universities connect with government and industry in a dynamic research and innovations setting. From here the triple helix model application broadened and was used to explain not only association but cross-functional intricacies of exchange, organization, and cooperation. The triple helix model now examines convergence of three worlds — actors, law or regulations, and institutions (Etzkowitz 2008, 7; Benner and Sandstrom 2000; Etzkowitz and Leydesdorff 1998; Viale and Ghiglione 1998, 3). Concept of triple helix has impacted the innovation discipline, given that fraternal innovation networks created under triple helix regimes have had a transformational effect on the global and national innovation environment (Gibbons et al., 1994). The triple helix interface is spirally structured in contrast to the traditional linear models of innovation. Its spiral arrangement captures the stand alone 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 and Sandstrom 2000).

Figure 2.4-1: The Triple Helix model of university-industry-government relations



Source: (Etzkowitz and Leydesdorff 2000)

During the cold war, with duelling socialist and capitalist hegemony, top-down centralized models with government at the helm of affairs as the prime regulator of firm and academic activities were largely successful. However, in the post socialist era, top down coordination has diminished and public finance has contracted sharply. The decentralization transition in capitalist societies has coincided with the change in government focus on innovation projects and a shift from disciplinary to inter-disciplinary research (Etzkowitz 2008, 60-61)

The three functionally and schematically distinct institutions, when introduced in a triple helix world, are found to develop capacities and expand their outputs. In fact the restructuring of different helices and enhancement of organization arrangements and incentives in the triple helix model are credited with fostering improvement in innovation and research results. This is attributed to the fact that the triple helix configuration, with rearrangements, mobility, and integration (evident in both macro-circulation and micro-circulations) that functions as a stimulant in hybridization, innovation, and research has evolved into a dynamic network of communication and interaction relationships (Etzkowitz 2008; Leydesdorff and Etzkowitz 2000). The triple helix model is unlike the *laissez-faire* model. The former facilitates interaction and interdependence while in the latter an entity's societal organization is based on boundary preservation, restricted interactions, and clear role distinction as industry does production, government works in regulation, and universities deals with basic research. The varying roles and combinations found in the triple helix system facilitate active exchanges, stimulates creativity, and improves individual entities of the participants in the process (Etzkowitz 2008, 12-18). The triple helix model creates a *revolving door* interface where the functionality of government, industry, and the university adjusts to "take the role of the other", while still performing the traditionally assigned tasks and maintaining distinct identity (Etzkowitz 2008, 9).

In a contemporary research setup, the triple helix facilitates role transitions by three means. First, government, in its fundamental role as regulator, functionally mimics industry in incentivizing innovation. This role of the government is termed as of a *public venture capitalist*. Second, industry along with its primary role as producer does high level research and training similar to the universities. Third, the university conducts its principle business of disseminating knowledge while adopting some of the business and governance functions. Notably, these trilateral interactions, connections, exchanges, and partnerships within a triple helix model are exceedingly crucial and significant (Etzkowitz 2008; Zhou 2007).

Practical triage in a research system has a potential to lead into novel recombination. An industrial sector's manpower and infrastructure shortage impedes internal handling of innovation projects and presses firms to request research assistance from universities and public research institutions. Industry also interacts with the government by requesting public venture capital for their risky or long term projects. On the other hand, in certain circumstances public research institutions can be strapped for research funds and may seek financial allocations from industry. Universities can assume the function of venture capitalist and support high tech spin-off and start ups in return for profits. All parties in this mutually symbiotic relationship can in return for monetary, manpower, or infrastructure partnerships, often direct their research focus towards the partner's research purpose. Such project based relationships lead to development of bi-lateral or tri-lateral partnerships, agreements, and network opportunities. The venture capitalist role of government is sometimes characterized as entrepreneurship — an expression that is often restrictively applied to development of new product or technology. In the context of the triple helix, this term connotes a process where public actors identify progressive opportunities, allocate resources in new prospects, and consequently create value through envisioning success — a role that government can at times effectively execute as a key stakeholder of the innovation process (Etzkowitz 1983). Contemporary changes in university directives, which assign the institution with research and innovation functions, have eroded the traditional organizational and normative precepts of the university system. The control of research is challenged as universities incorporate industrial and political interests into their evaluation process (Benner and Sandstrom 2000).

The operational convergence of triple helix institutional spheres is possible at three levels: *micro, meso,* and *macro*. At the *micro* level, the convergence of the triple helix spheres is evident when: academicians adopt roles of private entrepreneurs; private entrepreneurs take up employment in research facilities or in universities research sites; academicians and private researchers take responsibility for implementing government projects; and public researchers work in the industrial sector. At the *meso* level, convergence occurs when the university operates as a hybrid agent of innovation, hi-tech enterprise, or venture capitalist and assumes responsibility for production and use of knowledge; the innovation interface between enterprise and research setups is provided by tech-transfer agencies; and innovation coordinators such as mediator firms are made responsible for coordinating and managing segments of innovation process. At the *macro* level the convergence is evident in synergistic policy guidelines that integrates actors in financial and operational decision making (Viale and Ghiglione 1998, 2-5).

One predicament with the triple helix concept of inclusivity is that though the triple helix model depicts the research arrangement in the contemporary world, it lacks a specified model of interplay between transitional actors, organizations, and institutions. Triple helix interaction produces a network of reflexive relations where basis for innovation is not pre-synchronized. This confuses actors, analysts, and policy-makers who want to identify and sustain opportunities for innovation and re-organization (Leydesdorff 2005; Benner and Sandstrom 2000). Funding agencies play a crucial role in supporting a new institutional order by enabling "mimetic" or imitative processes (Benner and Sandstrom 2000, 292). The innovation projects or organizations that receive research grants are recognized in research circles as successful. Their processes and research directions are *mimicked* by competitors and reproduction of the research organization is enabled. Funding agencies provide base conditions for setting the new order, with successful application of funds, dependent on the permanence and focus of research (Benner and Sandstrom 2000, 293-296). This fundamentally complicates any analysis. In response, it is necessary to unpack the special processes through new and more sophisticated models and methods — usually involving the concept of social capital and social network analysis tools.

[2.5] Examination of Disciplinary and Individual Perspectives on Social Capital

The discussions on rural school and community centers by Hanifan (1916) initiated the use of term *social capital*. The expression was used to encompass the cultivation of good will, fellowship, sympathy, and social intercourse that completed a social unit (Hanifan 1916). In 1970s the term was used by Glenn Loury to indicate a socially invested phenomenon and to describe racial inequality — linking it to the absence of social connections (Lappe and Du Bois 1997, 119). Since 1990s, the concept of social capital has assumed a central place in social science literature and has been well received by "diverse host of individuals and organizations such as academics, governments, non-governmental organizations (NGOs), as well as transnational entities like the World Bank and UNDP" (Kazemipur 2004). Despite this extensive interest in the topic, social capital does not have a clear and undisputed definition due to its substantive and ideological complexities. While there are some commonalities in the meaning assigned to social capital in the literature, there are still substantial and perplexing differences (Adler and Kwon 2002). Social capital has often been described as an "elastic term" which can mean diverse things to diverse people in diverse contexts (Lappe and Du Bois 1997, 119). These variation can be based either on substance, sources, and effects of social capital (Robison, Schmid, and Siles 2002) or on actors relations, structure of actors relations, or type of linkages (Putnam 2000).

Given the absence of a universally accepted definition of social capital, any specific social capital definition depends "entirely on the discipline and level of investigation" (Robison, Schmid, and Siles 2002). Due to the challenge in defining social capital, most social capital thinkers discuss the concept, its intellectual origin, its diversity of applications, and its shortcomings before developing its interpretation and then adding their own definition to the collection. One of the foremost reasons for the lack of a universally accepted definition of social capital is that none of its definition is limited to answering what social capital is. Instead most of definitions answer questions such as: "Where does social capital reside? How can social capital be used? How can social capital be changed?" (Robison, Schmid, and Siles 2002, 2). The following literature review attempts to reveal patterns in existing definitions of social capital and extract answers for three main questions: what is social capital, where does social capital reside, and what are its outcomes?

Table 2.5-1 classifies frequently used definitions into four main typologies — (i) action based classification, (ii) classification based on structural placement in the network, (iii) classification based on psychological placement in the network, and (iv) resource based classification. Under the *action based classification*, social capital is defined as an entity that facilitates collaborative, cooperative, or common actions, or merely assists in the expectation of an action in a group or a network. This classification responds to the key enquiries. (i) What is social capital? It is an entity with social structure, causes an expectation for action within a collectivity, offers an ability of people to work together in groups, embodies informal values or norms shared by members in a group, or is the fabric of social relations. (ii) Where does social capital reside? It dwells in social structure, collectivity, networks, norms, trust, amongst members of group, or in social relations. (iii) What are social capital outcomes? It facilitates actions by stakeholders, affects the economic goals and goal-seeking behavior of its members, improves the efficiency of society by facilitating coordinated actions, permits cooperation amongst group members, increases community's cooperative acts, strengthens communal harmony that speeds diffusion of innovations, improves the quantity or quality of information flows, reduces transactions costs, splits risk, and allows persuasion of more risky and high return activities (Portes and Sensenbrenner 1993, 1323; Coleman 1990; Robison, Schmid, and Siles 2002, 3-4; Putnam 1995, 67; Fukuyama 1995, 10; 1997; Adler and Kwon 2002, 17-18).

Table 2.5-1: Social Capital typology based on commonly used definitions				
Typology	**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)	An entity with social structure	Social structure	Facilitates actions from structure stakeholders
	Portes and Sensenbrenner (1993)	The expectations for action within a 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 in a group	Among members of group	Permits cooperation amongst group members
	Narayan and Pritchett (1997)	-	-	• Increase community cooperative action • Strengthen communal harmony that speed diffusion of innovations improves the quantity and quality of information flows and reduces transactions costs • Split risk and allow persuasion of more risky and high return activities
	Kwon (2002)	Fabric of social relations	In social relations	It 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
	Portes (1995)	The 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 structure of their social relations	-
Social Capital as outcome of psychological placement of 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 a network • Network-as-resources	Personal networks	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

Source: (Coleman 1990; Robison, Schmid, and Siles 2002; Portes and Sensenbrenner 1993; Burt 1992 ; Portes 1995 ; Bourdieu 1985, 2006; Boxman, De Graaf, and Flap 1991; Putnam 1995, 67)

The classification of social capital based on *positional placement of individual in a network or structure* is based on the premise that the position of an individual in a group or a network can: be an asset, allow access to resources, facilitate pursuit of interests, and positively affect relationships. This definition elucidates the following queries. (i) What is social capital? It is a resource extracted by actors from social structures, the set of elements of the social structure, the capacity of individuals to command scarce resources, or resource available to actors as a function of their location. (ii) Where does social capital reside? It dwells in networks or broader social structures and relations. (iii) What is social capital's function? It is used to pursue actor's individual interests, affects relations among people, serves as input for the production or utility function, and receive opportunities to use other forms of capital (Baker 1990, 619; Schiff 1992, 160; Burt 1992 9; Burt 2000, 3; Portes 1995 12; Adler and Kwon 2002, 18).

The classification of social capital based on *psychological placement of the individual in a network* posits that social influence and authority held by an individual in a network can provide him with preferential treatment, give him access to resources, and can be converted to economic or monetary outcomes. The classification responds to the queries in the given manner: (i) what is social capital? It is a social obligation, social connection, or sympathy. (ii) Where does social capital reside? It dwells in exchange relationships. (iii) What are social capital's benefits? It is convertible into economic capital and produces potential benefits, advantage, and preferential treatment (Bourdieu 1985, 243; Robison, Schmid, and Siles 2002, 6).

The *resource-based classification* discusses social capital in relation to resource availability and access. In this context, we see a different mix of answers to the three queries. (i) What is social capital? This standpoint explains social capital as a property of a network; the sum of actual or potential network resources, and the process by which social actors create and mobilize their network connections. (ii) Where does social capital reside? It dwells in networks or broader social structures and relations. It resides in personal connections or in networks of institutionalized relationships. (iii) What is social capital's function? Social capital can be a "network-as-resources" which benefits social networks through exchange of social resources and facilitates access to other social actors' resources (Bourdieu 2006; Bourdieu and Wacquant 1992, 119; Boxman, De Graaf, and Flap 1991, 52; Nahapiet and Ghoshal 1998, 243; Knoke 1999, 18).

The above reviewed social capital perspectives suggest a range of agreements and contradictions in social capital definitions, based on either source, actors relations, affects of social, or type of linkages (Putnam 2000; Adler and Kwon 2002; Robison, Schmid, and Siles 2002). The review of the typologies demonstrates social capital as an inclusive all-encompassing concept which assumes meaning from the concepts of trust, culture, social support, social exchange, social resources, embeddedness, relational contracts, social networks, and inter-firm networks (Adler and Kwon 2002, 18). These typologies, all posit that social capital resides in one of the elements of a network — social structure, network structure, exchange relationships, or personal network. Moreover, the continued existence of network arrangements emerges as a mandatory condition for production and continuance of social capital. This set of perspectives adds to the discussion of knowledge production (mode-2) and innovation systems (NIS or Triple Helix) and are used to frame the data analysis in this dissertation.

[2.5.1] Social Structure, Resources, and Value Creation

The concept of social capital indicates that something of value has been produced for those actors who have this resource available and that the value depends on social organization. Social structures are classified by their functions. Social organizations are hypothesized to contribute value by providing access to resources (Coleman 1988, S100). Access to social resources is not just the outcome of strong ties — even "weak" ties can be instrumental in achieving optimum resource access (Nan, Ensel, and Vaughn 1981). The presence of weak ties has been found to often identify flows of well-codified knowledge, while existence of strong ties often ensures that actors can facilitate transfer of tacit knowledge (Yuan and Gay 2006).

Social capital combines different entities. All entities "consist of some aspect of social structures, and they facilitate certain actions of actors" within the social structure. It resides in the "structure of relations between actors and among actors" and never in the actors or institutions themselves. Social capital is productive and aids in achieving outcomes which would be non-existent in its absence (Coleman 1988). Thus, social capital basically exemplifies valuable resources for actors in the network environment that enable them to take action. Its value can be tangible taking the form of physical resources such as promotion to key leadership positions and access to insider advice, or in the form of usable financial resources. Social capital can also generate intangible benefits, such as prestige, power, influence, trustworthiness, trust, obligations, or expectations acquired from interacting in the network (Coleman 1988, S98-101). Thus, social capital is a communal concept which facilitates action and productive activity among network members — both access and value creation would be unattainable in absence of social capital.

Many innovations exhibit public good aspects where actors who invent and produce a new product or service only captures a small fraction of the value while the rest accrues to other system or community members. Given that social capital has external effects, as a concept it fits perfectly into the realm of public goods. Generally public goods are good candidates for public investment.

[2.5.2] Forms of Social Capital

In elucidating the concept, a number of forms of social capital were identified. Social capital can include trust or trustworthiness created in the process of obligations and expectations exchange, credit slips, and social norms that are escorted by sanctions, information channels with information-flow potential, goodwill, work contacts, and group or institutional affiliations.

Trust and trustworthiness are aspects of social capital that play a crucial role in the functioning of associations and partnerships and are credited with increased productivity in a group. Networks or groups with extensive trust and trustworthiness are able to accomplish much more than any comparable group that lacks trust and trustworthiness amongst its members (Coleman 1988, S101). Social capital can also take the form of *credit slips* that constitute a collection of social credit held for actions committed and not yet reciprocated. Social credit requires two prime behavior placements: trust and negligible bad debt that can incur from non-settlement of obligations. Dense and closed social structures have more credit slips in comparison to open networks populated with self-sufficient individuals. Credit slips rely on the presence of trustworthiness in social environment, which offers some confidence that obligations will be repaid. Actors holding high levels of outstanding obligations have high social capital which they can access when the situation demands. On the contrary, a high degree of social disorganization, cheating, fraud, and bad debts is inversely related to high level of social capital (Coleman 1988, S102).

Norms and effective sanctions in a social arrangement also constitute a form of social capital. Effective norms and sanctions depend on closure. Norms are established to combat negative external effects and to encourage positive outcomes. A close network entails a set of effective norms and authorizations, keeps a check, and steers behavior. In a closed structure defection from obligations and commitments can inflict a negative externality. Reputations are created, harnessed, and at stake in a closed network structure much more then in open network arrangement (Coleman 1988, S105-S107). Avoiding self-interest and including action sets that serve the interest of network as a whole are significant norms. The execution of these norms can be assured by internalization or through management of external rewards for philanthropic actions (Merton 1968, 197). Societies with well-established norms or sanctions, trust ratios, and overall cooperation, exhibit higher levels of social capital which is expressed through improved economic productivity, rapid economic development, and better institutional performance (Miguel 2003; Putnam 1993).

Information channels constitute another form of social capital. They have a potential to control and allow information to flow more effectively. Accessing information to justify decisive action can be a challenging process. Information channels can ensure access to decision enabling information. *Goodwill* often referred to as sympathy, trust, and forgiveness offered by friends and acquaintances is another form of social capital. It is produced by the fabric of social relations and can be mobilized to facilitate action. Goodwill produces influence, facilitates information flow, and generates solidarity. For any actor in the network, each of the above mentioned effects will have a different value that is dependent on personal moderating factors (Adler and Kwon 2002, 17-18).

Network embeddedness is typically taken as an organization or group-oriented concept and is an indicator of social capital in a network structure. The concept has individual or network level implications but they are so distinct from the organizational level of analysis that separate investigation is mandatory. Any organization of interest is believed to be strongly embedded in a network if its "relationships with suppliers, customers, and other organizations are recurring and characterized by trust, open communication, and joint problem solving arrangements" (Noorderhaven, Koen, and Beugelsdijk 2002, 1). Besides these characteristics, network embeddedness establishes expectations and creates and enforces norms. The concept refers to the quality of relationships between organizations and integrates social organization and social relations into the economic systems. Examination of embeddedness in a social network has been central in research that studies structural properties of social networks to explain outcomes. High degrees of embeddedness in inter-organizational relationships augment an organization's opportunities for learning, improve access to novel technologies and resources, increase legitimacy, and help an organization to enhance its competitive position. (Granovetter 1985). Thus, organizational structural and functional factors that positively encourage network embeddedness deliver outcomes or results, including people, professional practices, normative or social responsibility, innovation, teams, aggressive or action-oriented organizational culture, rich communication systems, and joint problem solving. In contrast, organizations that advocate a culture characterized by stability, display less network embeddedness (Noorderhaven, Koen, and Beugelsdijk 2002, 22-32). The embeddedness of organizations can either generate advantage by ensuring organizational assimilation (Sparrowe et al. 2001) and promotion (Burt, 1992) or be of disadvantage by leading to organizational exit (Krachhardt and Porter 1986).

Finally, social capital can exist in the form of external *work contacts* and as *group or institutional memberships*. This type of capital depends on network condition and network ties for its existence (Boxman, De Graaf, and Flap 1991, 51). Looking at social capital from the rational actor viewpoint, where every actor has control over and interests in certain resources and events, an actor that acquires trust, obligation, a credit slip, information, or goodwill primarily does this for their own self-serving benefit. He is neither aware of, nor considers, what future benefit his self-serving act will bring to the other network actors. He is also unconcerned about how his act will add to the surplus of network social capital, which later can be accessed by other actors in the network. Under the rational actor paradigm social capital is conceivable as a resource for action, but is seldom strategically constructed (Coleman 1988, S95, S119).

Lack of network closure or openness in social organizations are detrimental factors in creation of many forms of social capital, such as norms, sanctions, trust, credit slips and goodwill. Despite the fact that an open environment has copious affirmative external affects that are ideal for social capital, it can impede social capital formation. This is attributed to the lack of closure, making it one of the base conditions for formation and existence of social capital. This however can be double edged, for a closed environment surely facilitates internal exchanges but it hinders access to novel external information which is crucial for innovation. A balanced blend of closure and open network structures can effectively procure and sustain social capital (Coleman 1988, S108-110).

[2.5.3] Approaches to Interpret Social Capital Outcome

Social capital can be interpreted in three distinct ways. First, its deduction can be based on the assessment of network outcomes, specifically the amount of resources accessed or created while participating in the social relations and on the estimation of benefits derived from those social relationships. It is not particularly useful to know the number of alliances established. Rather it is more important to illustrate and assess the roles different members play and their relationship to public and private goods generated in the networks (Savboda 2010, 83). As with the *resources-based view*, the amount of network resources created and utilized are an important outcome. The relationship between resources, social ties, and social capital has attracted extensive attention towards processes that facilitate growth in social ties and hence social capital (Farr 2004).

Second, another common interpretation of social capital is through the micro, macro, and meso approaches. The *micro-approach* concentrates on the importance of collective action and focuses on actor's inclinations to cooperate in associations or groups with a purpose to fulfill certain objectives. This approach targets social capital as an outcome of any actor's motivation to form an association, note behavior while cooperating, and record viewpoint on collective issues such as social influences (Franke 2005, 1-2).

The *macro-approach* views social capital as integration, social cohesion, and collectivity. Here, social capital is analyzed as a product of environmental, social, and political structures. These developments enable more individuals to get involved in social life and increase social capital accumulation. Expansion of supportive communal structures is fundamental for creation of norms, trust, goodwill, and reciprocity. Norms and trust create conditions that positively impact social engagement and political participation (Franke 2005; Putnam 2000). Social capital involves aspects of social structure by its functions, despite any differences in form, appearance, and construction of social structure. Social capital has value to the actors in form of a resource that he can use to achieve his interests. The concept of social capital constitutes both an aid in accounting for different outcomes at the level of individual actors and an aid toward making the *micro-to-macro transitions* (Coleman 1988, S101).

Finally, the *meso-approach* interprets social capital by deciphering social capital from its instrumental value. The proponents of this approach are interested in social capital as both an individual benefit and as a collective benefit. This approach is aligned with the resource mobilization theory and understands social capital as the potential to produce resources by accessing novel information and monetary allocations in social networks. Any network member's position in the social structure is also a factor that determines the nature of resources and the way in which they are circulated in the network (Burt, 1984; Lin, 2001; Portes, 1998). This approach enables cooperation in social structures. The World Bank refers to the *meso* type of social capital as structural social capital. Also, social capital as a resource can have a major impact on actor's ability to act and on his perceived quality of life (Grootaert and Van Bastelaer 2001). The meso approach is dissimilar to micro and macro approaches as it assumes social capital to be more than either an individual or a collective property. It assumes social capital to arise from the interdependence between individuals and between groups in a community. Social capital is presupposed to be a resource that emerges from social ties and used by network actors whether individuals or groups.

The two aforementioned social capital interpretations affirm the contribution of social engagement and social ties with the progress and well-being of network actors. Yet, each interpretation addresses the cooperation aspect from complementary viewpoints. While the micro approach looks at cooperation as collective action, the macro approach elaborates it as participation, and the meso approach emphasizes cooperation as a social network phenomenon (Franke 2005, 1-2).

Third, it is possible to interpret social capital through *bonding* and *bridging* conceptualizations. Within the collective, bonding social capital focuses on internal ties while the bridging counterpart focuses on external relations (Putnam 2000). Putnam, Gittell, and Vidal (1998) gave the original definitions for bonding and bridging social capital, defining bonding as a form of capital that brings already acquainted actors closer and bridging social capital facilitates in bringing those actors or groups together who had no previous acquaintances (Gittell and Vidal 1998). While the bonding capital's view takes social capital as an internal group phenomenon, the bridging view — similar to the meso approach, takes social capital as a resource that is integral to the social network and ties focal actors to other network actors. This conception can potentially explain the differential success of actors and firms in competitive or rivalrous situations (Adler and Kwon 2002, 19). Bonding social capital impacts performance positively by reinforcing group cohesion and group think and by creating an environment of free exchange of ideas, cohesion, and trust that can minimize task and relational conflicts. On the contrary, bridging ties ensure novelty and diversity in ideas that are essential inputs in knowledge creation. The notion is that an individual can operate in a non-detached environment as such circumstances generate resources crucial for survival and progress (Yuan and Gay 2006). As an effect, the brokerage potential of the bridging ties can produce social capital (Burt 1997, 340).

The process of knowledge creation can be explained through the *structural hole* theory (Coleman 1990) and *closure model* (Burt 2005). Structural holes refers to "separation between non-redundant contacts" and are crucial to access external social capital (Burt 1997, 18; Yuan and Gay 2006). The dense, closed, and highly cohesive groups with excessive closure are excellent facilitators for exchange of internal information, whereas structural holes bridged with external actors, which are outside the group, are crucial to gain access to unique and varied information. Structural holes are defined as the absence of direct connections between any two network nodes. The actors that bridge the distant nodes function as brokers and control information exchange and communication. Bridge ties with the actors, outside of the group, functions as boundary spanning ties that contribute to competitive edge. These ties have the potential to procure information which legitimizes and aligns internal organizational practices with external competitors and industry to enhance performance (Burt 2004). The presence of external bridging ties expands individual or group ideas and increases connectedness with the peripheral environment, permits efficient access to external resources, broadens knowledge conception, and ensures diversity of opinion (Argote and Ophir 2002). In a knowledge-based economy, the ability to reach out and interact with dissimilar actors is as important as working together with similar actors. Diversity of information can result in improved intellectual exchange of ideas (Argote and Ophir 2002; Mollica, Gray, and Trevino 2003).

In a knowledge creation process, the success and competitive edge of any group is evaluated based on its external links to the concerned environmental norms. The external environment calibrates measures of performance. A top notch performer can slip from a top spot if there is transformation in the external environment. Strong external connections are a key to sustaining and leading in competitive settings. The presence of social capital can be assessed based on the evidence of a linked network structure between network actors. Similarly, absence of social capital can be ascertained by lack of network organization and the absence of links between actors. Thus, the presence of a network becomes a deterministic condition to judge the presence or absence of social capital. Networks evolve as a mandatory base environment for the creation of social capital.

[2.5.4] Factors in Creating Network Ties and Social Capital Formation

Three important factors namely — *homophily, location proximity,* and *team environment* — are found crucial in the development of network ties and social capital. The theory of *homophily* predicts that people with similar traits are more likely to interact and cooperate with each other than with those who have divergent traits. In particular, traits such as age, gender, race, education, career, and social status support homophily predictions. This research investigates the role of location and organizational membership as a form of conceptual homophily. Taking the case of large-scale multi-disciplinary projects, teams are distributed in diverse locations — group or organizational membership may define their work relationship boundary and the context for their interaction. *Group affiliations* in a large-scale project can breed network connectivity as group association creates hubs of activities around which actors organize their social relations (McPherson, Smith-Lovin, and Cook 2001; Mollica, Gray, and Trevino 2003; Yuan and Gay 2006; Ibarra 1993). While it is highly probable that people with similar traits will interact with each other, cohabitate, and co-produce, it is also possible that these interactions may reduce relations between people with dissimilar traits. Thus, while homophily at one end unifies the network, in a totally different context it ends up dividing the network (Yuan and Gay 2006). Homophily in groups encourages extensive communications, advice exchange, and socializing. The effect of group membership in facilitating network ties can be so intense that it can counteract other differences in actor traits such as age, race, religion, etc. In a distributed team environment, as is the case with large-scale projects, actors from within the same group affiliations may develop task-related instrumental ties with each other and withdraw or curb relations with actors who have different group affiliations (McPherson, Smith-Lovin, and Cook 2001). While this process facilitates closeness and communication between internal group members, it is detrimental for access to unique external information, which may be critical in the innovation and research process.

Location proximity also can have a significant impact on the formation of network ties. A common location assigns common social context, opportunities, and motivations for interaction. Actors placed in close proximity are frequently compelled to engage in real-time communications. On the contrary, distance can eliminate shared context, acquaintance, and closeness among the group members. Therefore, in a network arrangement, there is an inverse relationship between physical separation and real-time communication. In the case of distributed teams, such as in large-scale projects, with members positioned in different geographical locations, the physical distance divides the teams into smaller cliques. In distributed teams that lack commonality, familiarity and friendship in work contexts may become a challenge. In such settings, members of dispersed teams are more likely to form workable relations with people at the same location and curb interaction with actors at distant physical locales (Yuan and Gay 2006; Hinds and Bailey 2003).

The existence of a *team environment* may offset this and support the formation of network ties and social capital. The committed participation of actors in a team setting can have positive effects on the performance of the group. "Team interaction patterns, that are consistent with cohesive work groups, are positively related to teams' final grades" (Baldwin, Bedell, and Johnson 1997). The process of continual interactions and work complementarity in a team ensures higher levels of trust and enhanced trustworthiness amongst team members. The team is witness to both formal and informal types of ties. While formal professional ties in team settings impact performance positively, informal relationships can have the potential to hinder individual and group performance through impolite behavior and lack of assistance rendered to co-workers (Sparrowe et al. 2001, 322). A base condition for social capital formation is that the teams should be constituted to incorporate cross-disciplinary and multi-functional members that have abundant internal and external linkages. While internal linkages build a closed team with trust and norms, the external links ensure access to non-redundant information, a must for competitive standing.

[2.5.5] Factors Impacting Social Influence in a Network Setting

The social influence of an actor depends on social or network stability and social status. Social stability depicts society with people that work in sync to make the society better. The same conceptualization can be applied to a network environment where a stable structure involves network members being closely engaged in activities focused on the broader network goal. Stability ensures that relationships are close, mutually interdependent, reciprocal, and involve interconnected activities. The presence of stable relational traits has a positive impact on the social influence of an individual or group in a network (Belliveau, O'Reilly, and Wade 1996, 1572-1573). A group that possesses strong relational ties amongst its network members often reflects a stable environment where actors share common identity and have privileged access to resources compared to other groups (Kilduff and Krackhardt 1994).

Social status, a term depicted in social network analysis by the number of active ties, is a network component that has significant positive impact on actor's access to resources and social influence. It is an indicator of an actor's prestige attached to his position in the system. A person of low status, with a low number of network ties, usually has low social influence and limited access to resources, while a person with high status, with a comparatively higher number of network ties, has high influence and may play a crucial role in resource-related decisions. The social status of an individual or group not only impacts their social influence but also moulds the expectations that are essential predictors of behaviors (Belliveau, O'Reilly, and Wade 1996, 1572).

[2.5.6] Type of Network Linkages with their Impact on Knowledge Flows

The number of interpersonal linkages are conduits for channeling information and indicators of social capital in a network environment (Yangmin and Cannella 2008). Social capital exists in the *world of networks* where actors interact both formally and informally to exchange and combine knowledge (VALGEN 2009). Formal network ties are contractually agreed upon strategic alliances that indicate planned channels for knowledge exchange between networks. These types of ties can be easily integrated into an open innovation strategy where a network of actors in an innovation project identifies internal knowledge gaps and then, without building internally, approaches potential external collaboration partners to fill the gap. In practice, formal ties are exposed to unexpected knowledge spillover paybacks. For example, in the case of joint agreements, besides planned knowledge exchanges, the process can also enable actor mobility between groups and thereby create access to unexpected knowledge and networks through informal ties. The supposition that formal ties are embedded in social networks is consistent with the view that economic action is entrenched in social structures. The process of creating social capital through formal ties in an open innovation context requires recognizing and then capturing benefits of unanticipated knowledge spillovers (Simard and West 2006, 7; Granovetter 1985; Owen-Smith 2004).

Similar to the formal ties, informal relations can be an important conduit for knowledge flows and source of unforeseen knowledge usage. Informal ties have the potential to facilitate knowledge spillovers when actors move between projects or work in numerous organizations. The development of informal ties can be a result of formal professional relations or vice-versa. These informal relationships are an important breeder of social capital (Simard and West 2006, 7-9; Murray 2002). Sometimes informal connections can be critical to acquire top management positions or to effect promotions (Boxman, De Graaf, and Flap 1991, 51). The informal relations can arise in event of unsanctioned informal exchanges such as interaction for crucial strategic work related information or for work related advice or for gaining support to deal with personal work challenges. On the contrary, formal relations involve exchange of professional work through joint ventures, business alliances, or research and development partnerships. Thus, there is no concrete rule that collaborations or partnerships should be formal; they can have informal foundations that also can eventually lead to increased trust, commitment, and cooperation (Podolny and Baron 1997). The network structure of social interactions, whether formal or informal can either enhance or constrain access to valued resources and eventually be beneficial or detrimental (Ibarra 1993).

[2.6] Conclusions

The evolution of global research and innovation theory — from traditional rigid programs that only depicted inputs and outputs, to contemporary dynamic knowledge-based agendas that emphasize interactions, joint research, and personnel exchanges between institutional actors, has brought forth new opportunities. To address them, private enterprises, universities, public research institutes, and relevant people are pressed into partnership projects with cross-disciplinary and cross-national affiliations. A new institutional order is created at the intersection of these institutions. Innovation that once conformed to the linear configuration now operates in a complex social system. Learning and knowledge dissemination, involving actor interaction, emerge as central attributes of collaborative systems. Canadian innovation practices have adapted to these current and upcoming global developments through a range of new institutions, program and policies, including Genome Canada, the focus of this thesis.

Some of the contemporary processes such as heterogeneity, social accountability, reflexivity, quality control through peer review, and continuous upgrading in technology, mandate innovation and restructuring of knowledge. The resulting *mode-2* knowledge, backed with the theoretical underpinnings of National Systems of Innovation and the Triple Helix, posits innovation operates in systems. The notion of innovation expands to incorporate personnel interactions and experiences as key inputs. Knowledge no longer fits into traditional disciplinary boxes.

Contemporary innovation systems and triage interactions function as the breeding ground for social capital. Networks or groups with extensive trust and established norms (i.e., with a high levels of social capital) accomplish much more than comparable groups that lack trust and trustworthiness amongst group members. Actors holding high levels of outstanding obligations presumably generate high social capital. *Homophily, location proximity,* and *team or group environment* are crucial in social capital formation. Large-scale projects synergize group affiliations that breed network connectivity and social capital. Group level associations create a hub of activities that involve extensive communications, advance exchanges, and socializing, which positively affects outcomes of the group. Location proximity offers common social context, opportunities, and motivations for interaction through engagement in real-time communications and actions.

Overall, social capital is hypothesized to exist in the networks where actors interact both formally and informally to exchange and combine knowledge. Formal relations mandate exchange of professional work-related information through joint ventures, alliances or research, and development partnerships, while informal relations whether sanctioned or unsanctioned, vary from exchange of crucial strategic work-related information and advice, to managing personal or work challenges, to social support. Informal connections ensure access to information that is vital for promotion to top management positions. Overall, social capital is a network property that has beneficial outcomes limited not only to its producers but also to all others who are linked with the creators of social capital.

The rest of this thesis examines Genome Canada and its role in generating knowledge-based growth. The Applied Bioproducts and Crops (ABC) Competition in 2008 offers a case where we can examine the relevance of economic and social theories of innovation and gather data on the social network forming background to the competition and assess its impact on researcher success and program management. This will aid to ultimately infer from the case, the relative influence of different types and measures of social capital on the overall success of the competition and, by implication, on the network model that underpins Canada's current science and technology policy.

Chapter 3

RESEARCH METHODOLOGY AND ANALYTICAL FRAMEWORK

Introduction

A close-knit community of relevant stakeholders is emerging as one of the contemporary outcomes of innovation and research-based science projects. The process of innovation is no longer confined to local or national boundaries and has reached global research worlds — an occurrence that was once limited by local, national, international boundaries and rules. In other words, innovation projects are transforming into platforms for linking diverse, yet right combinations of actors with access to useful and mutually beneficial information. These actors are locally, nationally, and globally distributed and hold affinity with different sets of geographically dispersed institutions or organizations.

In such a diverse environment, it would be highly improbable to identify the best set of actors or individuals that contribute more effectively to the process of innovation in comparison to others. The process of identification of key players in network operations is complicated by the dynamic nature of network environment. Here, formal and informal linkages, can over time transform associations, set-up new standards, and formalize new trust relationships. The review of literature in Chapter 2 of the dissertation has brought to light crucial gaps and challenges requiring further investigation. There is a definite gap in the documentary and empirical evidence that can effectively rationalize the Canadian government's increased support for large-scale network-based research and innovation projects. It raises a critical question on the relationship between government's support for large-scale innovation project, systemic outcomes, and social capital.

Regardless of increasing interest in this subject, there is not enough theoretical or experimental evidence to assess and to quantify *social capital* that presumably is harboured in large-scale S&T projects or to relate this social capital with the large-scale innovation outcomes. The current research aims to substantiate this factual knowledge gap. This chapter focuses on extracting empirical evidence that will either support or negate the assumption that social capital is generated in large-scale network-based research projects and assess social capital's downstream productive residual outcomes. The work ultimately tests the hypothesis — *Contemporary innovation network systems create social capital which generates downstream productive residual outcomes.*

This hypothesis is unpacked into three conditional sub-hypothesis that are discussed earlier in Chapter 1 of the dissertation.

[3.1] Methodology

The chapter unpacks the methodology to extract the relationship between networks, network structures, positional placements, and social capital's downstream outcomes, if any. The research combines tools of social network analysis (SNA) to conceptualize the network — with a combination of input and output measures, to take into account the intricacies of stakeholder network dynamics. The methodology section consists of a two sub-sections that explain network of interest and data collection process. The analysis will test the relationship between large-scale projects and social capital using a *proxy* (detailed in Chapter 4) where we are unable to access data directly.

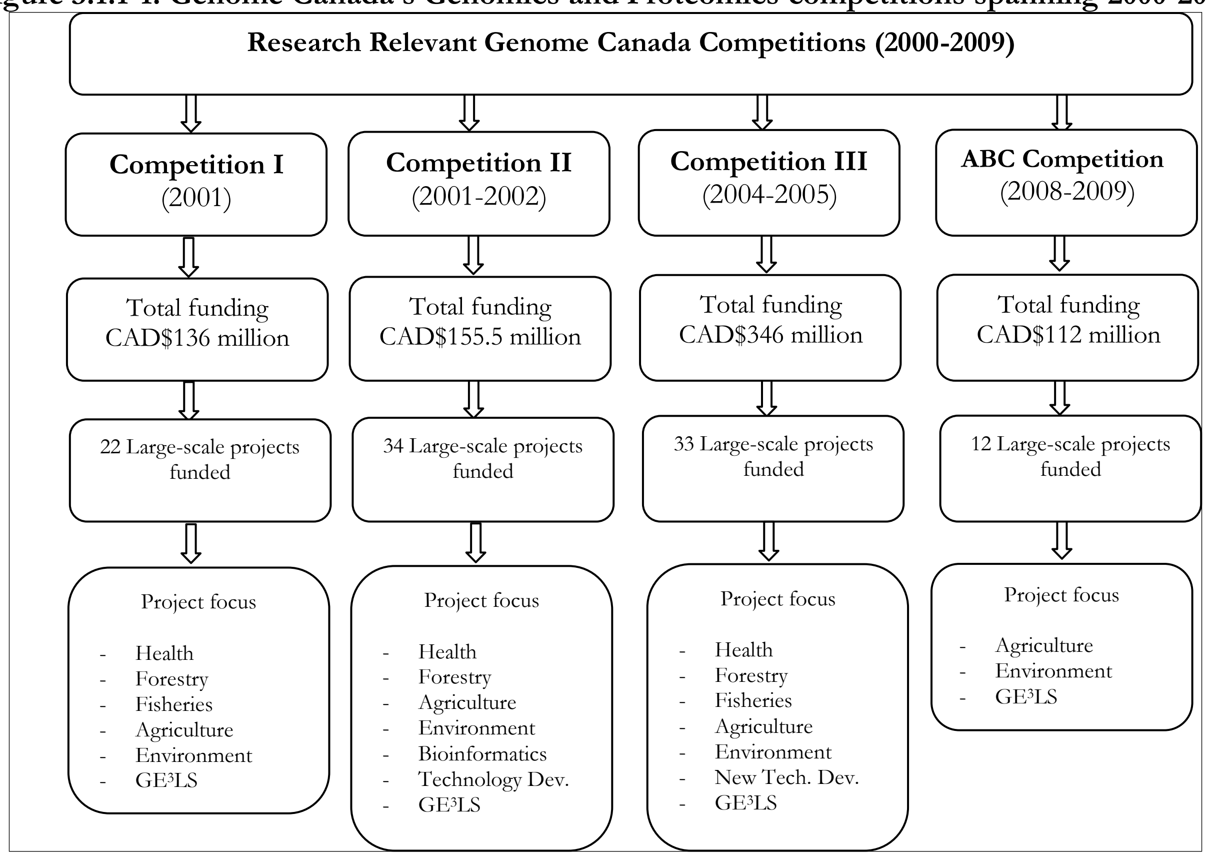
[3.1.1] Network of Interest

Genome Canada's funding initiatives into the Canadian agro-world research, spanning 2000-2009, sets the boundary of data collection for current research. Genome Canada is a not-for-profit organization founded in 2000 (Brzustowski 2010). One of the main reasons for selecting Genome Canada's funding initiatives in current research is that the organization is progressively being recognized as one of the foremost agencies that has adopted contemporary science and research management practices and an innovative network-oriented business model in Canada. The example of Genome Canada is pertinent to the context of current research for following five reasons. (i) The organization's overarching *umbrella model* functions to draw industry, government departments or agencies, universities, and the public together for effective opertionalisation of large-scale genomics and proteomics based research projects (Genome Canada 2011) (ii) Genome Canada manages large-scale, multi-disciplinary, and internationally peer-reviewed research projects in an effort to support a fundamental systemic change in research and innovation; (iii) Genome Canada has received substantial federal funding — over CAD $915 million between 2000-2009 (core budget and leveraged funds) — which makes it a leading agency in the government pursuit for realization of national research and innovation-based objectives (Genome Canada 2008, 3); (iv) The organization partners with the federal government to assist in its pursuit of global leadership, as laid out in their latest S&T Strategy documents (Publishing and Depository Services 2007) and; (v) Genome Canada research projects create an environment for multi-stakeholder tie-ups, partnership, and networking opportunities.

The research and innovation networks generated as an outcomes of Genome Canada's competitions — I and II (both held in 2001), III (held in 2004), and the Applied Genomics in Bio-products and Crops (ABC)

Competition (held in 2009), in collaboration and partnership with the AFM-NCE, ABIP, and the federally-funded ERCANs, will be examined for their social capital potential and contributions to innovation capacities. Genome Canada announced *Competition I* on April 4, 2001, as its first substantial investment amounting to CAD $136 million for supporting "17 large-scale research projects and 5 science and technology platforms" in Canada in fields of "health, forestry, fisheries, agriculture, environment, and GE^3LS." The GE^3LS term stands for Genomics and its Ethical, Economic, Environmental, Legal, and Social aspects. The GE^3LS researchers function as agents of policy change and help inform the development and evolution of laws and public policies at the federal, provincial and territorial levels. They also promote effective and well-balanced governance regimes to oversee major research endeavours (Genome Canada 2010).

Figure 3.1.1-1: Genome Canada's Genomics and Proteomics competitions spanning 2000-2009



(Source: Author's construct)

Competition II extended from July 19, 2001 to April 2002 and invested CAD $155.5 million into 34 projects in health, forestry, agriculture, bio-informatics, technology development, environment and GE^3LS. *Competition III* was launched in July 2004 and its results were declared on August 25, 2005. A total of CAD $346 million was invested in 33 large-scale genomics and proteomics projects, which lasted for 3-4 years. Finally, the Applied Genomics in Bio-products and Crops (ABC) competition ran from April 2008 to 2009 with two theme areas: bio-products and crops. In the bio-product theme, project proposals with a focus on feedstock optimization, micro-organisms for sustainable processing technologies, and value added-bioproducts were invited. These projects basically integrated genomic and proteomic approaches to understand and manipulate underlying biological processes. In the crops theme, research proposals that focused on basic plant genomics, application of plant genomics and agriculture, and food production sustainability were invited. These projects were designed to better understand genetic and physiological factors that contribute to the underlying biological processes of Canadian crops. A total of CAD $112 million was invested in 12 chosen research projects (Genome Canada 2011). Out of the four Genome Canada competitions selected from 2000-2009 for the purpose of current research, a total of 10 projects focused solely on the GE^3LS aspects of research.

The Value Addition through Genomics and GE^3LS (VALGEN) project awarded under the ABC competition, is particularly significant amongst the GE^3LS set of projects as it not only focuses on the GE^3LS subject area but also focuses on creating a network of GE^3LS researchers who might otherwise be isolated and fragmented in a variety of institutional, geographical, and disciplinary settings. The network-based goals of VALGEN project — intensifying the ABC network, creating potential synergies amongst ABC projects, information sharing amongst all alliance partners, and identifying patterns of exchange amongst ABC actors and projects, are closely aligned to the Canadian government agenda aimed at facilitating networks and partnerships among the social science researchers (VALGEN 2009).

The operations of research funding agencies are executed on three levels: the *coercive level* where researcher's applications are based on operational routines and administrative structures; the *normative level* where evaluation criteria influence researcher's normative orientation and; the *cognitive level* where funding agencies decide the types of performance and organization in research that should be rewarded (Jooste and Scott 2009). Genome Canada's funding model includes qualities of both *standards oriented* and *mission oriented* funding. While the former emphasizes adoption of issues and perspectives acceptable in the scientific communities, the latter encourages researchers to focus on matters of significance to social practice. The funding agencies thus influence both research performance and network formation. Genome Canada's funding model supports large-scale research initiatives and emphasizes international engagement and global quality of research, scholastic initiative, and projects with a networking orientation. In a way Genome Canada is assisting in the development of a new institutional order through "entrepreneurialism, trans-institutional research organization and trans-epistemic quality control" (Benner and Sandstrom 2000, 292-300). Genome Canada sponsored projects have facilitated multi-disciplinary teams of experts from national and international research communities to associate and link in internationally peer-reviewed research projects and S&T platforms. Presumably, Genome Canada's strategy to support large-scale research projects that demonstrate a potential to link research communities in network relationships, is an implicit acknowledgement that creation of networks can facilitate broader program objectives and synergistic research.

[3.2] Analytical Framework

This section combines the essentials of social network analysis and its tools and measures that are fundamental for devising appropriate outputs in a network environment.

[3.2.1] Social Network Analysis (SNA)

Social capital is intangible in nature, which makes quantification and estimation of its short and long-term impacts challenging. Mead (2001) argues that SNA can be used to "make the invisible visible" (Mead 2001). To counter this difficulty proxies for social capital are often employed. In this context, social network analysis offers a range of diagnostic tools to estimate different types of social capital and to analyze patterns of relationships among individuals interacting in a network environment. SNA descriptive statistics can be used to describe, predict, and test for the presence or absence of relationships in network situations. The analytical statistics provide information about the individual distributions of actors in the network and their relationships, attributes, joint distributions, and statistical associations. Social network relationships are complicated and generally involve large sets of actors that can reveal gross and subtle patterns amongst them. SNA provides a useful way of identifying and characterizing the complex and dynamic interactions and exchanges that occur among researchers in collaborative networks. These networks are platforms for generation of social capital. The link between SNA, network environment, and social capital enables its theories, models, and approaches to investigate and indicate factors that can generate social capital and explain downstream value generation in large-scale innovation projects.

As mentioned on VALGEN website, social network analysis is a "powerful tool for explaining variances in social behaviour, institutional dynamics and resources and can also be used to evaluate the socio-economic outcomes of research" (VALGEN 2009). As affirmed by Hanneman (2010), SNA permits to draw an inference on networks with confidence (Hanneman and Riddle 2010, 1). A social network denotes individuals, groups, or organizations that are linked with each other through socially consequential relations. "Social networks........are governed by shared norms of the exchange instead of legally binding contracts" (Angehrn and Gibbert 2005, 526). These relationships can be mapped to reveal the patterns underneath. Enquiries into the network patterns often leads researcher to investigate issues such as the quality of relationships amongst network actors, their network position, and the impacts of these attributes on network dynamics. SNA asserts the foundation for social life as relations and patterns are articulated by these relations. Social networks are primarily collection of nodes or actors that are linked to each other by one or more types of relations (Marin and Wellman 2009 ; Wasserman and Faust 1994). "Social network analysis seeks to understand networks and their participants and has two main focuses: the actors and the relationships between them in a specific social context" (Serrat 2009, 1). Social network analysis *de-layers* formal coordination structures within the organization but also makes "informal networks visible." As more and more organizations shift to network-based structures through "joint ventures, alliances, and other collaborative relationships," SNA facilitates further collaboration by assisting decision makers to "systematically assess and support strategically" important informal collaborations in essential groups such as "top leadership networks, strategic business units, new product development teams, communities of practice, joint ventures, and mergers" (Cross, Borgatti, and Parker 2002). The social network is a platform where different kinds of knowledge combine to produce new knowledge. This process expands and sustains the network and its outputs over time. Network ties function as modes for "transfer or flow of resources" but can also create "opportunities for or constraints on individual action." Network analysis can identify "boundary spanners, gatekeepers, knowledge bottlenecks and as well as under and over-utilized individuals or organizations (Ryan 2007, 46-47).

SNA can be used to examine how an actor's position in a network influences their access to resources such as goods, capital and information. This gives an economic meaning to social capital. SNA as a diagnostic tool takes on one of two approaches. The first approach deals with a closed group and investigates the relationships amongst actors working in an institution. The second approach deals with one person and seeks to understand their social relationships commonly referred to as their "egonet" (Clark, 4-5). Network characteristics such as "contacts, ties, connections, group attachments, and meetings as means to relate one actor to another" are most probable indicators of social capital and predictors of trust and power (Putnam, 1995: 67). The focus of SNA on examining these network characteristics makes it a most appropriate methodology for current research. SNA is unique as it not only provides quantitative measures but also gives qualitative insights to data analysis.

[3.2.2] Social Network Analysis Tools and Measures

This research employs *Analytical Technologies-UCINET*, one of the available SNA software, to perform social network analysis on data collected from the network of interest. Various network measures such as network density, centrality, and correlation algorithms are employed in the process. *Netdraw* software generates visual depictions of the relations between Genome Canada's project actors. The Sociograms generated by Netdraw provides valuable information about the social network positions and linkages amongst investigators. They are a symbolic representation of the network and detail crucial information about network structure. UCINET allows identification of groups and sub-groups, such as individuals or actor clusters, and pinpoints isolates in a network. *Core-periphery* network structure can be identified where a core includes actors that are densely tied to each other and a periphery consists of actors with more ties to core actors than amongst themselves. In contrast, emergent network structures initially have no clear boundaries and grow by pair-wise interactions. It is important to note that graphs generated in SNA are similar to maps that illustrate geodesic distance between nodes and giving a figurative depiction of the distance between network actors (Hanneman and Riddle 2010). In addition to generating a qualitative pictorial representation of a matrix in question, SNA software generates a number of measures that quantitatively depict the structure of a given network. Unlike graphs, these quantitative outcomes offer statistically verifiable representations of the network in question (Borgatti 2002).

According to Seibert (2001), social network tools and measures analyze networks as a way to shift social science research from an individual or a group to the relationships between individuals or groups and the impact of these relationships on the overall structure (Seibert, Kraimer, and Liden 2001). Social network analysis is applicable at two levels: ego level and whole network level. *Ego-centered* analysis focuses upon an individual agent and its relationship with others. The nodes in the network indicate an ego. Ego is an individual focal node. Egos can be persons, groups, organizations, or whole societies. This ego-centric approach provides an actor's contacts and sphere of influence. Reliable ego-centered data can be collected by using survey technique or extracting from whole-network data. This technique is used in setups where boundary is not easy to ascertain (Hanneman and Riddle 2010; Ryan 2007; Bien, Marbach, and Neyer 1991, 75). In contrast, *whole network* analysis takes into account all network nodes or egos rather than focusing on one single node. This analysis includes data on the presence or absence of relations between every pair of nodes. Here more than one relation is analyzed. This approach is constructive when boundaries are easily established (Marin and Wellman 2009). The current research deals with data at the whole network level.

Upon identification and selection of relevant relations for analysis, a network researcher has to decide between selecting ties that are: directed or reciprocated, such as from one node to the other or undirected, or between two nodes in no particular direction e.g. information sharing (Plickert, Cote, and Wellman 2007; Marin and Wellman 2009 14).

There are a wide range of metrics and measures that can be derived from SNA. The key SNA measures relevant to this research warrant some discussion. First, *network density* is one of the central measures in social network analysis. It pertains to the whole network and is non ego-centric in nature. Density creates a quantitative base to affirm the presence or absence of linkages amongst network actors and assess the intensity of linkages between them based on directed or undirected collaborative activity. The density measure is used to quantitatively assess the organization of the network of interest and to provide an insight into the nature of the ties between the actors. In this study, density measures are calculated for four identified collaborative activities amongst network actor's namely disciplinary affiliations, co-location, co-funding, and creation of knowledge. Density measures are also used to analyze the intensity of linkages amongst network actors in different collaborative setups.

The network density measure gives insights into the level of actor social capital and social constraint. It demonstrates the overall volume of interaction among a team's members in a network (e.g. the average number of ties per team member); and measures the ratio of interconnections within a given network (Knoke and Kuklinski 1982, 45; Borgatti, Everett, and Freeman 2002; Hanneman and Riddle 2010; Sparrowe et al. 2001). At the actor level, an individual's attributes and the nature of his social ties determine his social capital producing capacity. At the group level, the density and the structural components of interaction in a network determine a group's social capital outcomes. Density is an indicator of overall level of interaction amongst network members and is analogous to the mean number of ties per group member; a high number of in- and out-ties indicate higher density and higher levels of social capital (Sparrowe et al. 2001, 317; Belliveau, O'Reilly, and Wade 1996, 1572).

Binary one-mode datasets are constructed in this research. The density measure of binary networks is calculated as the total number of ties in a matrix divided by the total number of possible ties. The value of density ranges from 0 to 1 where 0 means no connection and 1 conveys that all actors are connected. Density is classically expressed by *equation 3.1* where all possible ties in a matrix are denoted by *N*, the total number of actual ties amongst the network actors is denoted by *L*, and the denominator of the equation accounting for all possible permutations and combinations is *N(N-1)*. One shortcoming of the classical network density equation is that it assumes all observations or relations to be independent. This is an unreasonable supposition.

$$Density_{Local} = \frac{2L}{N(N-1)} \qquad (3.1)$$

The second set of measures of interest address *centrality*. While density is a whole network measure, centrality deals with an individual actor position within an entire network (Wasserman and Faust 1994, 168-169). Centrality measures and their popular interpretations make implicit assumptions about the manner in which traffic flows through a network (Borgatti 2005, 55). In an alternative conception, centrality can be viewed as a node level outcome of implicit models of flow processes (Borgatti 2005, 70). The measure of centrality stands for power and influence of an individual in the network to affect decisions. Actors with higher numbers of ties, which reflects their access to information and resources, have higher network power (Valenti and Horner 2010; Friedken 1993). Centrality measures are engaged to identify dominant actors, institutions, or research-activities within the broader network. They can also identify central actors control over resource and greater choice of alternatives. Resources can vary from task-specific knowledge to classified work information (Sparrowe et al. 2001, 316-317). Ties can symbolize information sharing, assistance seeking, and guidance that are instrumental for an individual's job performance. Centrality in a network basically is the reflection of individual's involvement in exchanging assistance with co-workers and engaging in mutual problem solving. An individual who is central in the advice network can, over time, accumulate knowledge about task-related problems and workable solutions. This expertise facilitates problem solving. Conversely, actors in peripheral positions in an advice network could find it challenging to develop expertise and may be unable to develop competencies and expertise needed for crisis management (Baldwin, Bedell, and Johnson 1997; Sparrowe et al. 2001). Central actors in an advice network have higher levels of internal and external roles than tangential actors. Central positions in groups that deal with complex task are posited to relate positively to individual performance (Sparrowe et al. 2001; Molm 1994).

Apart from the actor level role, centrality measures are also administered at the whole network level and referred to as — *centralization* measures. While centrality is an individual oriented measure, centralization focuses on the whole network and allows for a network to network comparison. Centralization can be at two levels: network and group. *Network centralization* reflects the extent to which interactions are concentrated amidst a small number of network members rather than being distributed equally among all network members. *Group centralization* on the other hand is analogous to the variance in network ties per group member. When the variance in number of ties per group member is low, no group member enjoys substantially more links than any other group member, and therefore no group member is more central than any other. Conversely, when the variance in the number of ties per group member is high, some members will have proportionately more ties and therefore will be more central than others in a group (Sparrowe et al. 2001, 317). The centralization measure is positively related to group performance but only for simple tasks. Any increase in task complexity complicates the association between centralization and group performance (Sparrowe et al. 2001, 321-323; Molm 1994). The following centrality equation identifies core actors and facilitates in drawing conclusions about gaps and challenges in different collaborative networks. As per *equation 3.2*, the actual number of linkages are depicted by the sum of *xij* within the given network population, relative to aggregate output *(N-1)*.

$$Centrality = \frac{\sum x_{ij}}{N-1} \qquad (3.2)$$

The centrality measure is further delineated into three core measures: betweenness centrality (BC) via freeman's approach, degree centrality (DC), and eigenvector centrality (EC). (i) *Betweenness centrality* indicates the crucial channels for network flows and reveals those foremost actors who have closer links with the other nodes. Betweenness centrality is a measure of how often an individual lies between the shortest path linking two other individuals or actors. In the dissertation *freeman's approach* is used to ascertain betweenness centrality where a network actor will have high betweenness centrality scores if he is positioned on the geodesic paths (shortest distance) between pairs of other actors in the network. This high betweenness position confers power to the actor as he now can play a brokerage role by controlling communication and exchange of resources between other actors in the network.

$$CentralityBetweenness = 2\sum_i \sum_j \frac{\frac{g_{ij}(p_k)}{g_{ij}}}{n2 - 3n + 2} \qquad (3.3)$$

In *equation 3.3*, *gij* represents the number of ties linking *i* and *j* and *gij(pk)* is the number of these ties that contain individual *k* (Freeman, Borgatti, and White 1991, 141-154).

(ii) *Degree centrality (DC),* also referred as total degree centrality (TDC), is best defined as "the number of ties incident upon a node" or the "number of paths of length one that emanate from a node." Degree centrality represents the "extent to which a node connects to all other nodes in a network" (Borgatti 2005, 62). It is an implicit process that involves no indirect links and gives the summation of each row in the adjacency matrix of a network. In the case of a directed network, such as in this dissertation, the degree centrality is expressed via two distinct measures that are based on the direction information flow. These are in-degree centrality and out-degree centrality. In-degree centrality (IDC) gives the number of incoming links directed to a node, and out-degree centrality (ODC) gives the number of outgoing links from the node.

$$IDC(i) = \sum_{j=1}^{n} x_{ij} (i \neq j) \quad \text{and} \quad ODC(i) = \sum_{j=1}^{n} y_{ij} (i \neq j)$$ ....(3.4)

$$DC(i) = IDC(i) + ODC(i)$$ ....(3.5)

In *equation 3.4*, *xij* denotes the number of direct links from node *j* to node *i* and *yij* denotes the number of direct links from node *i* to node *j*. Normally, *xij* equals to 0 if an actor is an isolate or 1 if an actor is linked with every other network member, and the same is true for *yij*. As a result, in *equation 3.5*, the incoming links from the other *(n – 1)* nodes to node *i* are counted and outgoing links from node *i* to the other *(n – 1)* nodes are counted. This gives the total degree centrality (TDC) of node *i* as the sum of IDC and ODC (Haiyu and Yoong 2010, 233-234; Hanneman and Riddle 2010). The degree centrality measure gives the "degree and normalized degree centrality of each vertex and gives the overall network degree centralization." The normalized degree centrality is the degree divided by the maximum possible degree expressed as a percentage and should only be used in case of binary datasets (Freeman 1979; Borgatti, Everett, and Freeman 2002).

(iii) Another popular method to measure centrality is through the *eigenvector approach*. The eigenvector approach is an effort to find the most central actors — those with the smallest distance from other actors, in terms of the global or overall structure of the network and to pay less attention to patterns that are more local (Hanneman and Riddle 2010). This measure calculates the eigenvector of the largest positive eigenvalue as a measure of centrality. The eigenvalue captures the more global aspects of distances among actors; the eigenvector dimensions capture more specific and local sub-structures (Hanneman and Riddle 2010; Borgatti, Everett, and Freeman 2002). Eigenvector centrality is used as a measure of aggregate prominence as it calculates centrality as a function of centrality of others to whom an actor is connected via direct or indirect ties. The aggregate prominence index approach gauges an actor's centrality in a network environment and assesses how it is augmented when he links with other actors who themselves have high centralities (Ibarra 1993, 480; Bonacich 1987, 1172-1173).

$$\lambda v = Av$$ ....(3.6)

Here v is the eigenvector of A and λ is the associated eigenvalue (constant). The interpretation of the equation is that an actor who has a high eigenvector is actually adjacent to other actors who themselves have high adjacent eigenvector scores. In a network analysis large eigenvalues are preferred. The assumption in devising the eigenvector measure is that if an actor influences other nodes which then subsequently influence many other nodes, and the chain continues, then the first actor from where the chain originated is highly influential (Borgatti 2005, 61; Bonacich 1987, 1172). Based on the discussion, centrality measures operate at both the actor and network level (centralisation). This provides a comprehensive perspective on any network of interest. *Table* 3.2.2-1 details the affects of position occupied by an actor in the network on the outcomes for actors as well as at the network level.

Table 3.2.2-1 : Impact of social network position on actor level and network level outcomes

	Betweeness Centrality	**Degree Centrality**	**Eigenvector Centrality**
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 centre 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
Network level outcomes *(centralisation)*	Ascertains: -Level of network information flows -Extent of positional advantage to connector or broker in the network.	Ascertains: -Extent of intra linkages in the network -Extent of positional advantage to central actor.	Ascertains: - Network cohesion - Extent of positional advantage to central actors having functional ties to other central actors

(Source: Author's construct)

[3.2.3] Data Collection Process

Network data has been collected for 139 applicants of 12 successful projects from Genome Canada ABC competition. After the data was collected, individual identity and project affiliations of 139 investigators has been concealed by assigning them with unique numerical identifier.. Their prior capacity and linkages were then gathered from their involvement in large-scale projects awarded under Competitions I, II, III, and ABC over 2000-2009 timeframe, as well as a range of other complementary networked research projects. The decision to collect data through secondary sources e.g. Genome Canada reports, public databases, and scholarly websites was made because of previous experience of low response rates that could impede primary data collection.

Table 3.2.3-1: Distribution of 139 actors across 12 ABC competition projects		
ABC competition's successful projects	**Number of Investigators**	**Number of actors with affinity to multiple ABC projects**
BEEM: Bioproducts and Enzymes from Environmental Metagenomes	17	2
Genomics in Agricultural Pest Management	9	2
Genomics of Sunflower	14	0
Genozymes for Bioproducts and Bioprocesses Development	17	2
Grape and Wine Genomics	15	2
Metagenomics for Greener Production and Extraction of Hydrocarbon Energy	13	1
Synthetic Bio-systems for the Production of High-Value Plant Metabolites	14	7
TUFGEN: Total Utilization Flax Genomics	11	2
Microbial Genomics for Bio-fuels and Co-products from Bio-refining Processes	13	2
VALGEN	10	6
Bridging Comparative, Population and Functional Genomics to Identify and Experimentally Validate Novel Regulatory Regions	2	0
Genomics-Enhanced Forecasting Tools to Secure Canada`s Near-Term Lignocellulosic Feedstock Supply for Bio-energy using the Mountain Pine Beetle-Pinus spp.	4	0

Source: Author's research

Four types of ties are recorded among 139 actors. Based on the four identified types of ties, a multiplex dataset and four comprehensive mode-one actor-by-actor matrices or slices for each relationship were created in Microsoft Excel. A multiplex dataset is a combination of 4 matrices and contains a number of adjacent matrices which record the presence or absence of relations by 1 or 0. Multiplex data describes multiple relations among the same set of actors. The measures of relations can be directed or not. The Excel dataset, when transferred into UCINET software, is stored in the matrix form. The four square matrices have same number of rows and columns as the number of actors in the dataset and have binary[8] ties (1 if tie is present, 0 if tie is absent). The "elements" or scores in the cells of the matrix record information about the ties between each pair of actors (Hanneman and Riddle 2005).

[8] A binary matrix with 0's and 1's is also called an *adjacency matrix* because it indicates who is adjacent or next to whom in the social space. An adjacency matrix can be *symmetric (*undirected ties) or *asymmetric* (directed ties-recognized by both actors). Often the value of the diagonal is meaningless and is ignored however, when the rows and columns of a matrix are super-nodes or blocks then main diagonal assumes great importance (Hanneman and Riddle 2005, 93).

Excel data serves as input in UCINET software and is used for matrix analysis and generation of output measures. UCINET utilizes graph theory and algebraic constructs to analyze the data. SNA tools, algorithms, and network measures such as density, centrality, and correlation, embedded in *Analytical Technologies-UCINET software* (version 6.335) are used in the next step of data analysis. *Netdraw* software is employed to create sociograms that are visual depictions of the relationships between various network actors (Borgatti 2002).

We explicitly examine following four specific actor ties — *area of expertise, institutional connections*, *co-publication, and research grants*. The detail on each of the four, mode-one matrices is as follows. First, the *area of expertise matrix* captured the disciplinary synergy amidst the 139 research actors. Two action sets were devised to identify the ties. Each actor's curriculum vitae, available on the internet and the ones procured from Genome Canada, were examined for disciplinary affiliations. Through the examination of *ISI-Web of Knowledge* website, quantum information on disciplinary ties was revealed in the section titled *subject areas* where plain curriculum vitae examination comparatively revealed sparse information. Taking the information, five of the most prominent disciplinary streams were identified from the ISI website for 139 actors and then was compared to disciplinary affiliations of remaining actors to record commonalities in the area of expertise.

Second, the *institutional connections* matrix captures links that reflect any co-habitation in same institution during 2000-2009. In this case, two data collection options were explored. We searched for institutional affiliation by institution, for example in University of Calgary, and institutional affiliation by unit, for example in University of Calgary's Department of Microbiology. We were only able to get dense institutional connections. Departmental ties were found to be sparse and hence ignored. An actor-by-timeframe matrix, stretching across 2000-2009, was initially constructed. Each of the 139 key actor's curriculum vitae was extracted from websites of prominent university (national and international), research institutions (both public and private), genomics centres, or government ministries. A two-mode actor-by-timeframe matrix was then taken as a template for construction of one-mode actor-by-actor matrix which indicates the presence of actor ties across different institutions.

Third, as summarized in *Figure 3.2.3-1(a),* the *research grants matrix* indicates ties amongst 139 actors that are generated while corroborating on Genome Canada's research grants, research awards, or project funding from 2000-2009. Research grant relationship for the actors was extracted from the relevant institutions websites such as NSERC, SSHRC, CIHR, GC, and AFMNET projects. The SSHRC's awards search engine is a database of information about SSHRC grants and fellowship payments since 1998. The search engine allows you to search by year, program name, applicant, area of research, or by keyword. The results are displayed alphabetically by applicant. The results contain information about the project, such as the project title, institution, amount awarded, discipline and area of research (Social Sciences and Humanities Research Council 2011).

Figure 3.2.3-1 (a): Data sources for research grants matrix

Research Grant Matrix (2000-2009)

↓

Data sources

1. NSERC research awards
2. SSHRC research awards
3. CIHR awards/grants
4. Genome Canada competitions
   i. Competition I- *projects in agriculture, forestry, GE^{3}LS*
   ii. Competition II- *projects in agriculture, forestry, GE^{3}LS*
   iii. Competition III- *projects in agriculture, forestry, GE^{3}LS & health*
   iv. ABC Competition- *projects in agriculture, environment, & GE^{3}LS*
5. AFMNET Projects and Researcher list
   i. Toronto Nutrigenomics and Health Study
   ii. Social Issues in Nutritional Genomics
   iii. Understanding Consumer Acceptability of Functional Foods

(Source: Author's construct)

Figure 3.2.3-1 (b): Research grants data collection process

Steps to search relevant data on nserc.ca, sshrc.ca, and cfi.ca websites

i- nserc.ca → funding decisions → award search engines → put name of applicants → choose years
ii- sshrc.ca → competition results → award search engines → put applicants → choose years
iii- cihr.ca → view decisions → funding decision data → put applicants
iv- Genome Canada → Research portfolios → Competitions and funding initiatives

(Source: Author's construct)

Finally, for *co-publication ties* we constructed a matrix to act as an artefact for co-creation of knowledge. To extract the co-publication relationships amongst 139 actors, two resources were explored. First, the *ISI Web of Knowledge* website was examined to extract the narrow co-publication record consisting of published journal articles. Second, the actor curriculum vitae's were extracted from affiliated institution websites and from Google Scholar to reveal broad co-publication trends such as conference papers and working papers that are not cited in published journals.

[3.3] Method for Assessing Impact of Social Capital on Innovation Outcomes

The current research also uses *correlation* analysis to test the main hypothesis and the three sub-hypothesis. The correlation measures ascertain the relationship between probable strength of ties and the proxies for social capital's latent outcomes. UCINET software calculates the correlation relationship to test the symmetric association amongst the network actors. For example, where there are sets of actors that interact and exchange information, there is a higher probability that they may go on to collaborate in a financial partnership or co-production of research. This suggests that ties formed in an initial information exchange relationship can facilitate development of trust and confidence in the actors involved in that exchange. The probability for trusting becomes even higher when actors are linked via multiple types of relationship (as is the case with actors in current study where four types of ties are recorded among the 139 actors). A trustful environment has the potential to create a positive and reciprocal experience during information sharing and to positively impact development of future exchange relationships. The premise is that the pair of actors that connect and benefit from one type of directed relationship are more likely to connect in another type of relationship with future prospects. The relationship between two variables is quantifiable through the interpretation of the correlation coefficients. Unlike regression, correlation cannot distinguish between independent and dependent variable — therefore, it cannot infer causality. *Equation 3.7* generates the correlation coefficient *(r)* for observation ranging from *(x1, y1), (x2, y2),................(xn, yn).*

$$r = \frac{1}{n-1} \sum \left(\frac{x-\bar{x}}{s_x}\right)\left(\frac{y-\bar{y}}{s_y}\right) \qquad \text{…......................................(3.7)}$$

The value of correlation coefficient is between -1 and 1, indicating perfect negative and positive correlation respectively. A correlation value near to 0 indicates no association between the variables. The formula for *r* standardizes the variables and therefore any change in units of measurement has no impact on its value. For example: a negative r = -0.75 indicates that 75 percent of the time, when value of one variable is low, the value of other variable is high while a positive r = 0.75 indicates that 75 percent of the time, when one variable exerts a positive influence, the other variable also exerts a positive influence (O'Connor 2011 ; Yale University 1998).

The UCINET measure of correlation computes correlation coefficient for the entries in two or more square matrices and also assesses the frequency of random measures. This routine tests the association between networks where one network is taken as an observed network while the other is assumed as a model network. The algorithm computes the Pearson's correlation coefficient between corresponding cells of the two data matrices and then randomly permutes (hundreds of times) rows and columns of observed matrix and re-computes the correlation. A low p-value < 0.05 indicates that strong correlation between is unlikely by chance. A correlation matrix is always symmetric and the diagonal is invalid (Borgatti, Everett, and Freeman 2002, : Help Topics-correlation; Trochim 2006).

Table 3.3-1: Indications from correlation coefficients outcomes

Correlation coefficient	Indication
.8 to 1.0	Very strong relation
.6 to .8	Strong relation
.4 to .6	Moderate relation
.2 to .4	Weak relation
.0 to .2	Very weak relation

Source: (O'Connor 2011)

According to the correlation analysis procedure noted in *Figure 3.3-1*, the correlation matrix will test for linkages or patterns as artefacts of social capital downstream effect in large-scale science projects. In order to extract the relationship, a proxy for social capitals latent outcome is devised. In practice, the individual financial allocation to 139 actor participants from 12 successful projects awarded under the ABC competition is ascertained.

Figure 3.3-1: Correlation analysis process

Correlation analysis method

Correlation Matrix

Area of expertise *(disciplinary ties)*	Institutional connections *(co-locations)*	Research grants *(co-funding)*	Co-publication *(knowledge creation)*	Social Network Position (SNP)	$ amount allocation (ABC project funding)
				Betweenness Centrality	
				Total Degree Centrality	
				Eigenvector centrality	

Expected research outcomes

- Assessment of latent social capital and its residual productive outcomes in network based research projects.
- Rationalize basis for increased federal support of systemic changes within science and research funding in Canada.
- Support for increased level of public funding to large-scale network based research projects.

(Source: Author's construct)

To draw up a list of exact dollar allocations made towards each of the 12 ABC competition's awardee projects, following methods were used: (a) random project investigators were telephonically contacted to ascertain the amount, (b) individual project websites were examined, and (c) Genome Canada was contacted. In a perfect world we would use actual allocations but it was implausible to narrow search and establish individual investigator award amount and these numbers are unavailable. To sort this issue, the proxy of dollar award per investigator was calculated on the premise that project leads get a higher percentage of the cut in the overall projects awards. The project leader(s) individual dollar amount is ascertained by assigning 25 percent of ABC projects allocations to the project lead while the remaining and 75 percent of the remaining allocation is divided equally among the other listed as co-investigator(s). In case there are more than one project leads then the 25 percent is proportionally divided amongst them.

This $ amount proxy generated will be correlated with different centralization and centrality measures of degree, betweeness, and eigenvector for the four relations to draw quantitative conclusions. These centralization and centrality measures will test for social network position (SNP) at network and actor level. The correlation will test for relationships between the occupied network position (as an indicator of social capital) and the amount of financial allocation procured (proxy). Any positive correlations will be interpreted as a reflection of a relationship between the social capital produced in large-scale project environment and its ability to procure beneficial residuals in terms of research awards or allocation to realize their research goals.

To summarize, this chapter has identified the methodology and data that will be used to measure or quantify the strength of social capital in Genome Canada's research systems and to assess the relationship between that social capital and downstream research outcomes. Chapter 4 presents the findings and interprets the results.

C h a p t e r 4

DATA ANALYSIS

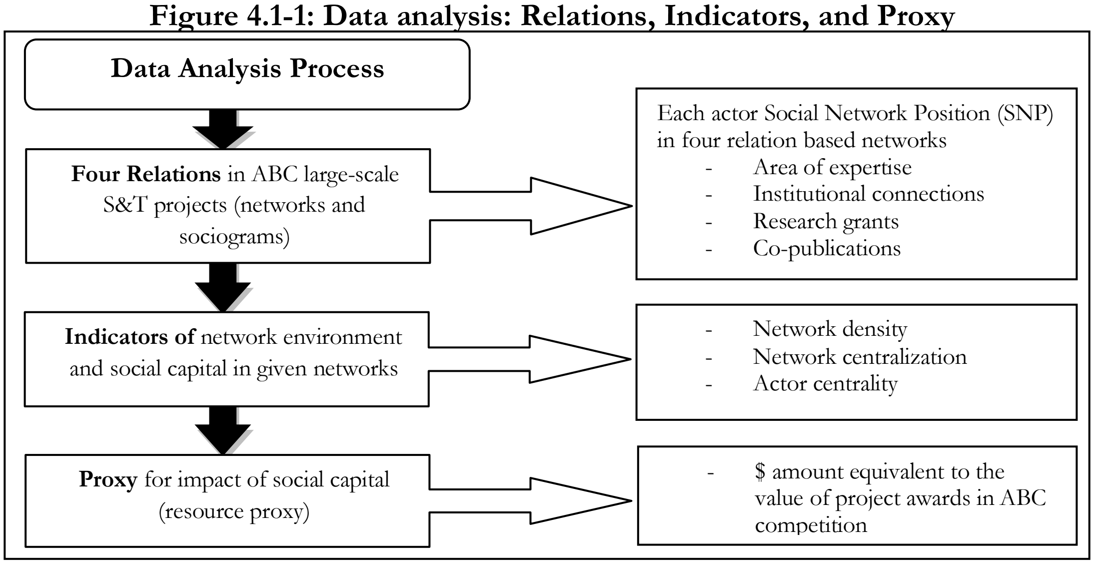
Introduction

This chapter describes the data analysis process and presents the research findings by using the measures and methods described in Chapter 3 of the dissertation. While the preceding Chapter 3 incorporated an overview of the methodology used to collect network data and identified relevant UCINET measures and research tools relevant to the research context, this chapter addresses the data analysis component, includes a description of measures applied, and narrates the resulting outcomes. The analysis provides a detailed description of network composition, its structural components, and the institutional configuration of four relations based interconnected yet *unique* networks.

[4.1] Analysis Process, Proxy generation, and Analysis Summary: An Overview

The elusive nature of social capital and the very fact that any set of *actor × actor* ties is limited in its ability to produce measurable latent outcomes, such as publications, journal articles, patent applications, provisional patents, licenses, or trained personnel within any assigned timeframe, forces us to adopt a circuitous analytical approach.

Figure 4.1-1: Data analysis: Relations, Indicators, and Proxy



Source: Author's construct

As indicated in *Figure 4.1-1*, we generate a proxy that can, if not directly, then indirectly assess social capital's latent effect. The selected *proxy* is the value of capital or funds awarded in dollar amounts to each of the twelve Genome Canada's ABC competition projects. Other forms of outcomes such as co-publications and patents needed more time to materialize and hence an alternate and less conventional option is selected. The analysis will test the relationship between social capital, social network position (SNP) (measured through centrality and is an indicator of social capital) and latent residual outcome in form of financial awards to the 12 projects. This will test the impact of each actor's social capital generated due to network position in the large-scale environment on their ability to procure research awards or future benefits.

As previously elaborated in the methodology and analytical framework section, Genome Canada's large-scale projects are based on pre-existing ties amongst the 139 investigators. The subsequent discussion is ordered to depict lowest to highest degree of engagement, ranging from sharing a common disciplinary background called areas of expertise, co-location and co-habitation illustrated in the institutional connections, monetary ties due to partnering joint research grants, and knowledge production based on co-publication relations. The rationale is that highest proactive investment will generate higher levels of social capital.

The names of 139 actors, functioning in the capacity of project leaders, co-investigators, and collaborators, are extracted from the final 12 ABC projects of Genome Canada. Based on the four groupings, representative networks are generated and then analyzed for their cohesiveness, collaboration potential, centrality, centralization, and correlation aspects using UCINET and Netdraw software. The impact of actor associations is then ascertained through a correlation analysis of the networks with the value of awards procured in 12 Genome Canada ABC projects. UCINET performs intricate estimations to quantitatively support the Netdraw sociograms of *agent x agent* networks and generate notepad outcomes.

At no point should the four relations of disciplinary ties, co-location links, and monetary relations, and co-publications connections be interpreted as four distinct networks. In fact these four types of relationships constitute a composite network where each relationship depicts a certain type of link between 139 actors. For the purpose of analysis, the composite network has been dissociated into four distinct domains where impact of each independent relationship on the network outcomes is distinctly identified and assessed. Such an approach is designed to expose both the positive and negative structures which may influence positive downstream results. If the fours domains were aggregated into a single, composite network level, that might generate an erroneous account of interconnectivity (in this case, the high degree of interconnectivity through disciplinary ties would link ritually everyone intensively, with 12529 connections and only 9 isolates – *see Table 4.2-1*).

[4.1.1] Threshold to Extract High Impact Actors

A key framing issue is to identify what signifies central placement in various systems. For the purposes of this study, keeping in view the range of data available, a threshold of above *2 standard deviations* is employed in order to extract central science and GE^3LS actors in the four relation based networks. Only those actors with personal centrality measures greater than 2 standard deviations above the mean of the source population were judged to exhibit aspects of central placement. This process allows intra-sample comparisons, as we can segment out low impact actors and compare them to the *stars*. Any actor with a centrality measures below the critical threshold is considered to not be undertaking central functions in that respective case. Each individual actor was evaluated for central actor functions by comparing his or her individual centrality scores against the average centrality score for each network.

[4.1.2] Summary of subsequent Network Data Analysis

Though network analysis and its findings are broadly discussed and elaborated in the following sections — to ease comprehension of analysis and introduce the results, an outline of the main findings from the analysis is presented in *Table 4.1.2-1*. The main findings, pertaining to each of the four networks, are summarized below.

The *area of expertise* network has highest comparative density amongst four relation based networks. In this case about 94 percent of the actors have commonality in discipline and were able to develop working ties during Genome Canada competitions. This is expected as most of the GC competitions examined to develop the networks have been theme calls — with a specific focus on agriculture-crop research. The dense ties create a cohesive and closed structure with restricted inflow of novel information into the system. The network is sparse in bridging social capital as actors have multiple alternative channels available for information flow. Dense organizational networks with multiple ties undercut gatekeeper or mediator advantage in the network. Also, the network actors are challenged to identify and access external information and the presence of numerous intra-linkages in dense network fails to sustain bonding social capital. None of the actors assert informal leadership or have a prominent role that could affect joint decisions. Overall, there is equality in power and influence of network actors and thus analysis could not access central actor or their affiliations.

Table 4.1.2-1: Summarized network analysis outputs

Relations	Number of active nodes	Network Density	Number and affiliation* of central network actors		
			Betweenness	**Degree**	**Eigenvector**
Area of Expertise	130	0.6533	9 Scientists=5 GE^3LS=4	44 Scientists=41 GE^3LS=3	122 Scientists=97 GE^3LS=25
Institutional Connections	105	0.0385	5 Scientists=2 GE^3LS=3	4 Scientists=2 GE^3LS=2	14 Scientists=11 GE^3LS=3
Research Grants	50	0.0143	2 Scientists=1 GE^3LS=1	2 Scientists=1 GE^3LS=1	11 Scientists=4 GE^3LS=7
Co-publications	100	0.0116	14 Scientists=4 GE^3LS=10	7 Scientists=7 GE^3LS=0	4 Scientists=4 GE^3LS=0

*Affiliation=Science or GE^3LS
Source: Author's research

The relations in *institutional connections* network are rich with cross-affiliations and cross-institutional ties. The incidence of dense intra-institutional linkages with sparse inter-institutional ties ensures a pronounced bridging role for core actors. The presence of bridging social capital broadens knowledge conception, permits access to external resources, and contributes towards diverse opinions. The instance of institutional homophily, with a few critically placed inter-institutional connections makes available high quality first-hand information or resources to relevant actors. The network's organization aids in identifying high degree core actors. The availability of bonding social capital in a large-scale network facilitates communications, resource exchange, and joint decisions between the affiliates. The high eigenvector actors occupy prominent and influential positions in the system by sustaining links with other prominent actors in the cluster.

In the *research grants* network, 35 percent of the total 139 actors have been able to develop research grants based relationships with each other through Genome Canada competitions. Bridging advantage is shared by central science and GE^3LS actors who due to their grants partnerships have superior ability to link the large-scale grants network. The high impact science (1) and GE^3LS (1) actors are found to have nearly equal access to the bonding social capital that facilitates communication and negotiations fundamental to research funding success. The presence of a set of 11 prominent and powerful network actors influences the network's decisions that impact research grant acquisition.

The *co-publication* network exhibits the lowest relative density, with about 18 percent of the 139 actors found with some central functionality. Here gatekeeper or linker advantage, in lieu of social network position, in large-scale environment facilitates operational independence and elevated information flow for bridge actors and ensures access to bridging social capital. The presence of 7 high degree scientists suggests that only science actor's exhibit bonding social capital which is critical in co-publication related decision-making and information exchange. The actors with hub function are assigned high social status. In short, the informal leadership is identifiable, with some of the co-publication network actors having access to novel information and having power to influence co-publication decisions and set directions.

[4.2] Estimation of Network Density

Network density is a measure that indicates presence of network relationship between actors. In contrast, a linearly structured relationship will have a density score approaching zero. An estimation of network density for the four unique relations amongst same set of 139 actors is performed. Each relation based network, with its 139 actors, differ from other networks in terms of the number of connected nodes and the isolates — nodes with zero connectivity. Each of the four large-scale networks has a mix of actors affiliated with disciplines of agriculture, economics, environment, law, or social science aspects and involved in genomics and proteomics research. The network density measure estimates whole network density scores.

According to *Table 4.2-1*, density for the four relations ranges from 0.6533 to 0.0116. The *area of expertise* network has 12529 total ties between the 139 actors, far exceeding the other three types of networks ties. This affirms that most of the network actors (130 out of 139) are connected to each other through common disciplinary affiliations than in any other way. This was indeed expected as most of the network actors hold affiliations to agriculture research fields.

Table 4.2-1: Overall network density values for four networks of interests

Networks	N	Overall Network density	Total number of active ties	Standard deviation	Number of linked nodes	Number of isolates
Area of Expertise	139	0.6533	12529	0.4759	130	9
Institutional Connections	139	0.0385	738	0.1923	105	34
Research Grants	139	0.0143	274	0.1187	51	88
Co-publication	139	0.0116	223	0.1072	100	39

* Arranged in ascending order of network density

The *co-publications* network has the lowest density amongst four networks that are created from large-scale GC competitions, indicating an inability of its 139 actors to develop and sustain high number of active co-publication linkages with each other during 2000-2009. The *research grants* network is generated by retracing NSERC, SHHRC, CIHR, AFMNET, and ABIP grants and the relationships among the 139 investigators during 2000-2009. The research grants network density of 0.0143 and *institutional connections* density of 0.0385 indicates that while 105 actors, induced by physical co-location and proximity, effectively interacted and collaborated with each other by engaging in face-to-face interactions, only 50 actors were able to develop grants based relationships. Further, the standard deviation column indicates maximum variation in the density score for the area of expertise network and minimum variation in the co-publications ties. The use of centralization measure assists in understanding relational and network dynamics which would be helpful in explaining outcomes of measures of centrality and correlation applied on the stated relations.

[4.3] Network Centralization Measures

Network centralization reflects the extent to which network exchanges are concentrated amidst a small set of network actors or distributed equally amongst all network members. In other words, centralization measures indicate whether a network or group is organized around its focal point or not. It is effectively a measure of integration or cohesion of the group where a highly centralized network reflects uneven distribution of knowledge and resources.

[4.3.1] Network Betweeness Centralization

Betweeness centralization results recorded in *Table 4.3.1-1* indicate that the *co-publications* network, with its highest betweenness centralization score of 12.80 percent, has the fewest number of pathways or channels available for flow of uninterrupted information amidst its member actors. In other words, the co-publications network, with its highest betweeness centralization score, hints at the presence of some central actors that significantly affect the flow of resources amongst the sub-network components and network members. These actors operate in broker or bridge capacity and significantly impact intra-network flow of information amongst the principals. The highly centralized co-publication network provides maximum information control to central actor(s) who command the pathways for information transfer. Conversely, the exchanges in the *area of expertise* network, where betweeness centralization score is lowest at 0.81 percent, shows that here actors can use many alternative active channels for network exchanges. A low betweenness centralization score — as in case of *research grants* or *area of expertise* networks, shows absence of central network actors and the presence of alternative channels for uncontrolled information and resource flow. Also, notably in the case of the area of expertise network when isolate nodes are excluded from the calculations, its network density of 0.7471 is highest and betweeness centralization value of 0.81 percent is lowest amongst the four networks. This is interpreted in the following manner: when 130 of 139 area of expertise actors are connected to each other by multiple ties in a dense network, the *gatekeeper* advantage for any actor is reduced. Whenever a pathway or channel for information or resource exchange becomes demanding in a dense network, the actors adopt an alternative exchange route or path through multiple ties.

Table 4.3.1-1: Freeman betweeness centralization index for *actor x actor* relations			
Relations	**Betweeness centralization index value** *(%)*	**Mean** *(Nrm)*	**Statistics from UCINET** *(Nrm)*
Area of Expertise	0.81	0.153	Min=0.000 Max=0.955 Std. Dev=0.143
Institutional Connections	12.22	0.391	Min=0.000 Max=0.825 12.521 Std. Dev=1.529
Research Grants	2.25	0.059	Min=0.000 Max=2.291 Std. Dev=0.248
Co-publication	12.80	1.156	Min=0.000 Max=13.862 Std. Dev=2.586

*Nrm=normalized, ** N=139

Out of the three relations — area of expertise, research grants, and co-publications — the betweenness centralization score for the area of expertise network is closest to the mean of the sample database. This suggests that the area of expertise network has a slightly below-average level of bridging activity amongst its principal actors. Only a few actors in the network connect sub-networks or groups of actors in this arrangement. The standard deviations for betweeness centralization score of the four networks indicate high variability in the institutional connections and co-publications networks, further affirming the presence of central actors in them.

[4.3.2] <u>Degree Centralization Scores</u>

The degree centralization scores reflect the extent to which maximum links are concentrated amidst a small number of network members rather than being distributed equally. As per *Table 4.3.2-1,* actors through their disciplinary relation are more closely linked relative to in other three relations. This is consistent with the network density outcomes recorded in *Table 4.2.-1* where a directly proportional relationship is exhibited between density and total number of network ties. In the *area of expertise* network the high degree centralization value indicates the presence of alternative multiple links and channels available to network actors. The low central tendency scores of 7.95 percent for co-publications network indicates the absence of multiple ties and the presence of few actors with control over network operations. This is further affirmed by the co-publication network's high eigenvector centralization score of 63.02 percent *(see Table 4.3.3-1*) where strong intra-linkage of co-publications actors is available and multiple channels for alternative communications are absent.

Table 4.3.2-1: Network degree centralization index for *actor x actor* relations			
Relations	**Degree network centralization index (%)** *(avg.)*	**Mean** *(Nrm-avg.)*	**Statistics from UCINET** *(Nrm-avg.)*
Area of Expertise	20.70	65.316	Min=0.000 Max=85.86 Std. Dev=27.03
Institutional Connections	10.72	3.847	Min=0.000 Max=14.493 Std. Dev=3.778
Research Grants	14.61	1.428	Min=0.000 Max=15.942 Std. Dev=2.804
Co-publication	7.95	1.163	Min=0.000 Max=9.058 Std. Dev=1.431

*Nrm=normalized, **avg. = Average of in & out degree centralization, *** N=139

[4.3.3] Network Eigenvector Centralization

In *Table 4.3.3-1*, the highest co-publication network's eigenvector score of 63.02 percent and research grant network's score of 54.69 percent indicates a highly cohesive large-scale structure. The co-publication relations and research grants ties give maximum positional advantage to central actors in terms of resource access through strong affiliations held with other key network actors. The high eigenvector scores also confirm the presence of powerful central actors in the co-publications and grants networks that crucially impact and influence resource access and the exchange processes. The standard deviation scores, relative to the means of the eigenvector centralization measures, indicate that institutional connections and research grants networks have high variability in statistical results confirming the presence of centralized network functions. The same is amiss in other two relations of area of expertise and co-location linkages (low eigenvector centralization scores)

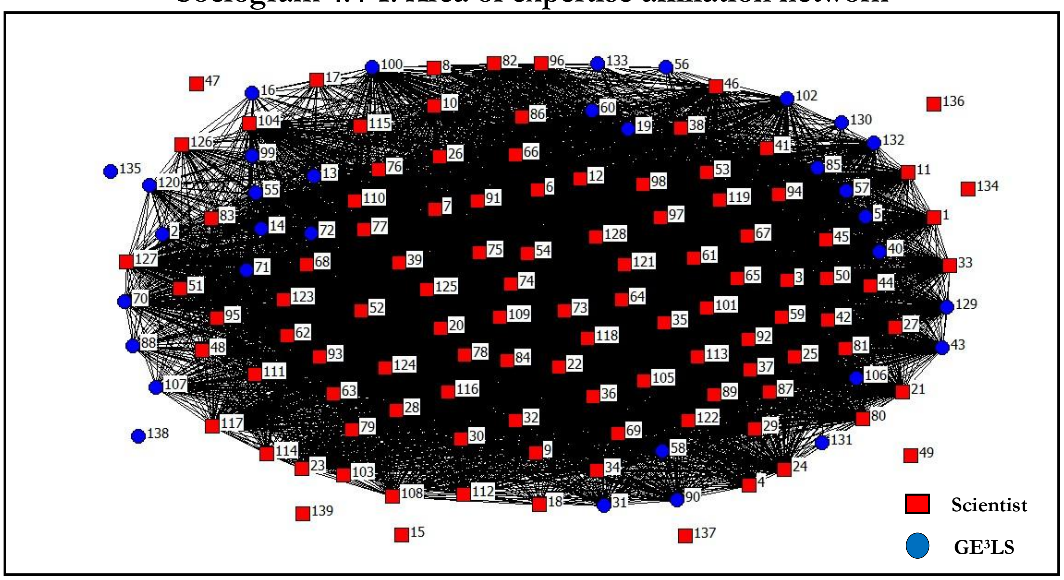
Table 4.3.3-1: Eigenvector network centralization index for *actor x actor* relations			
Relations	**Eigenvector network centralization index values (%)**	**Mean** *(Nrm)*	**Statistics from UCINET** *(Nrm)*
Area of Expertise	12.34	0.153	Min=0.000 Max=0.955 Std. Dev=0.143
Institutional Connections	36.97	4.363	Min=0.000 Max=37.941 Std. Dev=11.174
Research Grants	54.69	4.920	Min=0.000 Max=54.69 Std. Dev=10.940
Co-publication	63.02	1.156	Min=0.000 Max=13.862 Std. Dev=2.586

*Nrm=normalized, ** N=139

[4.4] Area of Expertise Network

The area of expertise is an outcome of discipline based ties (one of the four examined relations) between 139 actors and has the highest density amongst the four networks generated from GC competitions through 2000-2009. The composite density of the network, keeping the number of active ties constant at 12,529 is 0.6533. *Sociogram 4.4-1* illustrates dense active ties between 99 scientists and 31 GE^{3}LS actors across the disciplinary space. Simply put, 94 percent of the total actors are linked intensively with each other through common disciplinary roots. This is expected as Genome Canada competitions have been theme calls and most of the research projects awarded have been narrowly cased in agriculture-crop research field. The highly cohesive and dense network links have their advantages and disadvantages. While the presence of multiple nodal links augments information flows within the network, the downside to high density is that flows of novel external information may be restricted. High density disciplinary ties are network-centric and deficient channels to access and stream peripheral information.

Sociogram 4.4-1: Area of expertise affiliation network



* N=139, Active nodes= 130, Isolates=9

** Node color and shape indicates affiliation

[4.4.1] Area of Expertise Betweeness Centrality

The betweeness centrality scores for the expertise network actors are consistent across the population, with exceptional variance involving only a small group of five scientists and four GE^{3}LS actors. As disciplinary ties are numerous (high density), the fact that actors are linked with each other through multiple connections reduces individual actors' *gatekeeper* or *broker* privileges. The impact of high betweeness centrality scorers in GE^{3}LS and science communities, as conciliators in information transfer, communication flow, and network dynamics, is diluted amidst dense tie arrangement. Also, the variation in betweeness scores for 139 actors is found to be relatively small. This further weakens mediator advantages for network actors, as their multiple ties to each other ensure that when one route of communication or transfer is obstructed, other alternative channels can be effectively explored.

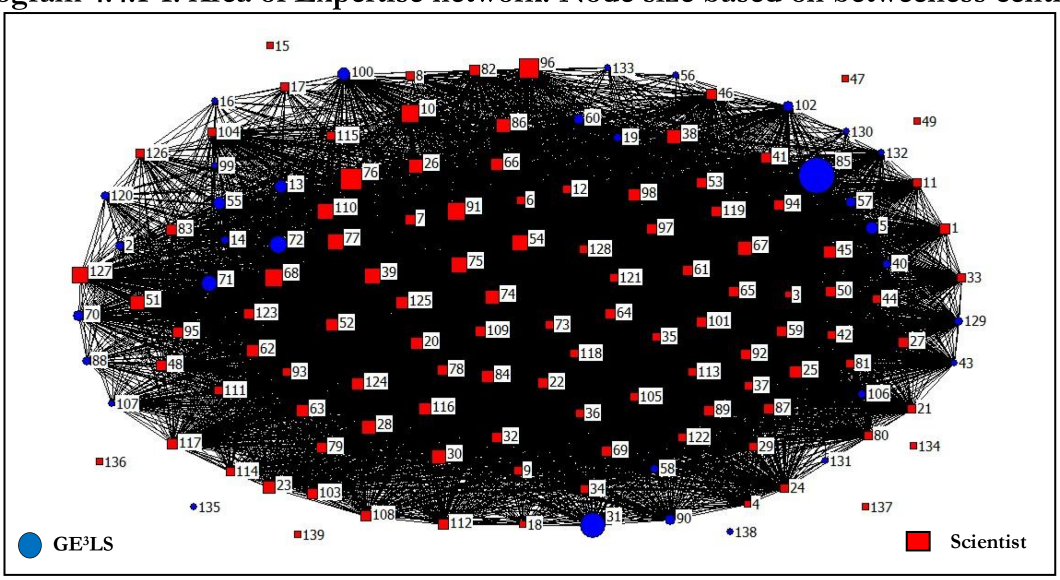
Table [4.4.1-1]: Variation in area of expertise betweeness centrality scores

Standard Deviations	Scientists	GEL³S	Total
<1SD	61	25	86
1SD	37	3	40
2 SD**	3	1	4
3 SD	5	1	6
4 SD	0	1	1
5 SD	0	1	1
6 SD	0	1	1

*One (0.148) or more standard deviations greater than the mean
** N for central actors=9 where GE³LS actors=4, Scientists=5
For details see *Appendix 1 Table [A.4.4.1-1]*
Source: Author's calculations

The privileges of bridge social position that offers access to novel information and control over information flows are restricted in high density setting. The reduction in the connector capacity of central actors, in a high density network, is further supported by the *knock-out* exercise. Omission of the five central GE³LS and science actors reduces the network density by a meagre 1.75 percent. This further affirms limited bridge potential in disciplinary relations.

Sociogram 4.4.1-1: Area of Expertise network: Node size based on betweeness centrality



* N=139, Active nodes= 130, Isolates=9 ** Node color and shape indicates affiliation

[4.4.2] <u>Area of Expertise Degree Centrality</u>

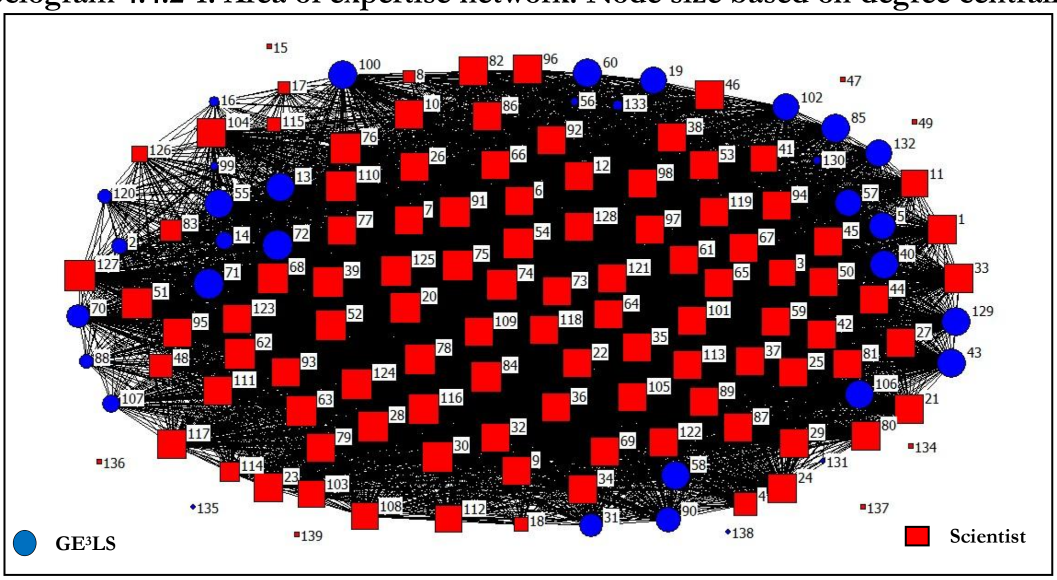
The presence of numerous disciplinary relations amongst 139 actors in area of expertise network is further supported by data obtained in *Table 4.4.2-1*. The variation in data points is minor, with most of the 130 active actors falling within 2-3 standard deviation range. The network lacks central actors that function as a network core or an activity hub to facilitate joint decisions, projects, or information transfer processes.

Table [4.4.2-1]: Variation in area of expertise degree centrality scores			
Standard Deviations	**Scientists**	**GE3LS**	**Total**
<1SD	10	8	18
1SD	8	7	15
2SD**	47	15	62
3SD	41	3	44

*One (27.031) or more standard deviations than the mean
** N for central actors=44 where GE3LS actors=3, Scientists=41
For details see *Appendix 1 Table [A.4.4.2-1]*
Source: Author's calculations

The absence of core actors is also supported in the relatively small variation in degree scores (standard deviation of 81.09) around the mean (27.03). *Table A-4.4.2-1* shows degree centrality scores up to a maximum of 91.739 within 3 standard deviations and network ties ranging from a minimum 38 to maximum 118 active links. The majority of high degree actors (41 out of 44) are from the science community but fail to function as a core in this high density network as dense intra-linkages marginalize their role.

Sociogram 4.4.2-1: Area of expertise network: Node size based on degree centrality



* N=139, Active nodes= 130, Isolates=9 ** Node color and shape indicates affiliation

The high density of the disciplinary ties confirms high incidence of cross-collaboration with dense immersing and emerging alliances. The high degree centrality usually enhances an actor capacity for informal leadership however, in discipline based cohesive setting, no informal leaders with positional or resource advantages can be identified.

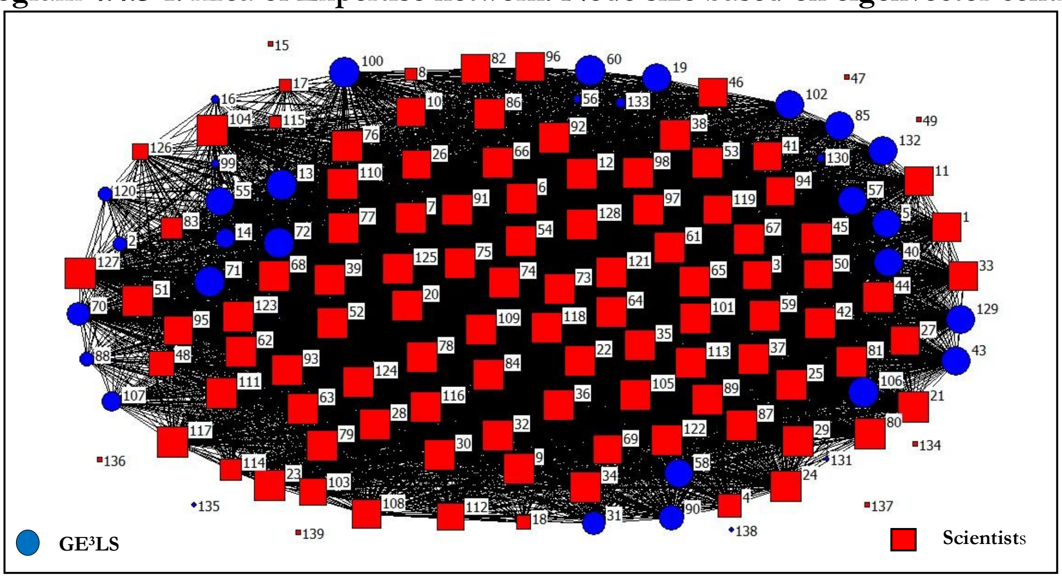
[4.4.3] Area of Expertise Eigenvector Centrality

The knock-out process offers somewhat odd results. If we eliminate all the actors with eigenvectors above two or more standard deviations above the mean for the population, we lose 96 actors from the network. In short, about 74 percent of the 130 active or linked actors are tied to other powerful actors in the network. In essence, there is no way to disentangle this community.

Table [4.4.3-1]: Variation in area of expertise eigenvector centrality scores			
Standard deviations	**Scientists**	**GE^{3}LS**	**Total**
<1SD	10	8	18
1SD	5	5	10
2SD**	7	8	15
3SD	84	12	96

*One (4.263) or more standard deviations than the mean
** N=122 where GE^{3}LS=25, Scientists=97
For details see *Appendix 1 Table [A.4.4.3-1]*
Source: Author's calculations

Sociogram 4.4.3-1: Area of Expertise network: Node size based on eigenvector centrality



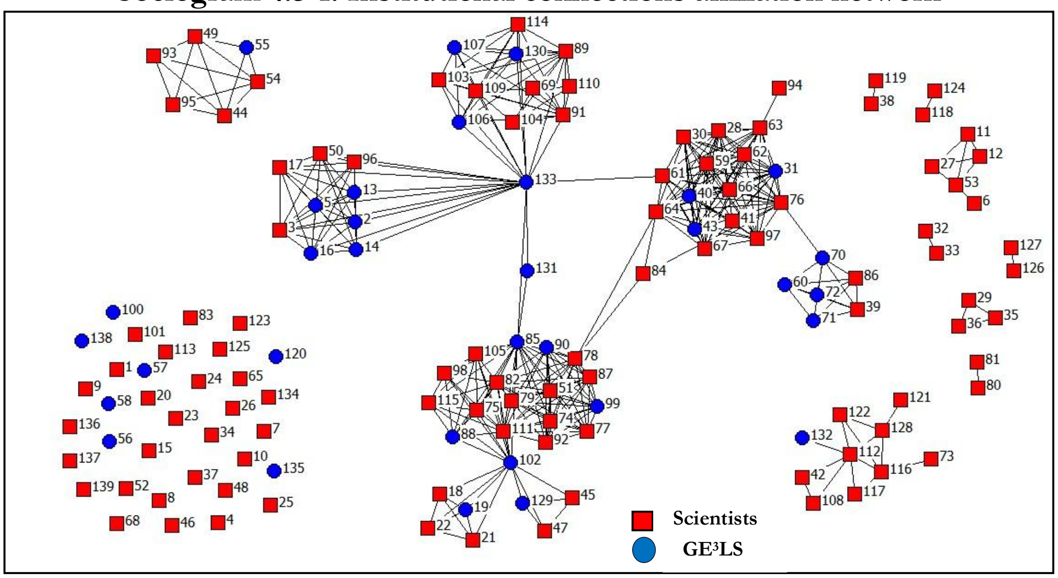
* N=139, Active nodes= 130, Isolates=9 ** Node color and shape indicates affiliation

The large number of high eigenvector individuals with disciplinary ties eliminates any possibility of any of them being able to impose authority and influence on network operations. There is relatively little variability in eigenvector centrality (standard deviation of 12.7) around the mean (4.2). This confirms that, overall there are few inequalities in actor centrality or power, when measured this way. Though high eigenvector scores usually indicate individual prominence, influence, power, and diversity in sources of information, these privileges diminish when many actors share the same rights. It is difficult to identify the most powerful GE^{3}LS or science actors amongst 139 actors when examining their discipline based links.

[4.5] Institutional Connections Network

An institutional connections network is an outcome of ties based on co-location, namely connections developed as a consequence of employment in the same universities or institutions. As depicted in *Sociogram 4.5-1*, 79 scientists and 26 GE[3]LS affiliated actors (76 percent of the total 139 actors) have successfully established parallel institutional linkages. The overall network density of active actors and isolates combined is 0.0385 with 369 active ties. The co-location network is distinct from the others in generating a multiple cluster arrangement of actors that are bridged by high betweeness counterparts. Here each cluster depicts a university or institution in Canada. Each cluster is a group with close internal links (intra-institutional ties) between science or GE[3]LS actors that have worked in the same institutions during 2000-2009.

Sociogram 4.5-1: Institutional connections affiliation network



* N=139, Active nodes= 105, Isolates=34 ** Node color and shape indicates affiliation

Actors outside the clustered organization have developed dyadic, triadic, quintet, or sextet relationships with each other. In the network structure, clear clustered demarcations based on close institutional affiliations, are apparent. Overall, the actors have intra-cluster multiple co-location ties with sparse yet significant external links (outside the cluster). The presence of strong intra-cluster links assists in exploiting internal resources and developing trust and trustworthiness amongst actors. Conversely, presence of external bridging ties between clusters expands individual or group(s) ideas and increases their connectedness with the peripheral environment, permitting efficient access to external resources, broadening knowledge conception, and ensuring diversity of opinion. The institutional connections also characterizes institutional homophily where actors' interactions, preference, and inclination for exchange of task-related information is targeted towards other actors that have common institutional affiliations instead of with actors who have diverse organizational links. In the network actors display pronounced co-operation behaviour with counterparts that dwell in or share real space or time. Common location aligns common social context, opportunities, and motivations for enhanced interaction. Actors working in close proximity have a higher probability of engaging in real time communication and in resource sharing. In the case of distributed teams, the existence of physical distance can divide the network into smaller cliques. Familiarity can become a challenge and actors are more liable to form working relationships with other actors residing at the same location.

[4.5.1] Institutional Connections Betweeness Centrality

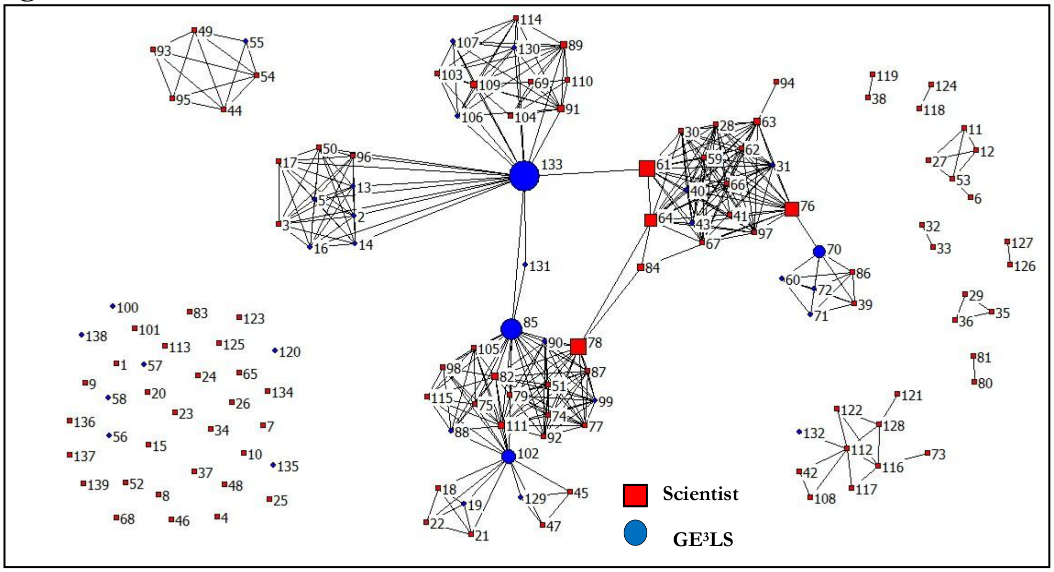
Out of 139 actors linked by past co-location ties, two scientists and three GE^{3}LS actors have centrality scores that are more than two standard deviations above the mean.

Table [4.5.1-1]: Variance in institutional connections betweeness centrality scores			
Standard deviations	**Scientists**	**GE^{3}LS**	**Total**
<1SD	101	30	131
1SD	0	0	
2SD**	2	1	3
3SD	2	1	3
5SD	0	1	1
7SD	0	1	1

*One (1.529) or more standard deviations than the mean
** N of central actors=5 where GE^{3}LS actors=3, Scientists=2
For details see *Appendix 1 Table [A.4.5.1-1]*
Source: Author's calculations

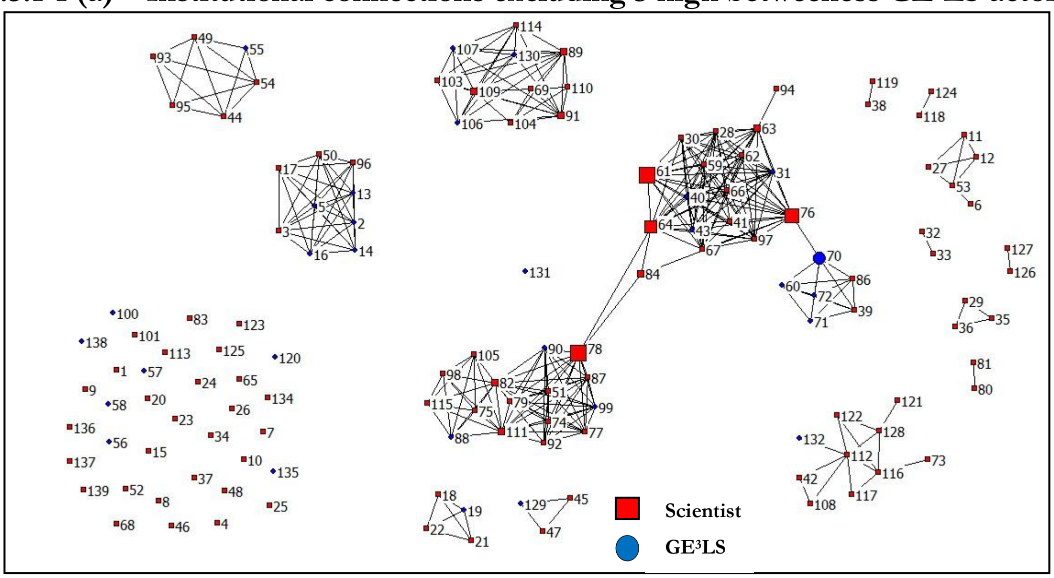
Sociogram 4.5.1-1 presents a unique structure where *mediator-ship* or *via-duct* potential of central actors is evident in discrete institutional groups. These actors operate as channels and connect detached clusters. The central actors function as *brokers* or *connectors* between different institutional clusters. Their social network position places them at a critical juncture of communication and knowledge transfer between assorted institutional groups. The high betweeness centrality scorers benefit from autonomy and are privileged to high quantity and quality of first-hand information. These actors control information flow to other nodes, facilitate cross-institutional connections, and have access to novel external information. If one considers the network without these core actors, we would see fragmented structures marked with dissociated clusters, isolates, cliques, dyads and triads. The exclusion of three GE^{3}LS actors reduces the network density by 8.8 percent to 634 ties (from 738) whereas omission of two high betweeness scientists reduces the density by only 3.6 percent to 684 ties.

Sociogram 4.5.1-1: Institutional Connection: Node size based on betweeness centrality



* N=139, Active nodes= 105, Isolates=34 ** Node color and shape indicates affiliation

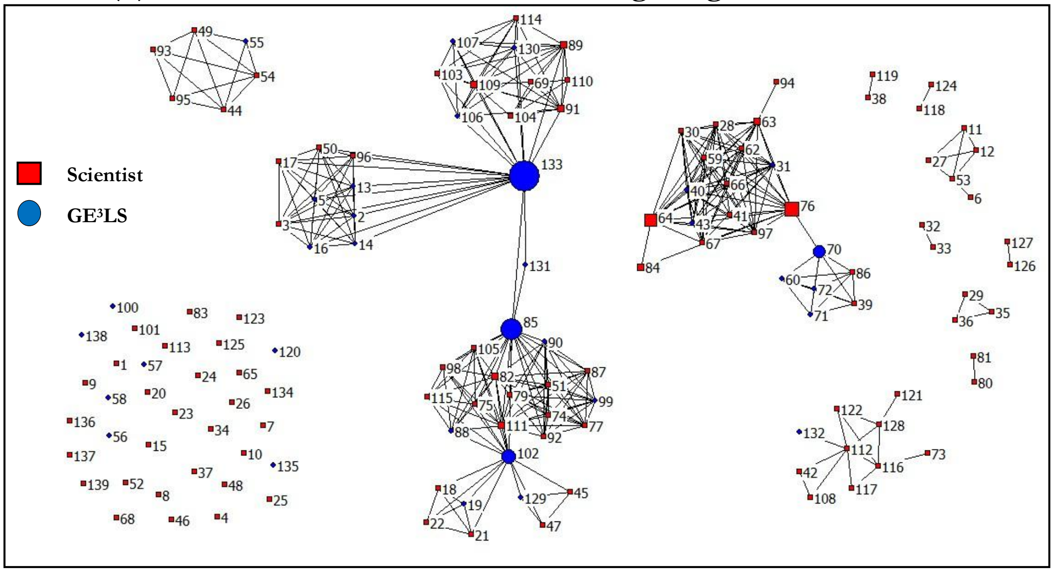
4.5.1-1 (a) – Institutional connections excluding 3 high betweeness GE^{3}LS actors



* Node color and shape indicates affiliation

On comparing *Sociograms 4.5.1-1 (a)* and *(b)* evidently when the lead GE^{3}LS actors nodes and ties are removed more fragmentation occurs. The process generates new set of dissociated clusters, triads, and isolates. GE^{3}LS actors emerge somewhat more influential, as prime linkers in co-location settings and are at the interface of individual clusters and their transformation into a network. They connect institutional clusters, accelerating probable collaborations on new research ventures and offering privileged bridging social capital to prospective large-scale projects.

4.5.1-1 (b) – Institutional connection excluding 2 high betweeness scientists



* Node color and shape indicates affiliation

[4.5.2] <u>Institutional Connections Degree Centrality</u>

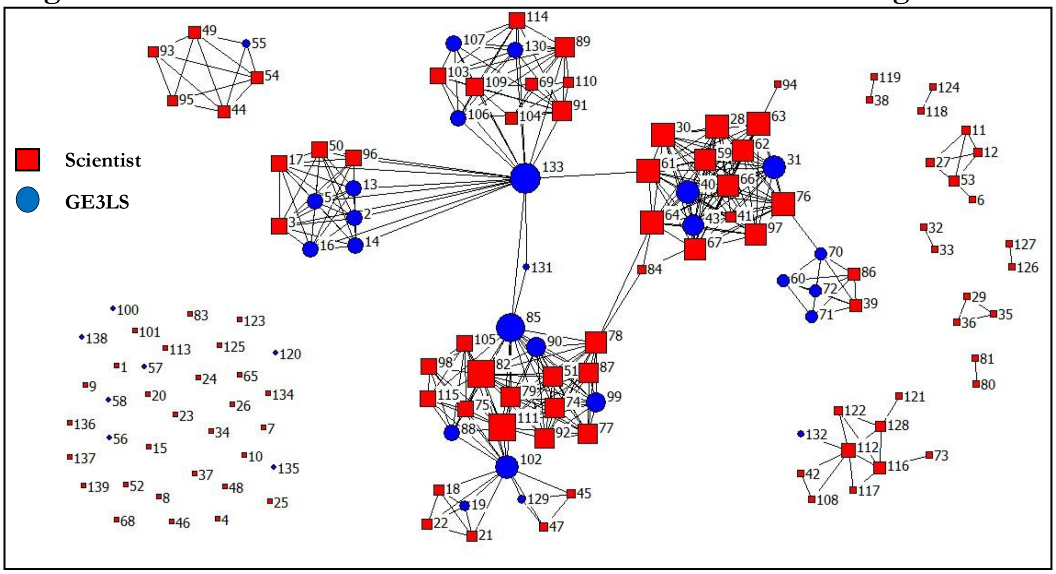
There are two scientists and two GE³LS actors with a large number of *in* and *out* co-location connections. An actor's degree centrality can be interpretable as power to manage flows through the network in form of information or communication. Degree centrality also points at the presence of bonding social capital in the network setting.

Table [4.5.2-1]: Variance in institutional connections degree centrality scores			
Standard deviations	**Scientists**	**GE³LS**	**Total**
<1SD	72	16	88
1SD	12	9	21
2SD**	20	6	26
3SD	2	2	4

*One (3.778) or more standard deviations than the mean
**N of central actors=4 where GE³LS=2, Scientists=2
For details see *Appendix 1 Table [A.4.5.2-1]*
Source: Author's calculations

The four high-degree scorers most likely benefit from generated bonding social capital. These four actors appear to play a crucial and decisive role in establishing workable relationships between other actors that belong to diverse institutions. Joint decision-making, communications, and knowledge dissemination are executed by these network binders. *Sociogram 4.5.2-1* further illustrates the social network position of four central GE³LS and science actors having the highest in-coming and out-going co-location ties (each has in the range of twenty active connections). This offers evidence of cross-institutional and cross-disciplinary exchanges between actors that worked in common or diverse locations.

Sociogram 4.5.2-1: Institutional Connections: Node size based on degree centrality



* N=139, Active nodes= 105, Isolates=34 ** Node color and shape indicates affiliation

These actors predominantly know more actors and sustain network cohesiveness of the network based on co-location ties and function as informal leaders. These actors have privileged access to network resources, high social status, and influence due to their links. The two GE^{3}LS affiliates have highest degree scores amongst 139 actors and thus likely exhibit higher decisional influence and generate more intra-network connectivity *(see Table A-4.7.2-1)* when compared to other two high degree science counterparts.

[4.5.3] <u>Institutional Connections Eigenvector Centrality</u>

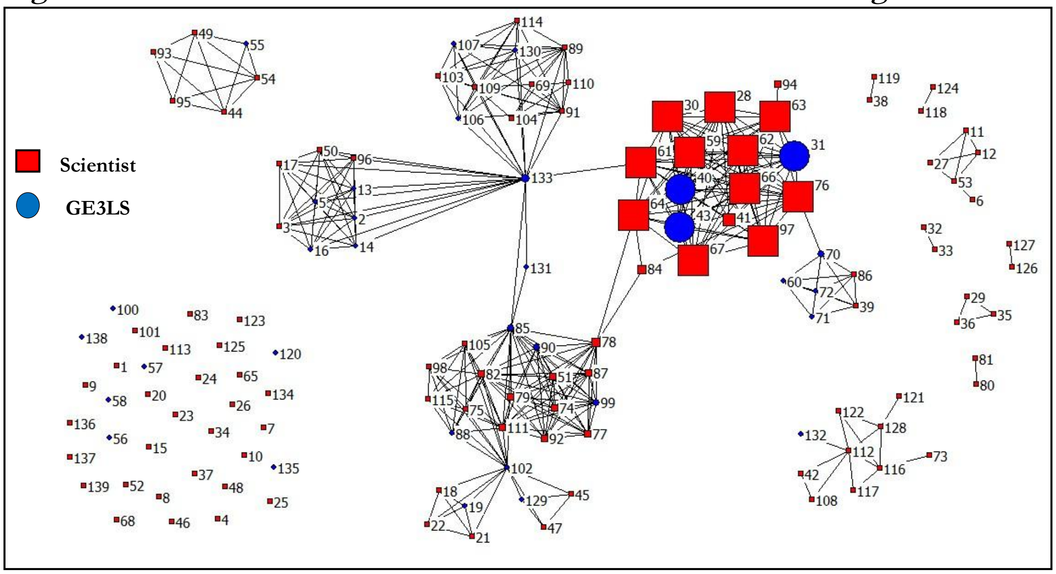
Three GE^{3}LS and twelve scientists are identified with co-location links to other influential people within 139 actor network team. The majority (12) of these powerful actors are scientist. Nevertheless, similar to the degree and betweeness results for institutional connection relations, these highest science eigenvector scorers are affiliated to GE^{3}LS field.

Table [4.5.3-1]: Variance in institutional connection eigenvector centrality scores			
Standard Deviations	**Scientists**	**GE3LS**	**Total**
<1SD	94	30	124
1SD	1	0	1
3SD	11	3	14

*One (11.174) or more standard deviations than the mean
**N for central actors=14 where GE^{3}LS actors=3, Scientist=11
For details see *Appendix 1 Table [A.4.5.3-1]*
Source: Author's calculations

The exclusion of 12 scientists from the network reduces the number of ties to 270 (from 738) and overall density by 53 percent. In contrast, omission of three GE^{3}LS scholars reduces network connections to 331 and density by 52 percent.

Sociogram 4.5.3-1: Institutional Connection: Nodes size based on eigenvector scores



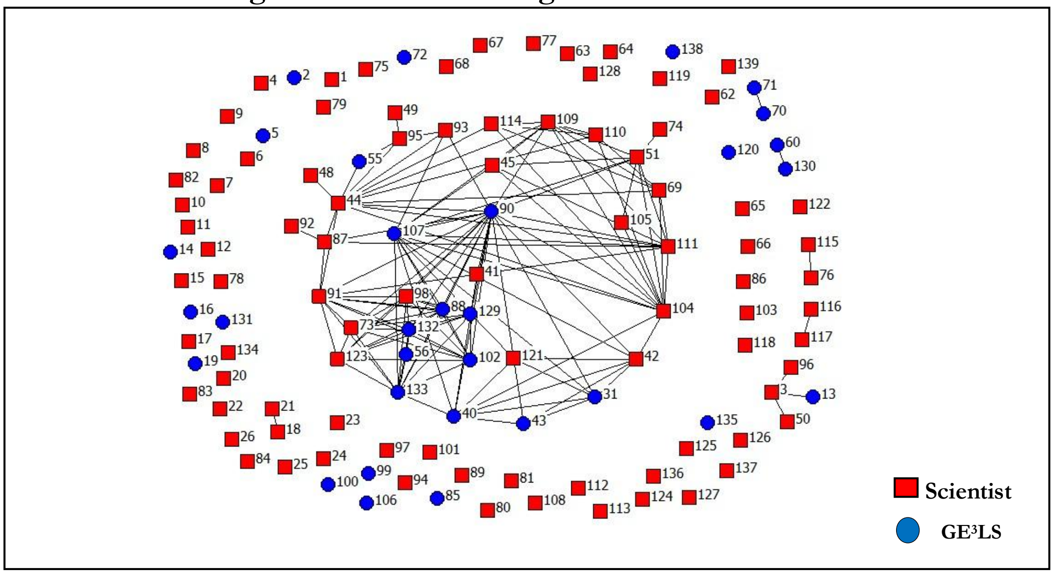
* N=139, Active nodes= 105, Isolates=34 ** Node color and shape indicates affiliation

Thus, each GE³LS actor's prominence and authority in lieu of their co-location ties is relatively greater, even though they are largely outnumbered by high eigenvector value scientists. The social capital harboured in the quality of connections gives high eigenvector network members power and authority on network operations. These actors have access to diverse and rich information from a wider range of sources. The above *Sociogram 4.5.3-1* illustrates that one of the clusters has an agglomeration of powerful actors (from GE³LS and science stream) are linked to other influential actors in the network.

[4.6] <u>Research Grants Network</u>

A network of research grants extracted from over a decade opertionalisation of Genome Canada's projects, offers insight into how these 139 participants have collaborated to secure research funding in the past. Grantsmanship requires both leaders and collaborators. In that context, it invokes a more proactive effort from the investigator than when they share a common discipline or live in the same community, but less effort than when they actually co-produce new knowledge. *Sociogram 4.6-1* displays the active network links between 33 scientists and 17 GE³LS investigators. Remaining 89 actors are isolates with no grants based partnership in the past decade. Amongst the four relations examined, grants relation network exhibits the second lowest density after the co-publications network. Only 36 percent of the total 139 network members have effectively collaborated and established working ties to procure research grants or financial awards to perform research on subject of genomics and proteomics. A majority of 139 network actors (85 agents) have failed to connect with others through sharing and operationalizing research grants. The actors with research grant ties have organized a tight cross-disciplinary cluster shaped arrangement in conjunction to a number of disassociated dyads that focus on agriculture or environmental research.

Sociogram 4.6-1: Research grants affiliation network



* N=139, Active nodes=50, Isolates=89 ** Node color and shape indicates affiliation

[4.6.1] <u>Research Grants Betweeness Centrality</u>

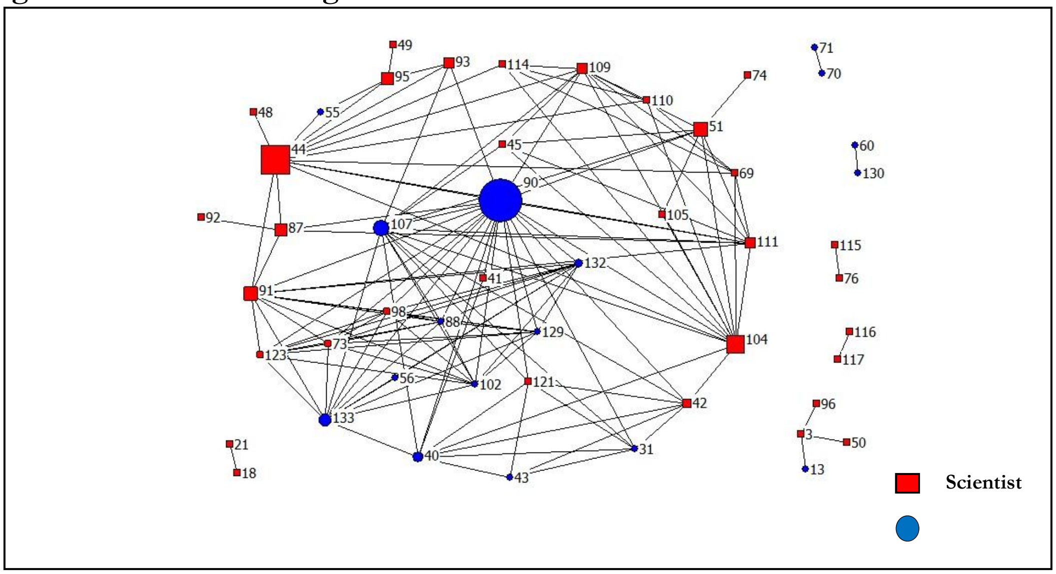
The extraction of high betweeness centrality actors indicates that there are two actors, one each from science and GE^{3}LS disciplines with research grants ties that function as major linkers or connectors and are privileged to bridging social capital.

Table 4.6.1-1: Variation in research grant betweeness centrality scores			
Standard deviations	**Scientists**	**GE^{3}LS**	**Total**
<1SD	100	30	130
1SD	4	1	5
2 SD	1	1	2
3 SD	0	0	0
5 SD	1	0	1
9 SD	0	1	1

*One (0.248) or more standard deviations than the mean
**N for central actors=2 where GE^{3}LS actors=1, Scientists=1
For details see *Appendix 1 Table [A.4.6.1-1]*
Source: Author's calculations

As one measure of impact, we could *knock out* each of the high betweeness central actors with grant based ties. The exclusion of one high impact GE^{3}LS actor reduces the network density by 57 percent to 115 ties while the removal of one core scientist reduces the network density by only 52 percent or 124 ties. Though not radically distinct, the betweeness impact is more for the GE^{3}LS agent who functions as *chief gatekeeper* or *channel* in the research grants related communications and negotiations. His network position indicates better control on network information flows, superior capacity to link the network, and higher potential influence in aggregated network decisions impacting research grants acquisition.

Sociogram 4.6.1-1: Research grants network: Nodes size based on betweeness centrality



* N=139, Active nodes=50, Isolates=89 ** Node color and shape indicates affiliation

On the whole, both high impact science (1) and GE^{3}LS (1) actors in regards to research grants ties fits into the high betweeness centrality range and are privileged with augmented operational independence, access to high flow of information, and ability to procure information from other low betweeness scorers who have an interest in co-operating on financial awards and grants. These two actor's ties generate firm network arrangements by linking nodes or sub-networks which otherwise would be isolates or fragmented structures. However, due to the very small fraction of linkers only some bridging social capital exists in this network relation.

[4.6.2] <u>Research Grant Degree Centrality</u>

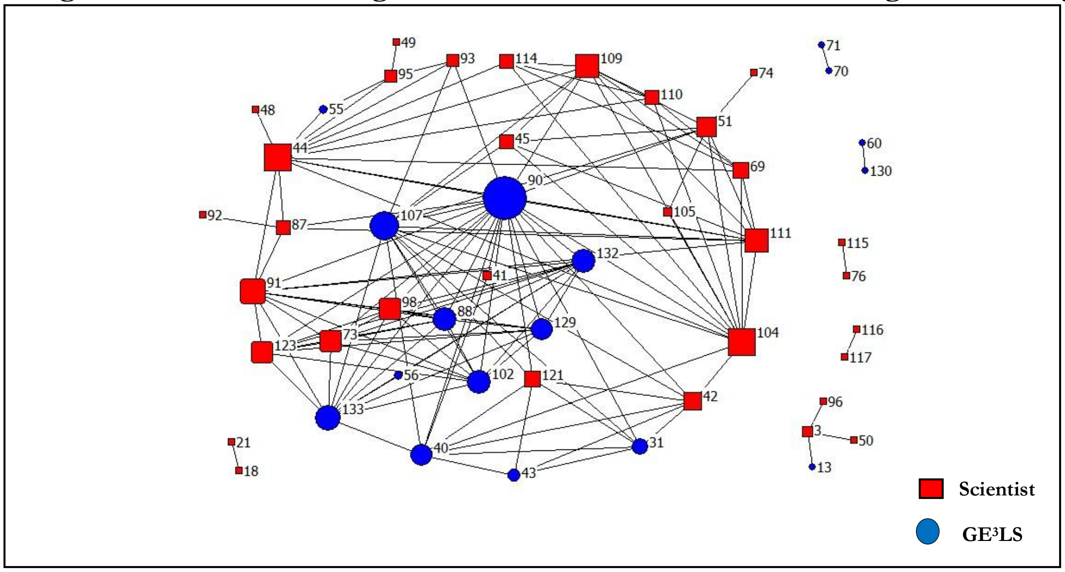
The process of extracting actors with maximum incoming and outgoing links *(see Table 4.6.2-1)* in terms of financial connections identifies two central scorers, one from each domain or discipline.

Table 4.6.2-1: Variation in research grant degree centrality

Standard deviations	Scientists	GE^{3}LS	Total
<1SD	89	26	115
1SD	10	2	12
2 SD**	6	4	10
3 SD	1	0	1
4 SD	0	1	1

*One (*1.715*) or more standard deviations than the mean **N for central actors=2 where GE^{3}LS actors=1, Scientists=1
For details see *Appendix 1 Table [A.4.6.2-1]* Source: Author's calculations

Sociogram 4.6.2-1: Research grant network: Node size based on degree centrality



* N=139, Active nodes=50, Isolates=89 ** Node color and shape indicates affiliation

A central and decisive role in financial collaboration is shared by both actors as they assume many functions of a *hub* of decision-making — possibly offering essential communications, negotiations, and directions on future research grant awards. These actors speak the same language and are joined in synergistic ventures. *Sociogram 4.6.2-1* illustrates monetarily linked actors, with a minimum of 3 to a maximum of 17 active ties. Similar to the co-publications network (discussed later in the chapter), the research grants network exhibits cross-disciplinary interactions amongst actors that are fundamental to large-scale projects. The cross-fertilization, external to one's group, diverges from the standard model where actors are more prone to developing internal ties within closed or tightly managed groups or teams. In contrast to the co-publications network, in research grants partnerships both GE^{3}LS and science core actors emerge as *centers* influencing network's cohesiveness. These two highly influential actors have privileged access to network resources such as information and knowledge flows. The number of *in* and *out* bound links is an excellent indicator of social status in the network. A low number of network ties (low degree) indicate low social status while high linkages (high degree) suggest an influential role in the social milieu for the actor. In the grants network, the core GE^{3}LS actor has the highest degree centrality score (7.246) while the science actor falls in second place (6.522). Both individuals occupy informal leadership positions, are influential, and crucial in intra-network connectivity.

[4.6.3] Research Grant Eigenvector Centrality

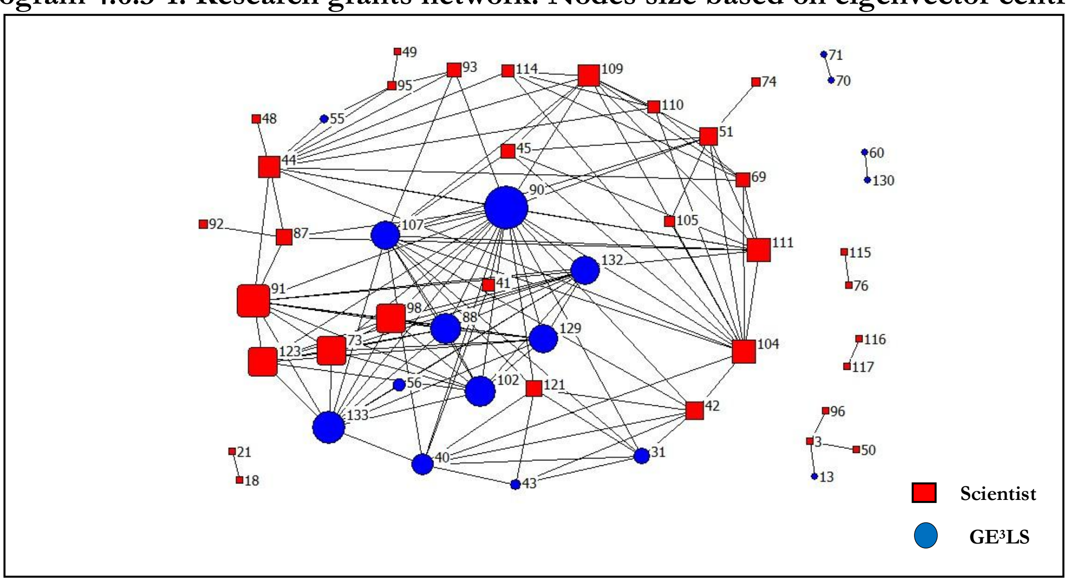
Here, total eleven scientists (4) and GE^{3}LS actors (7) have eigenvector scores at least two standard deviations above the mean of the population. This indicates that they have strong collaborative ties with other central network actors who themselves are linked with other influential network actors, from both of the disciplines.

Table 4.6.3-1: Variation in research grant eigenvector centrality			
Standard Deviations	**Scientists**	**GE3LS**	**Total**
<1SD	92	24	116
1SD	8	2	10
2 SD**	2	0	2
3 SD	4	6	10
4 SD	0	1	1

*One (*10.940*) or more standard deviations than the mean
**N for central actors=11 where GE^{3}LS actors=7, Scientists=4
For details see *Appendix 1 Table [A.4.6.3-1]*
Source: Author's calculations

Their social network position signifies them as prominent and powerful individuals who extensively influence grant based collaborations and set project funding directions in Genome Canada's project world. These investigators also have access to wider pertinent information. Notably, 6 of the 7 high eigenvector GE^{3}LS actors are from Genome Canada's stand-alone GE^{3}LS project namely Value Addition through Genomics and GE^{3}LS (VALGEN).

Sociogram 4.6.3-1: Research grants network: Nodes size based on eigenvector centrality

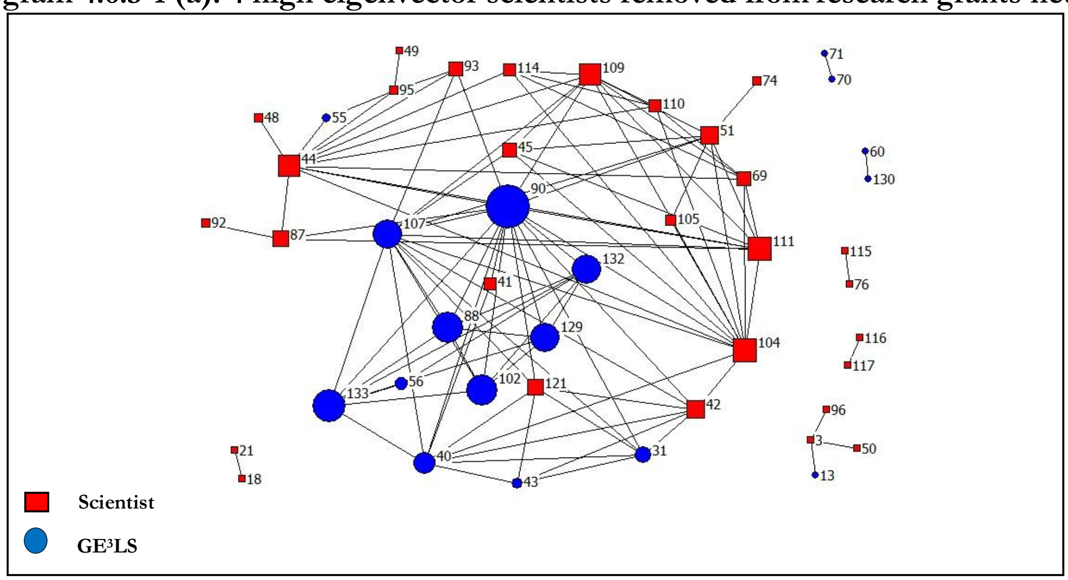


* N=139, Active nodes=50, Isolates=89 ** Node color and shape indicates affiliation

Sociogram 4.6.3-1 illustrates the network arrangement and social network position for the high eigenvector central actors with research grant ties. A closed clustered arrangement with concentrated internal links and weak external ties is exhibited for research grants in this subject area. Dyadic and triadic intra- and inter-links are also evident from the sociograms. The cohesive dense structure is live with bonding social capital as actors who might have crossed paths in one of Genome Canada's competitions find renewed linkage opportunity in the ABC competition.

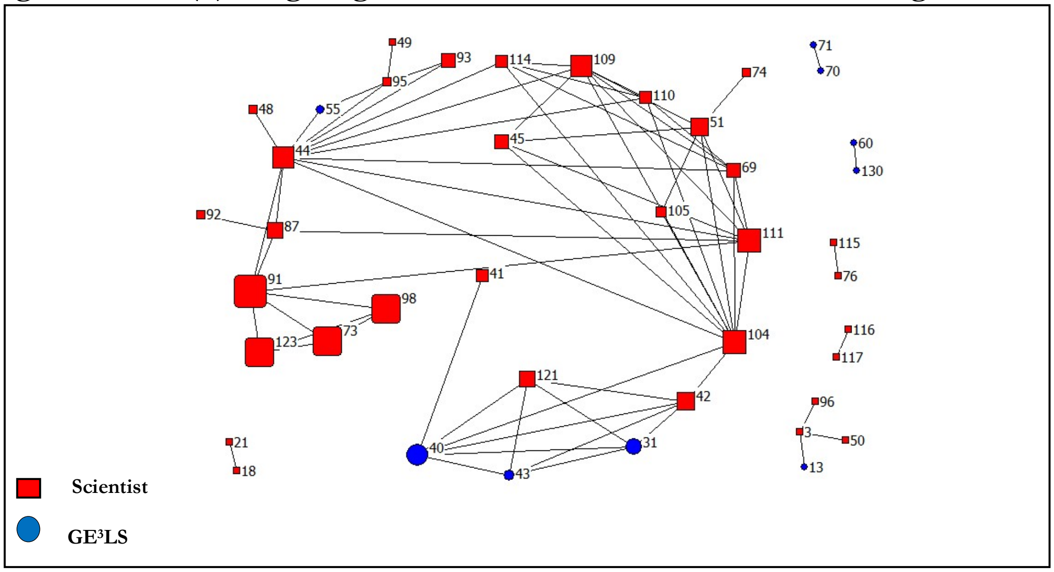
The relative power and prestige of GE^3LS scholars and scientists with grants based ties is further examined through *Sociograms 4.6.3-1(a)* and *(b)*. The cumulative fragmentation impact on research grant network, when seven central GE^3LS actor are excluded, is more pronounced than when four high eigenvector scientist grant based ties are removed. The exclusion of seven GE^3LS high scorers reduces the network density by 65 percent (to 0.0382) and shrinks the number of active ties to only 69 (from 274). The cluster opens up to reveal a loosely bound structure with star shaped sub-networks, quartets, and new isolates in *Sociogram 4.6.3-1 (b)*. On replicating the exclusion process on four leading science investigators, the network density decrease by only 53 percent (to 0.0502) and the active ties diminish to 104 links. In this case the fragmentation effect is less pronounced. This confirms GE^3LS actor's higher access to large-scale network's social capital and thus greater influence and power in informing grant based dynamics.

Sociogram 4.6.3-1 (a): 4 high eigenvector scientists removed from research grants network



* Node color and shape indicates affiliation

Sociogram 4.6.3-1 (b) 7 high eigenvector GE³LS removed from research grants network

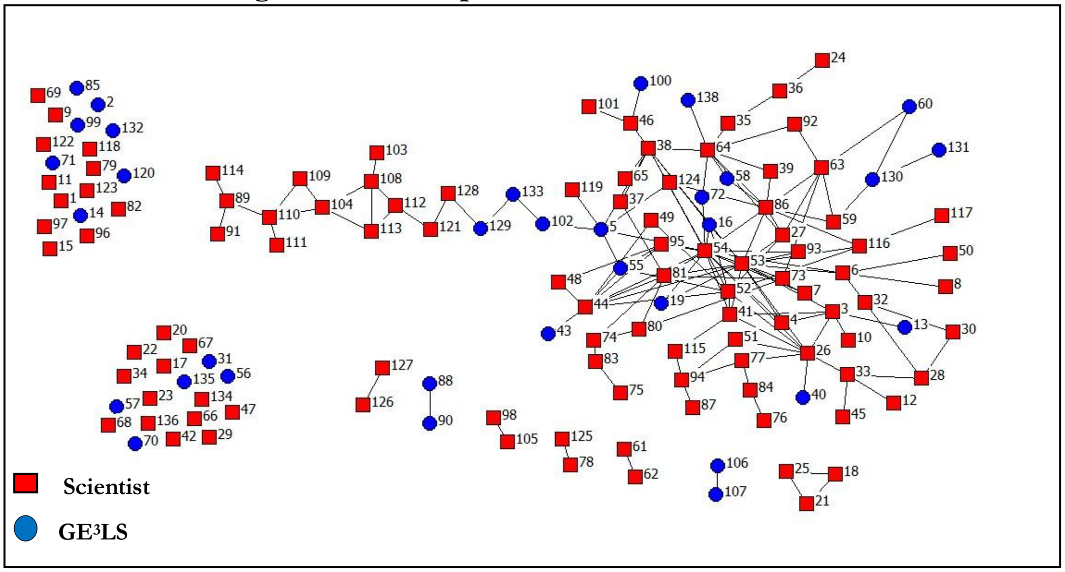


* Node color and shape indicates affiliation

[4.7] Co-publications Network

Co-publishing arguably involves the highest level of actor engagement and is thereby likely to generate the strongest and most important social capital. The process of generating and communicating new knowledge involves a range of activities that put strains on individuals to accommodate and accept alternate egos, epistemologies, and normative assumptions. The co-publication network is a large-scale outcome of a binary directed matrix that records co-publications during the decade. *Sociogram 4.7-1* illustrates active network ties among 21 GE³LS actors and 79 scientists, explicitly from research on basic and applied plant genomics and agriculture food production sustainability, that have been involved in Genome Canada funded genomics and proteomics research projects spanning 2000-2009. One can see that 79 percent of the total 139 network members are connected with each other through co-publication linkages. The structural arrangement of the co-publication network is unique and illustrates the crucial bridging role of GE³LS actors in generating an all-inclusive co-publications environment and creating a composite network. The GE³LS actors are seen in the role of principal connectors or bridge between a densely inter-linked cluster and a chain formation that signifies linear flow. The network relationships also exist in the form of dyads and triads revealing intra-group and inter-group affiliations. The data in *Table 4.2-1* confirms that the density score for the co-publications network is lowest in four networks. The density score is 0.0116 with active ties at 223. The role of scientists and GE³LS actors, in the co-publication network, is further quantitatively explored in the following sections.

Sociogram 4.7-1: Co-publications affiliation network



* N=139, Active nodes=100, Isolates=39 ** Node color and shape indicates affiliation

[4.7.1] Co-publications Betweeness Centrality

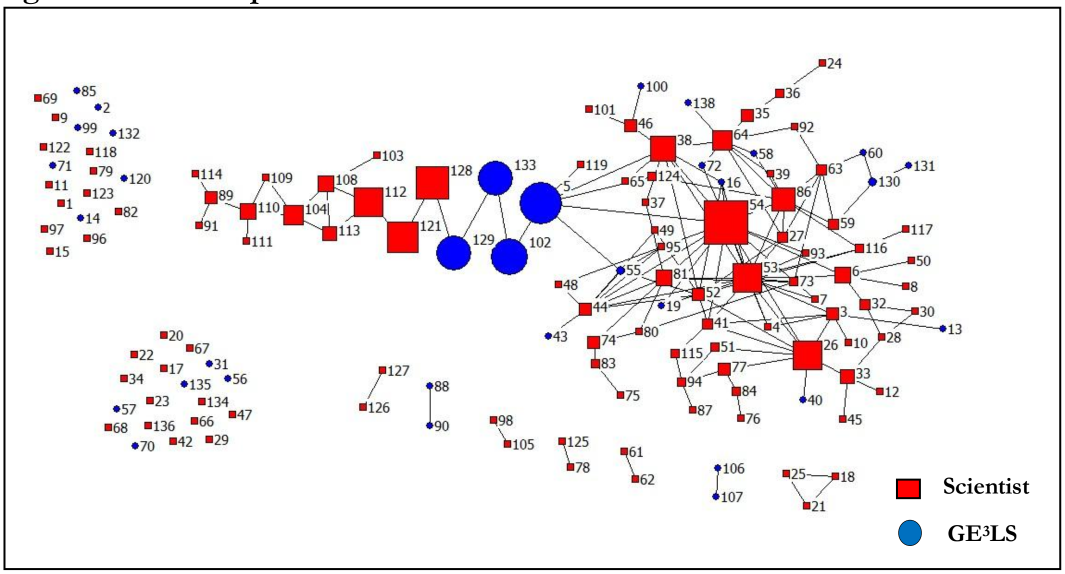
In co-publication network, as per *Table 4.7.1-1*, 14 out of 139 actors have betweeness centrality scores ranging from 3 to 12 standard deviations — indicating that about 10 percent of the population have high variability in the betweeness centrality values and function as central actors in the co-publication relation based network. This variation in data points is predominant for the science group, where 10 out of 14 actors have high betweeness centrality scores.

Table 4.7.1-1: Variation in co-publications betweeness centrality scores

Standard deviations	Scientists	GE^{3}LS	Total
<1SD	81	27	108
1SD	7	1	8
2 SD**	8	1	9
3 SD	1	0	1
4 SD	1	0	1
5 SD	2	0	2
6 SD	1	0	1
7 SD	3	0	3
8 SD	0	2	2
9 SD	1	1	2
10 SD	0	1	1
11 SD	0	0	0
12 SD	1	0	1

*One (1.075) or more standard deviations than the mean
**N for central actors=14 where GE^{3}LS actors=4, Scientists=10
For details see *Appendix 1 Table [A.4.7.1-1]*
Source: Author's calculations

Sociogram 4.7.1-1: Co-publications network: Node size based on betweeness centrality



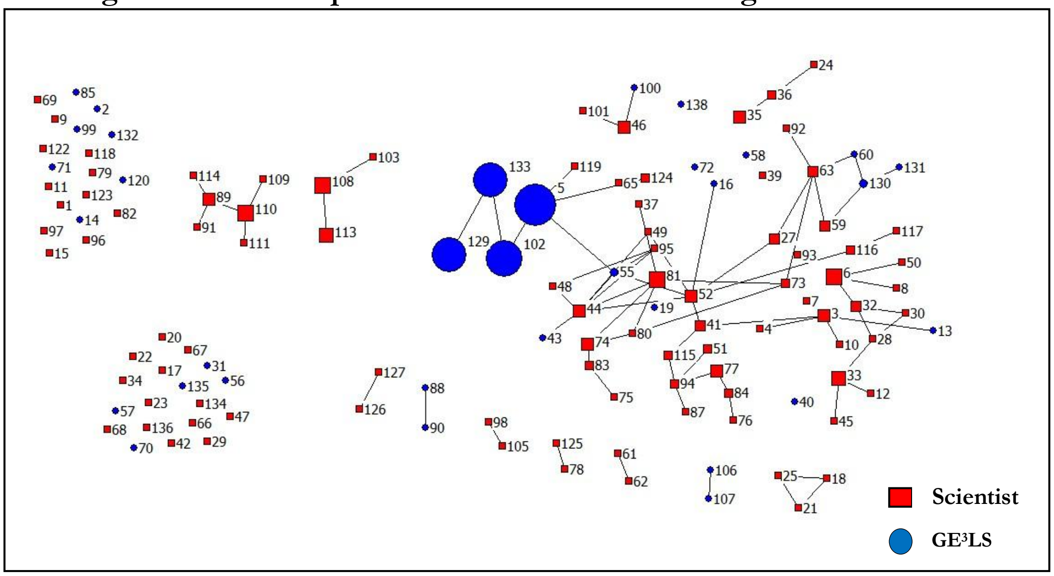
* N=139, Active nodes=100, Isolates=39 ** Node color and shape indicates affiliation

Contrary to *Sociogram 4.7.1-1,* that illustrates GE^3LS as major connectors, the quantitative data confirms scientists as major *gatekeepers* or *big linkers* in the co-publications related communication, knowledge transfer, and joint venture projects. The high betweeness centrality scores indicate that fourteen GE^3LS and science actors are operationally independent and have access to elevated flow of information in the network. These bridge actors' link nodes, sub-networks, or clusters, which in their absence would either be smaller dissociated clusters displaying sparse co-publication outcomes or isolates with no real links to the network. These high betweeness actors have comparatively higher levels of control over information transfer, knowledge production, and exchange of network resources than actors with low standard deviation scores.

Sociograms 4.7.1-2 is a result of excluding 10 core scientists with high betweeness scores. Consequently the total co-publications network connections are reduced by 37.66 percent to 139 active ties. The process results in high fragmentation, with creation of new triads and small sub-networks within the network arrangement. These actors are clearly more central than others and the relative variability in flow betweenness of the actors is relatively high.

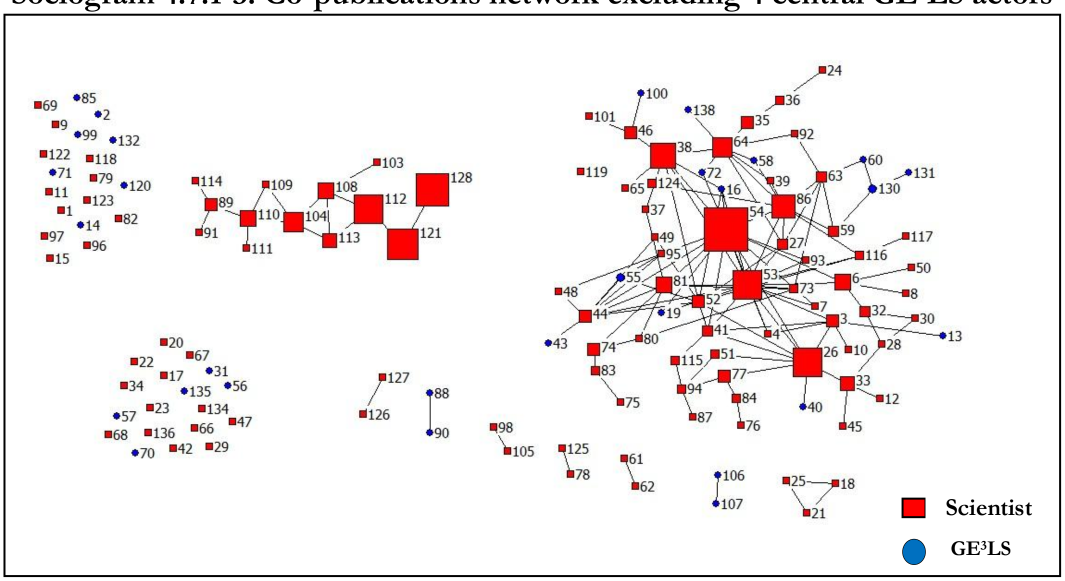
In *Sociogram 4.7.1-3*, four central GE^3LS actors, with betweeness centrality scores above two standard deviations or more were removed to see the connector significance of high GE^3LS linkers in the network. The total network connections are reduced only by 7.17 percent to 207 active ties. The process creates two distinct sub-networks where central GE^3LS actors had functioned as key linkers. Overall, the omission of high betweeness centrality scientists as well as GE^3LS actors fragments the cluster and chain network arrangement. However, in totality the impact of scientists on network connectivity is much more than GE³LS actors as their removal impacts the network with new sets of dyads, triads, additional isolates (apart from the pre-existing 39 isolates) and significantly reduces the composite network's size and density.

Sociogram 4.7.1-2: Co-publications network excluding 10 central scientists



*Node color and shape indicates affiliation

Sociogram 4.7.1-3: Co-publications network excluding 4 central GE³LS actors



*Node color and shape indicate affiliations

[4.7.2] <u>Co-publications Degree Centrality</u>

Here, high degree centrality tagged scientists are identified (*from Table 4.7.2-1*). All of the seven high degree centrality actors, with multiple links, are affiliated with the science community. These central actors are associated with Genome Canada projects that focus on agriculture-crop and plant genomics research and take on the function of *hubs* or *connectors* in the network with crucial roles in decision-making, communication flow, and information exchange processes. None of the GE^3LS actors are found with high degree centrality scores and make the cut in this network. The range and variability of degree scores are quite important as they describe whether the population is homogeneous or heterogeneous in structural positions. This is possible through examination of standard deviation scores and variability in data points. Clearly, the population is heterogeneous as 100 percent of the population has standard deviation scores above 1.

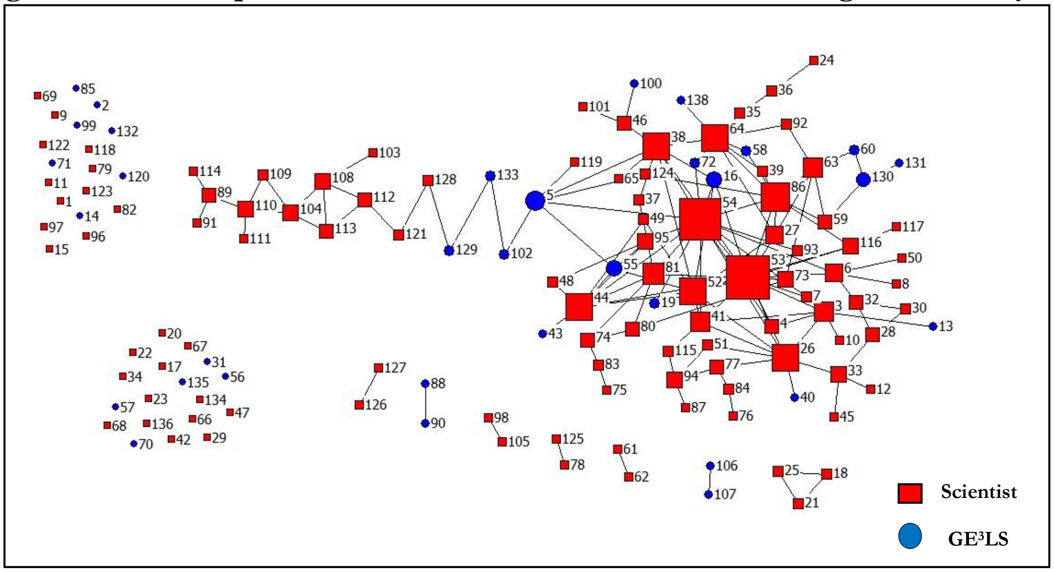
Table 4.7.2-1: Variation in co-publications degree centrality scores			
Standard Deviations	**Scientists**	**GE^3LS**	**Total**
<1SD	64	20	84
1SD	26	7	33
2 SD	9	6	15
3 SD	4	0	4
4 SD	3	0	3

*One (1.431) or more standard deviations than the mean
**N for central actors=7 where GE^3LS actors=0, Scientists=7
For details see *Appendix 1 Table [A.4.7.2-1]*
Source: Author's calculations

Examination of S*ociogram 4.7.2-1* shows nodes with degree centrality scores that span from a minimum 1 to a maximum of 17 ties connecting 100 active nodes. The co-publications relation structure defies group affiliations fundamental. While there is higher possibility of actors from the same affiliation to develop task related instrumental ties with each other than with external groups members, in this network, inter-group project linkages between science and GE^3LS communities are extensively established. This prevalence counteracts the presumption that *like attracts like*.

Also, co-publications network in *Sociogram 4.7.2-1* offers evidence of cross-group interactions and exchanges. The highest possible numbers of network connections emerge for those central science nodes that are privileged with bonding social capital. The seven high degree science scores are responsible for network cohesiveness *(reflected in their high number of links)* and have high social status. The co-publication opportunities are primarily presented in science disciplines where lead scientists facilitate effective sharing and learning conditions. High degree centrality scores give these seven core scientists the ability to exercise informal leadership. Most of the network members depend or could benefit through a relation with them via improved access on information and communications pertaining to co-publications. This suggests informal leadership and high social status through co-publications linkages resides within the science community.

Sociogram 4.7.2-1: Co-publications network: Node size based on degree centrality scores



* N=139, Active nodes=100, Isolates=39 ** Node color and shape indicates affiliation

Though isolates or low connectivity actors — with lower than two standard deviations, occupy low social status in the network, they definitely offer possible opportunities for future co-publishing collaborations. Such a transition would have a significant positive impact on their social influence, status, and access to resource, and ultimately would generate sustained returns to past investment in network.

[4.7.3] Co-publications Eigenvector Centrality

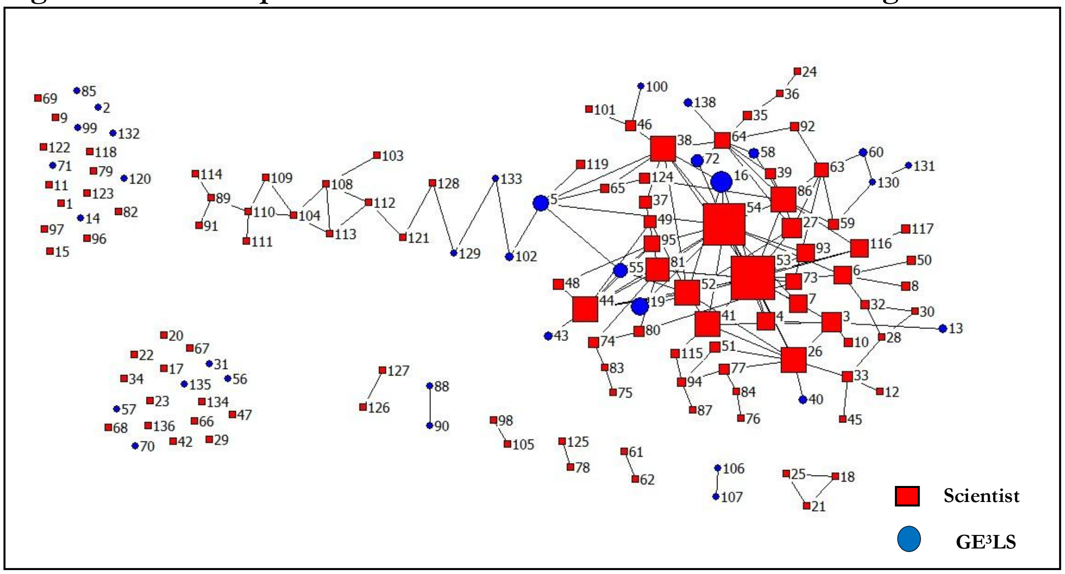
The co-publication eigenvector centrality network has a density of 0.0468 with 160 active ties amidst 100 nodes. Here four scientists have eigenvector scores above two standard deviations greater than the mean. These scientists seemingly exert power on network operations and have the ability to control the direction of co-publication.

Table 4.7.3-1: Variation in co-publications eigenvector centrality scores

Standard Deviations	Scientists	GE³LS	Total
<1SD	87	27	114
1SD**	9	4	13
2 SD	6	2	8
3 SD	2	0	2
4 SD	0	0	0
5SD	2	0	2

*One (10.663) or more standard deviations than the mean
**N for central actors=4 where GE³LS actors=0, Scientists=4
For details see *Appendix 1 Table [A.4.7.3-1]*
Source: Author's calculations

Sociogram 4.7.3-1: Co-publications Network: Nodes size based on eigenvector scores



* Active nodes= 100 ** Number of isolates=39

*** Node color and shape indicates affiliation

These lead actors, with very high eigenvector centrality scores in co-publication relation, not only have authority in the network but also have access to greater diversity of available information. All of the high eigenvectors actors are natural scientists. None of the GE^{3}LS actors are privileged to this power and authority. Notwithstanding GE^{3}LS actor's critical role in linking internal groups, they do not have decision-making power on the co-publication activities performed within the network.

[4.8] <u>Analyzing Correlation Outcomes for Four Relations of Interest</u>

The final task of this chapter is to assess which of the relation is positively linked with on-going and long-term research success of large-scale projects. *Table 4.8-1* records the correlation outcomes between individual actor centralities (indicator of social capital in lieu of social network positions) and their capacity to generate downstream research capital to advance research outcomes in the Genome Canada ABC competition. The research premise is that those large-scale network actors that collaborate, or occupy various lead roles in various relations resultantly generate social capital; that they then have a greater chance of collaborating subsequently and producing beneficial outcomes. It is important to note that the benefits of interacting in one type of relationship can pass on to another type of relation developed in the future. In other words, a network's social capital can possibly generate both current as well as future benefits for its members. The correlation matrix noted in *Table 4.8-1* suggests that induced social capital from past experience had a positive impact on success in the development and having funded a large-scale project in the ABC competition. The correlation matrix has tested the relationships between social network position (an indicator of social capital) and the amount of financial allocation procured by the 139 successful ABC competition actors. A positive correlation reflects the strength of the relationship between social capital that is produced as a result of interaction in the large-scale project environment, and its potential to acquire research awards or project capital. The correlation coefficient is the appropriate test statistic as we are examining the relationship between two variables.

Table 4.8-1: Correlation outcomes between actor centralities and actor-wise $ amount (N=139, df=137)

Relations	Density	Centrality Outcomes	Actor-wise $ amount**	Correlation coefficient (r) *(between centrality & $ amount)*	t-score	Probability
Area of Expertise (AOE)	0.6533	AOE Betweeness Centrality(Nrm)	$ amount	-0.234	-2.817	0.002**
		AOE Degree Centrality*	$ amount	-0.163	-1.933	0.027*
		AOE Eigenvector Centrality*(Nrm)*	$ amount	-0.186	-2.215	0.01*
Institutional Connections (IC)	0.0385	IC Betweeness Centrality (Nrm)	$ amount	-0.010	-0.117	0.45
		IC Degree Centrality*	$ amount	0.056	0.656	0.25
		IC Eigenvector Centrality *(Nrm)*	$ amount	-0.053	-0.621	0.26
Research Grants (RG)	0.0143	RG Betweeness Centrality(Nrm)	$ amount	0.178	2.117	0.01*
		RG Degree Centrality*	$ amount	0.049	0.574	0.28
		RG Eigenvector Centrality*(Nrm)*	$ amount	0.073	0.856	0.19
Co-publication (CP)	0.0116	CP Betweeness Centrality (Nrm)	$ amount	0.029	0.339	0.36
		CP Degree Centrality*	$ amount	0.147	1.739	0.04*
		CP Eigenvector Centrality *(Nrm)*	$ amount	0.079	0.927	0.17

Average of normalized *Out* and *In* degree centrality, Nrm=normalized
 * p<0.05, **p < 0.01, ***p < 0.001

Table 4.8-1 lists the correlation outcomes between 139 actors (including high impact actors) and proxy for dollar amounts awarded to the investigators in the ABC competition. The dollar award per investigator was calculated on the principle that project leads get a higher percentage of the overall projects awards. The project lead(s) are assigned 25 percent of ABC project allocation while the remaining 75 percent of the allocation is divided equally among the other listed co-investigator(s). In a perfect world we would use actual allocations but those numbers were not available. For projects with two leads, the 25 percent of the allocation is equally divided. The threshold is $p < 0.05$, where a (low) p value < 0.05 indicates that a strong correlation between the variables is unlikely a chance occurrence. Only statistically significant results are discussed in detail.

The correlation and probability statistics obtained for the *area of expertise* relation imply a negative or an inverse linear relationship between the three actor centralities (indicators of social network position and social capital) and their potential to procure investments for future research projects. The correlation between each 139 actor's number of direct links and their ability to procure future financial leverage is found to be negative at r= -0.163. The correlation coefficient of -0.234 indicates that an actors' *gatekeeper* or *brokerage* role in the network is weakly detrimental to generating financial capacity. Similarly, an actor's large number of links to prominent powerful and influential actors also impedes future investment procuring capability. All three correlations are deemed statistically significant ($p<0.05$) at 95% confidence interval. Overall, social capital produced via disciplinary ties is found to negatively impact their ability to generate financing. In other words, the large-scale project environment favours cross-disciplinary ties more than in-field relationships, and rewards those engaging in such efforts with monetary gains.

While many believe that real time interactions can generate long term relationships with distinct potential benefits, the data in *Table 4.8-1* confirms that in this case an actor's *co-location* links fail to generate any future incremental financial capacity. The relationship between an actor's number of direct link to other network actors as well as an actor's future capacity to generate research capital is very weak and statistically insignificant. Moreover, the social network position of an actor in a bridging role or as an eigenvector power (with co-location connections to other powerful actors) does not ensure future beneficial returns. The relationship between these variables is established as negative and insignificant.

In contrast, in the *research grants* relation, a positive linear trend was found between actors that function as bridges or connectors in network operations and their ability to draw in research awards in the future. This relation is significant at the 95% confidence level but is not a strong relationship. Meanwhile, network connections of highly connected actors are found to have a very weak association with an actor's capacity to securing funds for future research. A similar result was found for network agents who have close linkages with other influential actors in the large-scale environment (e.g. eigenvector power). Both these relationships are statistically insignificant.

In the *co-publication network*, the correlation between the funds procured in ABC competition and actor degree centrality scores is found to be positively correlated, but not strong *(within 0 - 0.2 range)*. This relation between an actor's direct links and financial success afterwards is statistically significant ($p<0.05$) at 95% confidence level. However, in the co-publications network, there is only very weak or non-significant results of correlation between research award amount and actor betweeness or eigenvector scores. Thus, the likelihood of co-publication linkages to generate beneficial outcomes for large-scale projects is more for core actors with multiple ties, than for actors that act as bridges or have eigenvector power.

[4.9] Conclusions

Genome Canada's large-scale research has facilitated abundant disciplinary ties between project investigators. If taken in isolation, the resulting cohesive structure is found with pronounced intra-discipline interactions but weak cross-disciplinary linkages, which could inhibit access to novel external information. Dense internal linkages sustain bonding social capital and limit bridging tendencies. The presence of institutional actor ties provides possibilities for real-time communication and exchanges. Co-location can provide an actor with bridging potential across clusters, broaden the knowledge base, and allow access to diverse opinions. Also, occupying a core network position in an institution can offer investigators with power and influence on network decisions. Grants based relations favour production of both bridging and bonding social capital linkages — with powerful and prominent actors, can influence future financial awards. Explicit co-production of knowledge, through co-publication, favour spanners with access to first hand external information, and hub actors with control of information exchanges and network decisions. The co-publication network helps to identify the social network position of prominent and powerful actors.

The level of investigator commitment and network exchanges required to generate and maintain each of the four sub-systems varies. Rationally maximum interactions should maximize social capital outputs and vice-versa. Therefore, it is logical that network with the most hands-on investigator interactions would generate maximum social capital and benefits. We found that disciplinary ties were, in some ways, a disadvantage for people seeking to secure further capital. Disciplinary affiliation is simply an insufficient condition to ensure potential award or benefits. In contrast, inter-disciplinary ties seem to enhance future fund raising capacity. Similarly, co-location did not generate any incremental value to those involved. In fact, social capital based on co-location links was negatively connected to competitive fund-raising capacity. In contrast, we can see the Matthew Effect in research grants — the metaphor *money attract money* is realised as social capital embedded in monetary ties was positively correlated to future financial success. Finally, co-publication ties are positively linked to capacity to generate downstream funding. Here absolute centrality, in the form of a high number of connected investigators is more important than spanner ties or relations with powerful individuals in generating future beneficial outcomes. Overall, none of the individual actor ties operate in seclusion. The benefits of large-scale research projects are best procured if different investigators bring different types of ties.

C h a p t e r 5

CONCLUSIONS, LIMITATIONS, AND IMPLICATIONS

[5.1] <u>Conclusions</u>

The current research has established and applied a novel methodology to assess the relationship between large-scale projects, social capital, innovation outcomes, and the Canadian government's strategic objective of aligning Canadian science to global leaders, as articulated in a number of recent science and research policy frameworks. Drawing on applied measures and correlation analysis, we have been able to test the three sub-hypothesis asserted in Chapter one. Sub-hypothesis #1 is tested by examining popular literature and theoretical perspectives, sub-hypothesis #2 is tested from the results procured while applying density and centrality measures to relevant data, and status of sub-hypothesis #3 is ascertained from the correlation analysis outcomes.

<u>Sub-hypothesis #1:</u> Fundamentals of contemporary innovation networks and systems theory are replicated in large-scale research projects.

This sub-hypothesis was tested by examining the theoretical and policy base of traditional and contemporary innovation systems to extract similarities with the underpinnings of Genome Canada's big-science strategy from 2000-2009. As indicated in *Table 5.1-1*, overall the comparison is carried out at three levels — the type of knowledge production, the level of personnel exchange, and intra-project associations. First, the theory and evidence assessed suggests that large-scale projects are encouraged to produce, distribute, and apply a novel form of knowledge which is context-driven, reflexive, heterogeneous, problem-focused, diffusible, and inter or trans-disciplinary — categorised more commonly as mode-2 knowledge. The production of this type of knowledge is a contemporary phenomenon, differing extensively from its traditional counterpart, mode-1 disciplinary knowledge.

Second, one of the leading objectives of Genome Canada is to create personal networks to enhance Canadian scientist's capacity to generate world-class science. Network-based actor-to-actor exchange is assumed to be an important factor that initiates, sustains, imports, and diffuses new innovations. Public-private functional linkages, cross-functional interactions, and network relationships between actors strongly support expansion of co-publications, co-patents, and cross-sectoral personnel mobility. Personnel partnerships at a global level are encouraged by aligning projects with global intellectual property rules, labour market policies, and exchange programs. The multiple and reciprocal relationships between public, private, and academic actors in Genome Canada's projects are assumed to generate an institutional order that facilitates active connections, stimulates creativity, and improves individual entities.

Table 5.1-1: Comparison of traditional *vs.* contemporary innovation systems: Identification of large-scale research project traits

	Traditional Innovation System	Contemporary Innovation Systems: Review of National System of Innovation and Triple Helix model	Genome Canada's Large-scale Research projects
Nature of knowledge	Discipline-based, academic, investigator-initiated, lacks theoretical underpinnings to explain innovation process and outcomes – *Mode 1*	Context-driven, reflexive, heterogeneous, problem-focused, diffusible, inter or trans-disciplinary, with profound theoretical basis to explicate innovation — *Mode 2*	*Mode 2*
Personnel exchanges	Restricted interactions, intra-disciplinary, individual based, independent — *Individual oriented*	Extensive interactions, inter-disciplinary, team based, collective action, interdependent — *Collective action, Network oriented*	*Collective action, Network oriented*
Project focus	Subject based associations, boundary preservation, achieve private objectives, individualistically defined role, clear role distinction — *Individual research focussed projects*	Cross-collaborations, triage partnerships, to realize group goals, role duality, joint research ventures — *Big science focus*	*Big science focus*

Source: Author's construct

Third, in line with the contemporary innovation systems theory, Genome Canada's large-scale research projects are found to encourage triage linkages between the state, academia, and industry at one level and between actors, regulations, and institutions at another level. These constituents are presumed foundational to the contemporary knowledge economy and its production and transfer processes. The interlinking of these three functionally and schematically distinct institutions are found to develop capacities and expand outputs both at the actor and system level. As posited in the Triple Helix model, the processes of rearrangements, mobility, cross-collaboration, and integration in big-science projects stimulate innovation, which in turn generates a dynamic network of communication, partnership, and interactions. Genome Canada's research projects seek to generate network relationships between global, national, regional, and local innovation systems, much in line with the contemporary innovation systems ideology. These network interactions are guided by resolute norm systems. Genome Canada's innovation projects operate with the premise that dynamic interconnectivity and role duality in big science projects helps to deal with modern-day challenges in innovation and research systems. While contemporary innovation systems theory offers many positive attributes, large-scale projects may be susceptible to systemic discrepancies, such as losses due to lack of productive interactions amidst system actors, lack of synergy between public and private research, mis-steps in technology transfer and divergence in information recognition and use. Overall, Genome Canada's large-scale research projects attempt to integrate contemporary innovation system principles, which than supports: joint industry activities, technical interactions, public-private linkages, and technology diffusion linked with cross-sectoral innovations and knowledge crossovers.

Thus, Genome Canada's large-scale research projects are found to have many similar traits to the contemporary innovation systems theory. Consequently, Sub-hypothesis #1 is not rejected based on the evidence examined and assessed.

Sub-hypothesis #2: Large-scale project exchanges produce a network environment for generation of social capital.

To test this sub-hypothesis, the existence of network exchanges in Genome Canada's large-scale projects is assessed through examination of a range of interconnections. Densities for different relations was ascertained, quite profoundly discrete visualisations were mapped, and three types of centralities (degree, betweenness, and eigenvector) were tested on four relations between 139 investigators funded by Genome Canada in the Applied Bioproducts and Crops (ABC) Competition (2009).

First, the very presence of network density outcomes for the four exchange arenas under examination indicates the presence of a range of network conditions amidst Genome Canada's 139 project actors. Second, network centralisation measures hint at specific investigators having positional advantage and differential access to network resources in the four relations based networks. The access to real time communications as well as access to network resources such as up-to-date information, advice, and support varies for actors that occupy either core or tangential social network positions. Third, a quantitative analysis of social network position shows that different network structures generate different outcomes. Group level activities such as co-publication (knowledge production) or partnering in research grants have formalised activity hubs that allow continual communications, facilitate advanced resource exchanges, and generate platforms that impact joint outcomes positively. In practice, Genome Canada's large-scale projects synergize different components of agriculture based proteomics and genomics research by drawing in diverse talents from different fields of study and providing a common purpose and context. The contextual and functional amalgamation generates group perspectives where opportunities and motivations for engagement multiply. *Table 5.1-2* reveals that each of the four relations has central actors that range from 1.4 percent to 88 percent of the total members (N) of the sub-systems. These central actors are privileged to social capital and certain benefits made possible by their social network positions.

Table 5.1-2: Core actor's SNP and social capital access in large-scale network (N=139)			
Centrality	**Relations**	**Percentage of central actors and social network positions**	**Social capital generated in network exchanges**
Betweenness	Area of Expertise	6.4 % of N agents in brokerage capacity *(but mediator benefits diminish in dense environment)*	Presence of bridging social capital in lieu of core actors linking sub-networks and isolates in composite network
	Institutional Connection	4 % of N actors link institutional clusters	
	Research Grants	1.4 % of N actors with linkage role	
	Co-publications	10 % of N actors have bridge functionality	
Degree	Area of Expertise	32 % of N actors as power hubs *(Advantage highly reduced in presence of multiple links amidst network actors)*	Bonding social capital in lieu of core actors sharing multitude ties with other actors in the network
	Institutional Connection	3 % of N agents with high number of *in* and *out* ties	
	Research Grants	1.4 % of N actors as central connectors	
	Co-publications	5 % of N actors as network hub	
Eigenvector	Area of Expertise	88 % of N actors share ties with prominent network actors *(Privilege highly reduced in dense network)*	Core actors privileged to benefits of social capital i.e. elevated power, prominence, high social status, and authority in network decisions and operations
	Institutional Connection	10 % of N actors are connected with other central network actors	
	Research Grants	8 % of N agents are connected to other central actors	
	Co-publications	3 % of N actors with links to other influential actors in the network	

*SNP=Social Network Position

Third, as Burton *et. al.* (2010, pp.1) asserts, "Social capital refers to the advantage an individual obtains via being connected to others. This advantage is created by a person's location in the structure of network relationships"(Burton, Wu, and Prybutok 2010). In this context social capital emerges as a range of benefits experienced by investigators because of their links with others network actors. An examination of diverse perspectives in Chapter 2 of the dissertation has confirmed that social capital is lodged in exchange relationships, network structures, social relations, and collective organizations *(see Table 2.5-1)*. Presence of a network organization in Genome Canada's projects suggests that social capital may lie in the specific actor-to-actor ties as theory affirms that networks are necessary for creating and sustaining social capital.

The *area of expertise* network, with its highly dense intra-network connections, has a high degree of redundancy. In practice dense and closed network setups support intra-network exchanges but restrict access and use of novel external information and resources. The network is found to lack a balanced blend of closure and openness in the network ties which can impacts social capital negatively. Virtually everyone is known to everyone else through their disciplinary ties, which is expected as Genome Canada competitions were theme calls in field of agriculture-crop research. The challenge is that the possibility of cross-disciplinary interactions is highly reduced in such dense systems. Social capital residing in discipline-based ties is generally stranded and ineffective, as the dense system reduces any actors' bridging advantage and blurs the possibility of distinct leadership in the network.

In the *institutional connections* network, a number of core actors have privileged access to social capital which could translate into real time interactions with other powerful, prominent, and authoritative personalities with influence on network decisions and operations. This conclusion hints at the possible benefits to the funding agencies of building project teams with common institutional affiliations. The confirmed potential of these linkages to generate latent benefits is however still debatable and is examined later.

Research based monetary links involve relatively high commitments from involved stakeholders and have the potential to mature into new downstream partnerships. Genome Canada, along with other sponsor agencies such as NSERC, SSHRC, CIHR, and AFMNET, have designed programs that are instrumental in connecting scientist and GE^3LS investigators through *grant-based* ties. The social capital accessible through monetary links can help investigators to control allocation of funding to specific priorities and to set future research directions. However, on the whole, fraction of total research population that has participated in or shared the research awards in Genome Canada's projects is small. There is certainly a scope for improvement of grant-based linkages in Canadian proteomics and genomics research.

Explicit knowledge production in the form of *co-publication* involves the highest level of proactive engagement and arguably generates the highest amount of social capital of the four relations examined. The co-publications relation produced, through Genome Canada's range of competitions appears to privilege core actors with control on research direction, novel information access, decision-making, and informal leadership. The bridging actors, in the co-publications network, create boundary spanning ties that ensure novelty in ideas, diversity of opinions, increased connectedness to the peripheral environment, efficient access of external resources, broadens knowledge conception, and procures a competitive edge. However, the small percentage of core actors in Genome Canada's competition projects that are actually involved in co-publishing suggests future opportunities for collaboration, at both internal (amidst disciplines) and external (cross-disciplinary) levels of knowledge production.

Genome Canada's large-scale innovation projects create an interactive and communicative environment for concerned stakeholders and expose them to the benefits of networked social capital. Therefore, *Sub-hypothesis # 2* is not rejected based on the evidence examined and assessed.

<u>Sub-hypothesis #3:</u> Social capital produces latent or residual innovation outcomes.

Each of the actor ties calls for different levels of proactive engagement from each investigator. While disciplinary affiliations require the least active involvement, knowledge production mandates maximum commitment; institutional connections and research grants require a middle range of investment. One might assume that less actor commitment would negatively reduce network social capital. In current research the discussion on social capital and its benefits was extended to include its latent or residual benefits which might motivate public and private research sponsors to fund projects with an explicit network component. In this research the latent advantage of social capital was assessed by correlating social network position (as a proxy for individual social capital) with the dollar amount of funds allocated to each investigator in the ABC competition.

The dense discipline-based network reflects the well-integrated crop-based research community in Canada. There were virtually no outliers. Interestingly, we found a statistically significant negative correlation coefficient between stronger disciplinary ties amongst project investigators and their ability to generate capital in the ABC competition. In short, more disciplinary linkages were disadvantageous in procuring downstream research funding. Disciplinary affiliations do not appear a sufficient condition to ensure prospective funds or benefits. Hybridization across disciplines seems to enhance fund raising capacity. However, this may not be a generalizable outcome as Genome Canada competitions were explicitly structured to promote cross-disciplinary research, but the point is still worth further investigation.

Institutional connections ties are synonymous to breathing the same air. Contrary to the common belief that real time interactions are unambiguously positive for innovation, our work found them to be marginally negatively (but not statistically significantly) connected to innovation outcomes. Social capital generated via face-to-face interactions, in this case are unable to generate any incremental value to the involved actors. In fact, social capital in co-location links is marginally disadvantageous to scholars in procuring downstream returns.

The comparative award-based social network positions shows that actors who span and link other actors or sub-networks through grants are able to positively impact downstream research success. In the grants-based network, absolute centrality and tie-ups with powerful network actors have positive effects on future fund raising but in case bridging actors they have relatively less success. Overall, the social capital ingrained in financial ties, developed in large-scale networks, is positively correlated with future innovation and has the ability to generate and sustain economic linkages in the future.

Joint co-publication ventures in theory do not require real-time interactions and can thrive sufficiently over remote connections. However, in practice they do involve some inter-personal connection. Co-publication derives from relationships with strong trust and a culture of give and take. Parties or actors involved in knowledge production often have a shared vision and sense of responsibility to deliver a *first-to-market* result, in an appropriate and timely manner. The correlation between co-publication ties and capacity to generate funding is positive, and statistically significant but not very strong. Absolute centrality, in the form of high number of connected investigators, is important in generating future beneficial outcomes. The number of connections seems to be more crucial than having links with powerful and prominent network actors (eigenvectors). Also, centrally-linked actors (with high betweenness centrality) have only a very weak role in generating downstream funding. Overall, social capital positively impacts production of beneficial residual outcomes in co-publication and research awards networks, but it has negative effect in networks based on common fields or co-location. *Sub-hypothesis #3* is not rejected as the results suggest that social capital has a relationship — whether positive or negative, with downstream results.

To summarize, based on the analysis, calculations, and assessments of the four networks and the proposed hypotheses, large-scale projects appear to facilitate generation of a networked environment where network exchanges generate social capital, which then can deliver downstream latent affects — a prominent reason for public as well as private institutions to support large-scale research (that are breeding grounds for social capital) and platforms to procure social capital's current and downstream benefits.

[5.2] Research Limitations

The framework had two main challenges in realistically predicting social capital's latent outcomes. First, there was lack of personalized information available in public artifacts on 139 investigators. Primary data sources were not explored for primary data collection process is both time intensive and the observed rate of response from the same population, in other research studies, had been quite low. Hence, secondary and tertiary information resources were investigated as main data sources.

Second, the analytical framework utilized a resource proxy in order to decipher the latent impact of social capital. The challenge was that ultimate downstream effects — such as, publications, journal articles, provisional patents, patent applications, or trained personnel, need significant time to evolve and materialise, making it difficult to identify explicit links between the Genome Canada efforts over 2000-2009 and the realization of goals of knowledge, highly skilled people, and commercial application. This forced us to adopt a circuitous approach. This was compounded because factual information on the exact percentage proportion of funding allocated to project leads, co-investigators, and collaborators was unavailable. Hence, a presumptive and experience-oriented rule was used to divide the funds awarded to generate the dollar amount per investigator.

[5.3] Recommendations for Future Research

This study has assessed the functionality of social capital in the large-scale research environment to identify any downstream residual effects. There is reasonable evidence to suggest that social capital generated in networks has broader and long reaching advantages. However, at this stage it is impossible to demonstrate and ascertain whether the source of any residual benefits is internal (intra-project) or external (inter-project) social capital. Moreover, the assessment of impact at the level of any specific funding agencies is not possible in this study. For example: in the present context, in addition to Genome Canada, the grant-based assessment includes the ties generated via the efforts of NSERC, SSHRC, CIHR, etc. However, at this stage it is unfeasible to extract and predict social capital generated solely through Genome Canada or any other individual organization. This would require further investigation, possibly using multiple regression analysis of more refined social metrics as developed and assessed here. Ultimately, the framework and methodology developed in the current research could be extended to investigate other networks and systems.

[5.4] Research Implications

Recent communications from the federal government suggest that they are becoming impatient with the results of large-scale and networked projects. The returns on research and development funding are slow to emerge and downstream products or processes are seldom realised for several years. In one sense, the analytical framework used has provided an evidence-based rationale for funding big science research. Current research and the modular framework developed therein contribute to understanding the role of social capital in ensuing superior future research objectives. Taken together, the results of current investigation provide a strong rationale for the integration of people, disciplines, and institutions under the umbrella of genomics and proteomics research.

The identification of downstream impact of social capital provides a strong rationale for the federal government's recent financial backing of big-science research in genomics and proteomics. The social capital generated within large-scale projects not only has a present day beneficial effect but also imparts benefits with time. For example, co-publications ties furbished in large-scale research projects can be precursors and pathways to future knowledge production efforts. Similarly, actors collaborating to procure and share research grants can later combine efforts to procure and cooperate on new research ventures.

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APPENDIX

Table [A.4.4.1-1]: Area of Expertise Betweeness centrality scores

Area of Expertise network actors code	Betweeness Centrality scores*	Science/GE³LS Affiliations
65	0.151	Scientist
53	0.152	Scientist
54	0.153	Scientist
131	0.153	Scientist
90	0.155	Scientist
93	0.155	GE³LS
7	0.156	Scientist
81	0.159	Scientist
125	0.159	Scientist
46	0.165	Scientist
111	0.165	Scientist
116	0.169	Scientist
25	0.173	Scientist
52	0.173	Scientist
92	0.173	Scientist
22	0.174	Scientist
68	0.176	Scientist
76	0.179	Scientist
86	0.193	Scientist
109	0.193	Scientist
79	0.197	Scientist
47	0.199	Scientist
55	0.199	Scientist
85	0.207	Scientist
102	0.207	Scientist
133	0.208	Scientist
132	0.209	Scientist
105	0.214	GE³LS
20	0.218	Scientist
69	0.226	Scientist
77	0.234	Scientist
87	0.239	Scientist
103	0.241	Scientist
124	0.247	Scientist
62	0.249	GE³LS
78	0.252	Scientist
89	0.265	Scientist
31	0.268	Scientist
39	0.278	Scientist
70	0.296	Scientist
13	0.306	GE³LS
29	0.306	Scientist
26	0.358	Scientist
118	0.407	Scientist
74	0.411	GE³LS
23	0.421	Scientist
135	0.435	Scientist
10	0.487	Scientist
94	0.500	Scientist
S100	0.523	Scientist
73	0.571	GE³LS
32	0.818	GE³LS
88	0.955	GE³LS

**One (0.148) or more standard deviations greater than the mean*
***N=53 where GE³LS=8, Scientists=45*

Table [A4.4.2-1]: Area of Expertise Degree centrality scores

Area of Expertise network actors code	Degree Centrality scores** *(Avg. Normalized Out & In Degree)*	Science/ GE^3LS Affiliations
18	27.536	Scientist
91	27.536	GE^3LS
128	27.899	GE^3LS
2	31.159	GE^3LS
72	31.522	GE^3LS
134	33.333	Scientist
115	40.580	GE^3LS
14	41.304	GE^3LS
71	42.754	Scientist
58	44.203	GE^3LS
77	44.348	Scientist
122	48.189	Scientist
86	51.812	Scientist
79	52.899	Scientist
78	53.261	Scientist
4	55.797	Scientist
32	59.420	GE^3LS
49	60.870	Scientist
93	64.131	GE^3LS
64	66.667	Scientist
65	68.116	Scientist
140	71.014	GE^3LS
73	71.739	GE^3LS
3	72.464	Scientist
11	72.464	Scientist
111	73.188	Scientist
120	73.188	Scientist
19	73.913	GE^3LS
110	73.913	GE^3LS
116	73.913	Scientist
5	74.638	GE^3LS
42	74.638	Scientist
1	75.725	Scientist
59	75.725	GE^3LS
44	76.087	GE^3LS
41	76.812	GE^3LS
51	76.812	Scientist
61	76.812	Scientist
62	77.174	GE^3LS
34	77.536	Scientist
84	77.536	Scientist
98	77.536	Scientist
114	77.536	GE^3LS
137	77.536	GE^3LS
63	77.899	Scientist
67	77.899	Scientist
99	77.899	Scientist
127	77.899	Scientist
27	78.261	Scientist
45	78.261	Scientist
66	78.261	Scientist
83	78.261	Scientist
85	78.986	Scientist
54	79.348	Scientist
69	79.348	Scientist
88	79.536	GE^3LS
9	79.710	Scientist
21	79.710	Scientist
24	79.710	Scientist
43	79.710	Scientist
46	79.710	Scientist
55	79.710	Scientist

68	79.710	Scientist
105	80.073	GE^{3}LS
6	80.435	Scientist
39	80.435	Scientist
47	80.435	Scientist
82	80.435	Scientist
95	80.435	Scientist
112	80.435	Scientist
130	80.435	Scientist
25	80.797	Scientist
26	80.797	Scientist
70	80.797	Scientist
89	80.797	Scientist
100	80.797	Scientist
136	80.797	Scientist
7	81.159	Scientist
12	81.159	Scientist
30	81.159	Scientist
35	81.159	Scientist
36	81.159	Scientist
38	81.159	Scientist
90	81.159	Scientist
96	81.159	Scientist
113	81.159	Scientist
119	81.159	Scientist
121	81.159	Scientist
129	81.159	Scientist
131	81.159	Scientist
75	81.160	Scientist
76	81.160	Scientist
37	81.884	Scientist
53	81.884	Scientist
92	81.884	Scientist
125	81.884	Scientist
126	81.884	Scientist
23	82.247	Scientist
74	82.247	GE^{3}LS
117	82.247	Scientist
10	82.609	Scientist
13	82.609	GE^{3}LS
33	82.609	Scientist
52	82.609	Scientist
56	82.609	GE^{3}LS
102	82.609	Scientist
109	82.609	Scientist
124	82.609	Scientist
87	82.971	Scientist
103	82.971	Scientist
22	83.333	Scientist
81	83.333	Scientist
132	83.696	Scientist
133	83.696	Scientist
31	84.058	Scientist
40	84.058	Scientist
20	84.783	Scientist
29	84.783	Scientist
118	85.145	Scientist
135	85.145	Scientist
94	91.739	Scientist

**One (27.031) or more standard deviations than the mean*
***N=121 where GE^{3}LS=25, Scientists=96*

Table [A4.4.3-1]: Area of Expertise Eigenvector centrality scores

Area of Expertise **network actors code**	**Eigenvector Centrality scores****(Nrm)*	**Science/ GE^{3}LS Affiliations**
123	4.442	Scientist
91	4.739	GE^{3}LS
128	4.745	GE^{3}LS
18	5.108	Scientist

2	5.241	GE³LS
134	5.623	Scientist
115	7.373	GE³LS
14	7.404	GE³LS
122	8.390	Scientist
86	8.510	Scientist
72	9.747	GE³LS
4	10.070	Scientist
32	10.229	GE³LS
49	10.437	Scientist
93	11.098	GE³LS
111	12.165	Scientist
120	12.205	Scientist
116	12.281	Scientist
58	12.292	GE³LS
140	12.333	GE³LS
11	12.399	Scientist
3	12.463	Scientist
110	12.539	GE³LS
5	12.554	GE³LS
19	12.596	GE³LS
42	12.639	Scientist
88	12.865	GE³LS
1	12.895	Scientist
85	12.917	Scientist
100	12.968	Scientist
51	12.991	Scientist
26	13.031	Scientist
41	13.038	GE³LS
98	13.050	Scientist
44	13.065	GE³LS
56	13.109	GE³LS
34	13.130	Scientist
137	13.130	GE³LS
10	13.141	Scientist
127	13.154	Scientist
47	13.166	Scientist
27	13.179	Scientist
71	13.189	Scientist
99	13.194	Scientist
45	13.207	Scientist
114	13.208	GE³LS
83	13.216	Scientist
84	13.216	Scientist
39	13.245	Scientist
105	13.269	GE³LS
59	13.279	GE³LS
79	13.286	Scientist
78	13.318	Scientist
43	13.321	Scientist
46	13.330	Scientist
6	13.338	Scientist
13	13.354	GE³LS
23	13.363	Scientist
21	13.367	Scientist
9	13.382	Scientist
95	13.387	Scientist
89	13.391	Scientist
82	13.417	Scientist
25	13.420	Scientist
12	13.428	Scientist
129	13.428	Scientist
136	13.428	Scientist
24	13.433	Scientist
112	13.433	Scientist
130	13.433	Scientist
90	13.452	Scientist
7	13.455	Scientist

125	13.464	Scientist
131	13.464	Scientist
62	13.470	GE³LS
87	13.477	Scientist
102	13.493	Scientist
30	13.499	Scientist
35	13.499	Scientist
38	13.499	Scientist
113	13.499	Scientist
119	13.499	Scientist
121	13.499	Scientist
73	13.501	GE³LS
69	13.513	Scientist
66	13.518	Scientist
92	13.519	Scientist
67	13.523	Scientist
103	13.527	Scientist
36	13.530	Scientist
96	13.530	Scientist
63	13.547	Scientist
132	13.547	Scientist
124	13.555	Scientist
109	13.564	Scientist
68	13.569	Scientist
37	13.576	Scientist
126	13.576	Scientist
135	13.577	Scientist
64	13.591	Scientist
117	13.610	Scientist
22	13.616	Scientist
52	13.617	Scientist
33	13.618	Scientist
61	13.620	Scientist
40	13.629	Scientist
118	13.641	Scientist
29	13.645	Scientist
31	13.645	Scientist
94	13.663	Scientist
81	13.670	Scientist
65	13.680	Scientist
133	13.680	Scientist
54	13.691	Scientist
75	13.693	Scientist
55	13.718	Scientist
20	13.758	Scientist
70	13.767	Scientist
77	13.768	Scientist
76	13.853	Scientist
53	13.877	Scientist
74	13.883	GE³LS

**One (4.263) or more standard deviations than the mean*
*** N=122 where GE³LS =25, Scientists=97*

Table [A.4.5.1-1]: Institutional Connections Betweeness centrality scores

Institutional Connections network actors code	**Betweeness Centrality scores*** *(Nrm)*	**Science/ GE³LS Affiliations**
72	3.385	GE³LS
66	3.978	Scientist
78	4.147	Scientist
110	4.718	GE³LS
81	5.05	Scientist
63	5.708	Scientist
88	7.677	GE³LS
141	12.521	GE³LS

**One (1.529) or more standard deviations than the mean*
***N=8 where GE³LS=4, Scientists=4*

Table [A.4.5.2-1]: Institutional Connections Degree centrality scores

Institutional Connections network actors code	**Degree Centrality scores**** *(Nrm Out & In Degree)*	**Science/ GE³LS Affiliations**
72	4.348	GE³LS
120	5.072	Scientist
77	5.797	Scientist
91	5.797	GE³LS
103	5.797	Scientist
111	5.797	Scientist
113	5.797	Scientist
114	5.797	GE³LS
115	5.797	GE³LS
122	5.797	Scientist
123	5.797	Scientist
138	5.797	GE³LS
2	6.522	GE³LS
3	6.522	Scientist
5	6.522	GE³LS
13	6.522	GE³LS
14	6.522	GE³LS
16	6.522	GE³LS
17	6.522	Scientist
51	6.522	Scientist
100	6.522	Scientist
117	7.246	Scientist
52	7.971	Scientist
76	7.971	Scientist
79	7.971	Scientist
82	7.971	Scientist
90	7.971	Scientist
92	7.971	Scientist
93	7.971	GE³LS
94	7.971	Scientist
95	7.971	Scientist
104	7.971	GE³LS
44	9.420	GE³LS
61	9.420	Scientist
64	9.420	Scientist
68	9.420	Scientist
69	9.420	Scientist
81	9.420	Scientist
102	9.420	Scientist
29	10.145	Scientist
31	10.145	Scientist
32	10.145	GE³LS
41	10.145	GE³LS
63	10.145	Scientist
65	10.145	Scientist
66	10.87	Scientist
78	10.87	Scientist
110	10.87	GE³LS
85	12.319	Scientist
119	12.319	Scientist
88	13.768	GE³LS
141	14.493	GE³LS

**One (3.778) or more standard deviations than the mean*
***N=52 where GE³LS =18, Scientists=44*

Table [A.4.5.3-1]: Institutional Connection Eigenvector centrality scores

Institutional Connections network actors code	**Eigenvector Centrality scores*** *(Nrm)*	**Science/ GE³LS Affiliations**
42	11.549	Scientist
44	37.124	GE³LS
61	37.124	Scientist
64	37.124	Scientist

68	37.124	Scientist
69	37.124	Scientist
102	37.124	Scientist
65	37.325	Scientist
63	37.413	Scientist
78	37.773	Scientist
66	37.939	Scientist
29	37.941	Scientist
31	37.941	Scientist
32	37.941	GE³LS
41	37.941	GE³LS

**One (11.174) or more standard deviations than the mean*
***N=15 where GE³LS =3, Scientist=12*

Table [4.6.1-1]: Research Grants Betweeness centrality scores

Research Grants network actors code	Betweeness Centrality scores**	Science/ GE³LS Affiliations
141	0.299	GE³LS
90	0.360	Science
99	0.367	Science
94	0.410	Science
52	0.469	Science
115	0.581	GE³LS
112	0.693	Science
45	1.422	Science
93	2.291	GE³LS

** One (0.248) or more standard deviations than the mean*
*** N=9 where GE³LS=3, Scientists=6*

Table [A.4.6.2-1]: Research Grants Degree centrality scores

Research Grants network actors code	Degree Centrality scores** *(Avg. Normalized Out & In Degree)*	Science/ GE³LS Affiliations
90	1.812	Scientist
118	1.812	Scientist
3	2.174	Scientist
71	2.174	Scientist
112	2.428	Scientist
43	2.536	Scientist
52	2.899	Scientist
99	2.899	Scientist
137	3.261	GE³LS
41	3.261	GE³LS
103	3.261	Scientist
131	3.261	Scientist
46	3.623	Scientist
110	3.623	GE³LS
117	3.623	Scientist
122	3.623	Scientist
91	3.624	GE³LS
140	3.624	GE³LS
94	4.348	Scientist
32	4.348	GE³LS
129	4.348	Scientist
119	5.073	Scientist
75	6.522	Scientist
115	7.246	GE³LS

**One (1.715) or more standard deviations than the mean*
***N=24 where GE³LS=7, Scientists=17*

Table [A.4.6.3-1]: Research Grant Eigenvector centrality

Research grant network actors code	Eigenvector Centrality scores *(Nrm)*	Science/ GE³LS Affiliations
96	11.059	Scientist
46	11.737	Scientist
90	13.731	Scientist
32	14.195	GE³LS
129	14.195	Scientist
43	16.388	Scientist
52	17.111	Scientist
41	20.491	GE³LS
117	20.991	Scientist
45	21.826	Scientist
119	24.145	Scientist
112	24.634	Scientist
115	33.299	GE³LS
75	33.400	Scientist
103	33.400	Scientist
131	33.400	Scientist
137	33.400	GE³LS
91	36.361	GE³LS
110	36.361	GE³LS
140	37.380	GE³LS
94	38.710	Scientist
141	38.843	GE³LS
93	54.696	GE³LS

**One (10.940) or more standard deviations than the mean*
***N=24 where GE³LS=9, Scientists=15*

Table [A.4.7.1-1]: Co-publications Betweeness centrality scores

Co-publications network actors code	Betweeness Centrality scores**	Science/ GE³LS Affiliations
3	1.674	Scientist
123	1.534	Scientist
47	1.587	Scientist
92	1.587	Scientist
132	1.684	Scientist
65	1.914	Scientist
62	1.930	GE³LS
61	1.978	Scientist
42	2.286	Scientist
34	2.33	Scientist
138	2.358	GE³LS
121	2.499	Scientist
84	2.698	Scientist
66	2.788	Scientist
6	3.099	Scientist
118	3.099	Scientist
45	3.148	Scientist
116	3.298	Scientist
112	4.474	Scientist
26	5.835	Scientist
89	6.164	Scientist
120	7.034	Scientist
129	7.622	Scientist
55	8.086	Scientist
136	8.187	Scientist
137	8.732	GE³LS
141	9.255	GE³LS
110	9.758	GE³LS
39	9.786	Scientist
5	11.413	GE³LS
53	13.862	Scientist

**One (1.075) or more standard deviations greater than the mean*
*** N=31 where GE³LS=6, Scientists=25*

Table [A.4.7.2-1]: Co-publications Degree centrality scores

Co-publications network actors code	**Degree Centrality scores**** *(Avg. Normalized Out & In Degree)*	**Science/ GE³LS Affiliations**
61	1.087	Scientist
18	1.449	Scientist
21	1.449	Scientist
25	1.449	Scientist
4	1.449	Scientist
49	1.449	Scientist
59	1.449	GE³LS
52	1.449	Scientist
31	1.449	Scientist
37	1.449	Scientist
38	1.449	Scientist
83	1.449	Scientist
129	1.449	Scientist
132	1.449	Scientist
136	1.449	Scientist
117	1.449	Scientist
123	1.449	Scientist
138	1.449	GE³LS
141	1.449	GE³LS
137	1.449	GE³LS
110	1.449	GE³LS
74	1.449	GE³LS
75	1.449	Scientist
27	2.174	Scientist
16	2.174	GE³LS
47	2.174	Scientist
29	2.174	Scientist
33	2.174	Scientist
124	2.174	Scientist
92	2.174	Scientist
98	2.174	Scientist
99	2.174	Scientist
120	2.174	Scientist
121	2.174	Scientist
6	2.899	Scientist
56	2.899	GE³LS
34	2.899	Scientist
112	2.899	Scientist
116	2.899	Scientist
118	2.899	Scientist
42	3.261	Scientist
3	3.623	Scientist
5	3.623	GE3LS
41	3.623	GE3LS
84	3.623	Scientist
66	3.623	Scientist
26	5.072	Scientist
45	5.072	Scientist
39	5.072	Scientist
89	5.072	Scientist
54	5.779	Scientist
55	5.797	Scientist
53	6.522	Scientist

**One (1.431) or more standard deviations greater than the mean*
*** N=53 where GE³LS=10, Scientists=43*

Table [A.4.7.3-1]: Co-publications Eigenvector centrality scores

Co-publications network actors code	**Degree Centrality scores** *(Nrm)*	**Science/ GE³LS Affiliations**
74	10.8	GE³LS
65	11.495	Scientist
56	13.817	GE³LS
75	15.455	Scientist
99	16.035	Scientist
5	16.713	GE³LS
66	17.058	Scientist
7	17.327	Scientist
19	17.327	GE³LS
96	17.327	Scientist
124	18.198	Scientist
6	18.496	Scientist
4	20.416	Scientist
3	21.621	Scientist
27	21.907	Scientist
16	26.477	GE³LS
83	27.14	Scientist
42	30.072	Scientist
88	30.963	GE³LS
53	31.062	Scientist
26	31.912	Scientist
45	32.885	Scientist
39	32.977	Scientist
55	58.528	Scientist
54	62.733	Scientist

** One (10.663) or more standard deviations greater than the mean*
*** N=53 where GE³LS=6, Scientists=47*