PERFORMANCE OF PUBLIC-PRIVATE COLLABORATIONS IN ADVANCED TECHNOLOGY RESEARCH NETWORKS:

NETWORK ANALYSES OF GENOME CANADA PROJECTS

by

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ABSTRACT

Globalisation and the quest for competitiveness in a global market represents a new era of connectedness within public-private networks of experts in an effort to pursue research objectives in advanced technology industries. Balancing the competing interests of public good and private gain, reducing the barriers in terms of access to knowledge and intellectual property and ensuring that efforts result in socially valuable outcomes in the form of new innovations can be difficult, to say the least.

Although widely advocated and implemented, collaborations have not, as yet, been fully examined nor have appropriate performance evaluation models been developed to evaluate them. This dissertation hypothesizes that a history of social relationships or collaborative activity amongst network actors is positively correlated with high performance in networks. Incorporating descriptive statistics with the social network analysis tool, this dissertation proposes and tests a novel framework and compares two distinct Genome Canada funded research networks. Other factors explored are the roles of proximity, institution and research focus in characterizing network structure and in affecting performance.

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Note: all currency is denoted in Canadian dollars unless otherwise indicated

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In everyone's life, at some time, the inner fire goes out.
It is then burst into flame by an encounter with another human being.
We should all be thankful for those people who rekindle the inner spirit.
~ Albert Schweitzer ~

GLOSSARY OF ACRONYMS

ABA	Abscisic Acid (plant hormone)
AIDS	Acquired Immune Deficiency Syndrome
CBA	Cost-Benefit Analysis
CCPPP	Canadian Council for Public-Private Partnerships
CDN	Canadian
CFI	Canadian Foundation for Innovation
CIHR	Canadian Institute of Health Research
CRC	Cooperative Research Centre
EC	Environment Canada
ECTG	Enhancing Canola through Genomics
FGAS	Functional Genomics of Abiotic Stress
FPMI	Functional Pathogenomics of Mucosal Immunity
GC	Genome Canada
GE3LS	Genomics: Ethics, Economics, Environment, Law and Society
GoC	Government of Canada
GP	Genome Prairie
GPRA	Government Performance and Results Act
HIV	Human Immunodeficiency Virus
IDRC	International Development Research Centre
IPE	International Political Economy
ISRN	Innovation Systems Research Network
KBV	Knowledge based View
MAF	Management Accountability Framework
MIT	Massachusetts Institute of Technology
MRRS	Management Resources and Results Structure
NCE	Networks of Centre of Excellence
NGT	New Growth Theory
NIC	National Innovative Capacity
NIE	New Institutional Economics

NIH	National Institute of Health
NIS	National Innovation System
NPM	New Public Management
NPV	Net Present Value
NRC	National Research Council
NSERC	Natural Sciences and Engineering Research Council
OECD	Organisation of Economic and Cooperative Development
ORA	Organisational Risk Analyser
PAA	Program Activity Architecture
PBI	Plant Biotechnology Institute
PPP	Public-Private Partnership
PRI	Policy Research Initiative
R&D	Research and Development
RBV	Resource-based View
RIS	Regional Innovation System
RMAF	Results-Based Management and Accountability Framework
SME	Small or Medium Enterprises
SNA	Social Network Analysis
SSHRC	Social Sciences and Humanities Research Council
TBS	Treasury Board Secretariat
TBoC	Treasury Board of Canada
TBoCS	Treasury Board of Canada Secretariat
TCI	The Competitiveness Network
UBI	United Bioinformatica Inc.
UK	United Kingdom
US	United States
USPTO	United States Patent and Trademark Office

DEDICATION PAGE

I dedicate this dissertation, with love and gratitude, to my children:
Tanya and Hayden.

You have and always will be my inspiration; my muses:

Kids: they dance before they learn there is anything that isn't music.
~ William Stafford ~

Chapter 1

INTRODUCTION

Globalisation and the quest for competitiveness in a global knowledge-based economy represents a new era of connectedness as well as new challenges for the research-focused strategic agenda. Emerging with the new economy are unique laws concerning knowledge and knowledge dynamics.

While not always explicitly recognized, these new laws of knowledge drive and govern stakeholder efforts to achieve sustainability and prosperity. Properly managed, such efforts result in commercially, economically and socially desirable innovations. Proper management protocol involves not only efficient and effective access to and creation and dissemination of knowledge, but the willingness to engage in collaborative arrangements (formal and informal) with partners that are often institutionally distinct and geographically dispersed.

The 'fuzzy' territory that lies within the overlap of public and private sectors, cross-national boundaries and inter-organisational projects creates a space wherein traditional economic approaches for evaluating performance and outcomes are no longer effective. According to the World Economy Survey (1996), "[e]conomic theory has a problem with knowledge: it seems to defy the basic economic principle of scarcity…" The only scarcity that appears to exist in the new knowledge-based economy is the ability to understand, use, access and assess knowledge.

The knowledge economy may be a relatively new concept but the complexities associated with evaluating performance in science and technology are not. According to Herbert Shepard[1], a well known pioneer in organisational development, "…no other branch of

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[1] Herbert A. Shepard (1920 – 1985) was born in Hamilton, Ontario, Shepard received his PhD from MIT where he remained as Professor and researcher for several years. Among his many accomplishments, Shepard founded the graduate program in Organization Behaviour at case Western Reserve University (Cleveland, OH) and was the President of the Gestalt Institute of Cleveland. Over the course of his life, Herbert Shepard continued to apply his theories and research in science

industrial activity causes as much managerial unrest and uncertainty as does research and development" due to difficulties in evaluating actual and potential economic contribution (1956: 295). As Shepard refers to it, this "never-never land" of research and development is further complicated by the inapplicability of traditional methods of calculation as tools to assess whether performance is good or bad. Shepard further addresses these challenges in management:

> "It used to be said that the way to do industrial research was to hire good scientists and leave them alone. Certainly no such formula can be taken seriously today. But neither have we arrived at the point where discovery of the secrets of successful research and development management can be claimed." (295-296).

Little has changed since Shepard made this statement fifty years ago. To date, no simple formula exists to test capacity or measure causal performance in research and development. In fact, the complexities associated with increasing specialisation in science and research and the fragmentation of knowledge represents even more uncertainty for stakeholders and benefactors in pursuing research objectives. Shepard's "never-never land" is becoming increasingly more complex.

New institutions, in the form of networks, have developed and are mechanisms purported to mitigate some of these uncertainties and to "handle the transfer, acquisition and use of various forms of knowledge" (Phillips 2005: 8). However, wrapped up within the network complex are the legal, social and economic variables that complicate the knowledge management process. Balancing the competing interests of public good and private gain, reducing the barriers in terms of access to knowledge and intellectual property and ensuring that efforts result in socially valuable outcomes in the form of new innovations can be difficult, to say the least. Although widely advocated, these new and complex relationships or collaborations have not, as yet, been fully examined nor have appropriate performance evaluation models been developed to evaluate them.

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and technology. He was affiliated with many institutions including the U.S Department of Energy's Organization for Scientific and Technical Innovation (OSTI) and the Yale University School of Medicine.

1.0 Background

Formal evaluation policy has been apart of the Canadian government mandate to a greater or lesser degree for the last 30 years. The evaluative process is used to assess program or policy effectiveness. It is also intended to assess delivery efficiency and output as it relates to returns on public investment. According to the Treasury Board Secretariat (TBS), evaluation policy provides "…initiative to make judgments about relevance, progress or success and cost-effectiveness, and/or to inform future programming decisions about design and implementation" (TBS 2001)[2]. Accountability is the primary impetus behind most evaluation mechanisms. For instance, the Organisation for Economic and Cooperative Development (OECD) has recently lead discussions regarding accountability in public-private partnerships for innovation through workshops held in Paris[3].

As Shepard suggests, we can try to impose some 'order in the never, never land', but there are no cut and dry formulas for success – even now. Although there are macro level programs and guidelines developed and implemented that endorse or support the evaluation process, it is not evident how these broader mandates are carried out at the project level. It appears that federally supported projects *are* the end-product or goal. Evaluation measures at the project

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[2] In April 2001, TBS released a newly developed 'evaluation policy'[2] designed to "…ensure that the government has timely, strategically focused, objective and evidence-based information on the performance of its policies, programs, and initiatives to produce better results for Canadians" (TBS 2001). According to TBS, good evaluation is subject to its interdependency with good planning which, combined with feedback from efficacious performance measurement activities should represent a stronger governance model upon which to build and monitor policy and policy implementation. These performance measurement activities, as referred to under the evaluative Management Accountability Framework (MAF) revolve around the regular collection of, what appears to be, rather arbitrary information. However, the program-level Results Based Management Framework (developed after 2001) attempts to integrate the evaluative function of the MAF with results-based management linking such activities with Management Resources and Results Structure (MRRS). The latter is implemented at the organisational level and provides guidance for the integration of programs, resources and management practices with anticipated results[2]. The budget delivered for 2005 promised more rigour in terms of program management with improved information on performance and a clear link between spending and outcomes[2]. As the Comptroller General stated at the Planning Exchange (PPX) Symposium early in 2005 in his keynote address "…evaluation [should be used] more widely to guide expenditure management decisions…" (St. Jean 2005). St-Jean further states that such expenditure management "…has to be focused on results – on value for money" and that such evaluations should be "…complete, fair and balanced" (2005) [2].

[3] The OECD Working Party on Innovation and Technology Policy (TIP), in collaboration with the U.S. National Academy of Sciences, held a workshop in December of 2001 in Paris. The objective of the workshop, among other things, was to identify critical factors for determining the success of PPPs in innovation. In particular, there was a focus on programme design, financial arrangements, and evaluation from both the public and private sector perspectives (OECD 2005).

level are incomplete with the project's potential role as a mechanism for innovation and growth largely ignored.

Innovation is a widely adopted term in the globalised economy and defines many nation-state strategies for growth, including the support for public-private partnerships. The Canadian federal government has made significant efforts to improve its performance relative to the global economy by directing funding efforts towards enhancing research and innovation capacity. The introduction of Canada's Innovation Strategy[4] in February, 2002 signaled the launch of a federal innovation strategy with lofty objectives to push Canada into the position as one of the world's most innovative countries by 2010. The federally funded Genome Canada program and its projects involve an array of public-private partnerships that are expected to contribute to the goal.

Genome Canada was launched in 2000 and established five regional genome centres in Atlantic Canada, Québec, Ontario, the Prairies[5], and British Columbia. Genome Canada, together with its five Centres along and other public and private partners, invests and manages large-scale research projects in key selected areas such as agriculture, environment, fisheries, forestry, health and new technology development. Genome Canada also supports research projects aimed at studying and analysing the ethical, environmental, economic, legal and social issues related to genomics research (GE^{3}LS). Since its launch, Genome Canada has committed more than $560 million in projects. This, combined with funding from other partners, totals $1.2 billion of funding targeted to over 100 innovative research projects and sophisticated science and technology platforms across the country.

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[4] The launch of the Strategy was followed by the release of two companion documents: *Achieving Excellence: Investing in People, Knowledge and Opportunity* and *Knowledge Matters: Skills and Learning for Canadians*. The papers outline the goals, milestones and targets that will improve Canada's innovative capacity.

[5] In 2005, Genome Prairie was split off into Genome Alberta and Genome Prairie. The former maintains its head operations in Calgary while Genome Prairie, representing the interests of both Saskatchewan and Manitoba projects and partners, is now located in Saskatoon.

1.1 Problem Statement

According to Genome Canada, public-private collaborations are and will continue to be a central part of its strategy. Genome Canada projects – and other projects funded by agencies such as the Canadian Foundation for Innovation (CFI)[6], Natural Sciences and Engineering Research Council (NSERC)[7], the Canadian Institute of Health Research (CIHR)[8] and Social Sciences and Human Resources Council (SSHRC) – are often lead by of a number of individuals representing different organisations such as universities, research institutes and private sector companies. Genome Canada has brought together partners from provincial governments, international charities, not-for-profit organisations and private sector companies. Of the $1.2 billion invested to date, 81% comes from the public sector (federal government, provincial governments, universities and hospital foundations) while another 11% is sourced through the private sector and the remaining 8% comes from international sources (Genome Canada 2006).

The primary objective in the first five years of Genome Canada was to "build the assets" or develop the "raw material of new knowledge". Stage II (2005-2009) represents objectives to support and "develop [the] asset for social and economic benefit"; in other words to 'develop the commercial potential' of Genome Canada research projects (Genome Canada 2006). Both mandates represent ambitious yet ambiguous goals which lack a clear strategy as to how and if projects should be awarded and if, in fact, they have the capacity to generate desirable output or outcomes. These collaborative research projects and the institutions that support them

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[6] The CFI, established in 1997, has a budget of $3.65 billion and funds up to 40 percent of a project's infrastructure costs. Funds are invested in partnership with eligible institutions and their funding partners from the public, private, and voluntary sectors who cover the remaining costs of the project. By 2010, it is expected that total capital investment by the CFI, the research institutions, and partners, will exceed $10 billion.

[7] NSERC (May, 1978) has a significant role within the research community as approximately 65% of Canadian university researchers working in the natural sciences and engineering are NSERC-funded. Prior to 1978, University-based research had been supported through the National Research Council. The report of the Senate Special Committee on Science Policy led to Bill C-26, which created NSERC. NSERC has grown since that first day, from a budget of $112 million, to a current annual budget of $771 million.

[8] CIHR was first announced in the 1999 federal budget and replaced the Medical Research Council of Canada. CIHR has developed a series of 13 virtual institutes linking investigators from all areas of health research to address the health needs and priorities of Canadians. Seventy per cent 70% of research funding is investigator-driven (peer-reviewed open competition for university based researchers) while 30% is reserved for strategic initiatives (standard competition cycle, peer reviewed and targeted to address major health challenges).

have the potential to offer substantial benefits in terms of outcomes, however, they can also create the potential for higher implicit and explicit transaction costs if knowledge is not properly managed.

In its early stages of development, Genome Canada experienced problems in establishing structures to organise and support the projects it funded. There were doubts regarding how to manage intellectual property (IP) outcomes let alone how to value incoming in-kind IP. Also, incomplete specifications and challenges associated with managing contracts across numerous firms and organisations with varying institutional support mechanisms and accountability structures caused delays in the transfer of funds to awarded projects. Preliminary research indicates that this led to impediments in achieving project based milestones or objectives (Ryan, Pothier and Phillips 2003). According to Phillips (2005), the Genome Canada model: "...[W]ould appear to be flawed, both on theoretical and on practical grounds". Furthermore "…the Government of Canada and the Genome Centres would do well to consider the economic implications of their activities and to contemplate using a wider range of institutional options to manage the creation and use of genomics-based products and technologies" (22). Consideration for 'economic implications' and the utilisation of a wider range of management options would suggest a more in-depth look at the performance and management capacities of Genome Canada projects as they currently are structured.

Genome Canada supports the public-private collaborative model as a mechanism or structure to govern and carry out activities associated with funded projects. However, even in light of common goals or related skills and competencies in areas of research interest, such partnerships are still comprised of an assimilation of individuals and experts (scientists and researchers) with often diverging objectives, cultures and strategic approaches. A public sector partner has aspirations to increase his or her given knowledge base, to train new technologists or personnel, to tap into needed private sector funds or it even may endeavour to be part of more downstream efforts in terms of product development. Alternatively, the private sector actor is attempting to tap into new sources of knowledge and expertise to improve upon existing products and product lines or in an effort to bring a new and innovative product to the market.

Developing guidelines for evaluating collaborations and performance is not straightforward. Furthermore, it is not clear how to implement such evaluation or performance-based activities at the program or project level. Thrown into this mix are the complexities associated with rapid technological change. Public research institutes and universities often take lead roles in performing research and development activities. However, a rapidly evolving global economy in terms of technological advancement and innovation suggests that ongoing access to relevant and reliable sources of knowledge is required to stay current and remain competitive from a nation-state perspective (Gilpin 2001). Encouraging and supporting private sector investment through public-private partnerships ensures that the knowledge required for such innovation is accessible and utilised and that much-needed financial resources are there to assist in the process. Also, the private sector is able to move knowledge-based products or processes further downstream to markets where the real social value is.

Aside from these complexities, there is little consensus about what might be defined as an appropriate analytical framework (including metrics or measures) or about the design of data collection strategies. Chances are that even if an appropriate methodology is developed, it may not be easily understood by policy makers.

The challenge herein is to identify and test a model for evaluating performance in public-private collaborations taking into consideration the complexities of knowledge and the formal and informal network of actors and experts that comprise such collaborations.

1.2 Hypotheses

This dissertation rests on the following assumption:

> *There is a positive relationship between the history of social exchange and structure of a given network of interest and its performance in terms of knowledge output and knowledge management capacity.*

Building upon this assumption, this dissertation will test the nature of relationship between social capital and performance in public-private collaborations by testing the following conditional hypotheses:

1. A history of collaborative activity or institutional linkages amongst a set of actors of interest may result in self-organisation of said individuals into formalized research networks.
2. Self-organised research networks, as opposed to those that are imposed, may generate higher levels of knowledge creation and exchange over time.
3. How a network is structured – in terms of organisational affiliations, research focus and the level of geographic dispersion of actors – may affect output and network-based knowledge management capacity.

1.3 Scope of the Study

Imposing a 'cookie-cutter' or 'snap shot' methodology or framework for evaluation would be counterintuitive to the dynamic and complex nature of collaborative arrangements. Evaluating performance in networks is subject to the development of a model or framework to capture the full spectrum of historical knowledge accessed, created and exchanged by network actors over time as well as the new knowledge or innovations developed and disseminated by the network or project as a whole. Of equal importance are the capacities of institutional structures (e.g. Genome Canada) that fund such networks. Do they support or constrain innovation?

In attempting to address these challenges, Shepard (1975) offers a suggestion: "Start where the system is". This would suggest that exploring public-private collaborative formats directly at the network level may be a feasible approach. These projects or networks are the direct results of targeted funding as awarded through the Genome Canada peer review process. The fact that these networks or collaborations operate beyond the level of the firm or organisation but below the nation-state and global levels would support this targeted approach. More traditional approaches (for instance, from the firm or nation-state perspective alone) would fall short in their ability to capture the nuances of these complex relationships. Also, the proxies that are often employed (patents or other output measures) do not take into account the dynamics of knowledge flows.

This dissertation addresses these gaps by proposing and testing a method for evaluating performance in genomics based research and development projects. The proposed framework employs the public-private collaborative network as the unit of analysis, evaluating it over time. This unique methodology uses social network analysis as a tool to evaluate ex-ante and ex-post network performance in genomics research. Utilising a case-based approach, two Genome Canada projects are evaluated. The case-based approach to testing the framework allows one to take into consideration a number of complex and differentiated factors particular to each case. The projects in question were selected as they are both centralised in the Saskatoon region. Therefore, the notion or value of proximity in R&D can also be tested. The projects in question were awarded through two different Genome Canada competitions (I and II). They were also granted under two different governance paradigms: one was awarded outright while the other was subject to more government intervention by Genome Canada in terms of network structure.

1.4 Organisation of Dissertation

The dissertation is structured in six further chapters as follows: Chapter two outlines the supporting and related literature for this topic including more traditional theories of economics and institutions, as well as well more contemporary approaches including new institutional economics and proximity theories and new growth theory. Theories of innovation, governance, networks and tools for analysis, new public management as well as theories of the firm are outlined.

Chapter three introduces a three part framework or methodology that is applied in the case-based analysis of the two Genome Canada projects. The framework consists of a three part process that includes pre-award analysis, point-of-award analysis and post-award analysis. The framework employs the social network analysis tool at various points in order to illustrate both static and evolutionary aspects of public-private collaborations or networks. A combination of relational analysis, descriptive statistics, and institution-based analysis – including output measures – is utilised to support case based analysis in order to draw comparisons across both projects.

Chapter four and five outline the analysis of each case study respectively, employing the aforementioned framework. Chapter six draws comparisons between the two networks of interest, normalising case-based results according to network size. Chapter seven outlines the limitations and implications of this research, assesses the generalisability of the proposed framework and makes suggestions for future research.

Evaluating performance in genomics based research projects is complex. As Phillips (2005) suggests "…it is far from clear whether [Genome Canada research] will result…in the transformation of inventions into socially-valued products or services" (29). Technology is rapidly changing. Relevant knowledge is widely distributed. The need for efficacious performance and evaluation has been acknowledged but it is not yet clear what methodologies can be implemented. This dissertation project is an attempt to address some of these complexities and test a potential model for analysing performance in the genomic research context.

Chapter 2

LITERATURE REVIEW

2.0 Introduction

Globalisation and the quest for competitiveness in a global knowledge-based market represents a new era of connectedness as well as new challenges for the research-focused strategic agenda. Additionally, with the new 'knowledge-based' agenda, new laws of knowledge dynamics are emerging that challenge theories, notions and approaches in traditional economics. Technology is rapidly evolving and knowledge and expertise is globally and institutionally dispersed. Accessing resources and knowledge, creating new knowledge and disseminating that knowledge requires collaborative activity (both formal and informal) that often cuts across geographical and institutional boundaries. This draws the investigator into 'fuzzy' territory that lies within the overlap of public and private sectors, cross-national boundaries and inter-organisational projects. Evaluating performance in the collaborative projects or partnerships that operate in and around these grey lines is difficult and, again, traditional analytical approaches appear to be incomplete and ineffective. Contributing to the problem is that the concept of collaboration and collaborative activity are not well understood or developed with incentives and institutions varying from case to case. These new and complex relationships need to be more fully examined from both theoretical and empirical standpoints.

Despite the lack of understanding of such arrangements, one thing is evident. The primary motivation behind collaborative activity in R&D appears to be access to the knowledge and resources required for longer terms goals for innovative products or processes. Knowledge (as measured through intellectual property rights (IPRs)) is fragmented and dispersed, requiring active collaboration or networking in order to access resources and achieve research objectives. According to John Ziman (1994) knowledge creation is "being collectivised" (p. viii) and is dependent upon the "active collaboration of scientists with specialised skills drawn from a number of distinct areas or traditions" (60). Additionally, actual scientist-to-scientist collaboration is increasingly motivated by a natural curiosity to expand the knowledge base in what has been termed an 'internationalisation of science and technology' (Wagner, Yezril and Hassell 2000). Specialisation and complexities of modern science means that it is difficult to work in isolation. At one point, good scientists were hired and left alone. This type of strategy no longer holds true – neither for scientists nor for the firm or institution that employ them.

Needless to say, balancing the interests of collaborative partners (both public and private), increasing access to and managing knowledge and intellectual property all while "work[ing] side by side" (Phillips 2005: 8) represents huge challenges for managing R&D as well as the institutional structures that support such activity.

In the new knowledge-based economy, institutional, geographical as well as conceptual boundaries have blurred in terms of carrying out 'good science'. Understanding, or even practically assessing, knowledge management capacity in this 'fuzzy' collaborative space requires an understanding of a broad collection of both fundamental and contemporary theories as well as approaches that are currently in practice. While this piece-meal collection of approaches spans literatures related to traditional economics, institutions and governance, the often interdisciplinary literature notions of 'innovation', 'knowledge' and 'knowledge management' are of particular interest here. The public-private collaborative reality, so predominant in R&D, challenges the traditional theories and models of economics and social systems that assume the independence of the individual, organisation or firm. Going beyond these more traditional approaches elicits other concepts such as 'networks' and 'social capital', all which reflect attempts to muddle through the growing complexity of innovation in a broader social context.

Again, many of these concepts are 'fuzzy' which represents challenges in terms of assembling and interpreting the literature. However, an even greater challenge – or opportunity, rather – lies in the fact that little has been done to pull all of the related literatures together in a meaningful way. This chapter addresses this gap by drawing together relevant literatures and approaches.

To begin, part one of the literature review attempts to muddle through the fuzzy concepts of knowledge and innovation in order to more easily identify motivations for collaborative activity. Following this, the theoretical stream of governance is explored, including relevant theories of the firm and new public management. Newer theories and concepts associated with new institutional economics, knowledge management, proximity and social capital are also reviewed. Finally, this section concludes with an overview of collaborative models as governing institutions, outlining both typologies and real-world examples of collaborative models.

The next section examines performance first from a theoretical standpoint reviewing the areas of traditional economics and economic analysis along with new growth theories and international political economy. In order to shed some light on contemporary approaches to performance evaluation, some examples of methodologies and analytical frameworks currently in use are outlined as well. The various indicators for assessing performance are also reviewed. This leads to an examination of the role of social capital and the network paradigm in mitigating or enhancing performance.

Finally, social network analysis (SNA) and associated theories, models and approaches are explored to determine how the SNA methodology can used to evaluate performance in R&D networks. This tool is proposed to integrate and explore the complexities of knowledge, knowledge management, social capital and performance in collaborative networks.

2.1 Managing Knowledge for Innovation: the KBE imperative

While not always explicitly recognized, new 'laws of knowledge' drive and govern the foundation of efforts for stakeholders to achieve innovative outcomes and competitive advantage. By bringing together the relevant resources, and by properly managing those resources, this may result in socially and economically desirable outcomes (e.g. innovation). Proper management protocol involves not only efficient and effective access to and creation and dissemination of knowledge, but the willingness to engage in collaborative arrangements (formal and informal) with partners that are often institutionally distinct and geographically dispersed.

As previously stated, the knowledge-based economy brings with it new laws of knowledge dynamics. First and foremost, knowledge multiplies when it is shared. Second, the more knowledge is shared, the more it grows. Finally, innovation value is created or optimized when knowledge moves downstream from the point of origin to the market or end user. Given that knowledge and knowledge resources are fragmented, collaborating for mutual benefit provides a potential pareto improvement solution to institutional and geographical barriers which may impede efforts to share or transfer knowledge where it is most useful. While not always explicitly recognized, these laws drive and govern the foundation of efforts to achieve stakeholder sustainability and prosperity (Woodall 1996).

Managing knowledge to achieve innovative output appears to be a predominant adage in the knowledge-based economy. 'Knowledge' is a key input (or, depending upon how you look at it, output) while 'innovation' has been suggested to be the overall desired outcome or objective. The latter is in keeping with the more traditional approach which views innovation as simply a tangible output or, in some cases, as a linear process moving from technological input through to a commercialized product. This process-based view of innovation has altered significantly in recent years its definition evoking a more complex, iterative and dynamic model. The driver for change has been due to the "new scientific knowledge" that has transformed what was once a simple system into one with multiple loop-backs and the need for explicit knowledge management. The meaning of innovation, today, is multifaceted and requires the right mix of knowledge and efficacious tools to manage this knowledge (Phillips forthcoming).

While the two concepts of 'innovation' and 'knowledge' have been widely adopted within the new economy, the multifaceted nature of both has led to little or no consensus as to how each is defined, perceived and utilized. Section 2.1.1 will review the knowledge concept from its origin to its application in modern day society, including a review of the various definitions of knowledge and an overview of knowledge types. Section 2.1.2 similarly explores the notion of innovation both in terms of the varying definitions and interpretations of the concept and in its application. Bridging the concepts of knowledge and innovation is the notion of 'institutions' and governance. Section 2.1.3 provides an overview of governance and new public management theories as well the theories on institutions. Both newer and more traditional theories about proximity and social capital affect the institution and in particular, knowledge management capacity. These latter two topics are also explored.

2.1.1 Knowledge and Knowledge in Action

So what is this 'new' resource that we call 'knowledge'? Knowledge is one of those rather vague concepts with definitions that vary broadly from context to context.

Historically speaking, knowledge has ancient roots in early civilisation where Aristotle distinguished between universal and theoretical knowledge, instrumental and practice-related knowledge and normative, common sense-based knowledge. A modern turn on Aristotle's knowledge taxonomy divides knowledge into four categories. According to Lundvall and Johnson (1994) they are know-what, know-why, know-who and know-how. Know-what and know-why are forms of codified knowledge related to facts or information and the principles that explain. Know-who and know-how are embedded forms of tacit knowledge, which relate to competence and skills and involve knowing how to obtain desired end-states, knowing what to do in order to obtain them, and knowing when to do it (OECD 2000, 12). Polanyi coined the term tacit knowledge and argues that when one acquires a skill, one attains a corresponding understanding that defies articulation or codification (1966). While codified knowledge is systematic and reproducible, tacit knowledge is considered intangible—residing in the heads of those working on a particular process or embodied in a particular organisational context (Gibbons et al 1994, 24).

Although the aforementioned collection of definitions and typologies are enlightening, they by no means explicitly link knowledge with activities. Knowledge should be limited to definitions that are somewhat ambiguous. Rather, knowledge can be categorized further as fundamentally discrete entities valued differently by different institutions and linked to specific strategies and business models. Malecki (1997) further categorises knowledge in order to identify which strategy a firm or institution might adopt to acquire or develop knowledge needed to innovate. Following in Malecki's footsteps, Ryan and Phillips (2003) adapt the Lundvall and Johnson (1994) typology of knowledge and categorically link those discrete knowledge types with specific knowledge management activities for institutions involved in or that support R&D within a cluster. Know-why is linked to science-based activities conducted in academic or public research institutes while know-what knowledge is affiliated with technology-based activities affiliated with private companies. Know-who and know-how is connected with the membership-based activities of collective organizations such as trade associations. While the latter tacit knowledge is considered to be an open platform of pooled knowledge available to a membership, know-why knowledge is categorized as publicly available knowledge in the form of publications or copyright. Know-what knowledge, on the other hand, is comprised of exclusively protected patents or trade secrets.

These more recent contributions to the knowledge-based literature facilitate the transition of knowledge as 'concept' to knowledge as an identifiable 'asset'. This is important, particularly when exploring knowledge management capacity or performance. Other new theoretical approaches are developing out of this knowledge-based trend in literature. For example, Coenen et al (2005) assert an epistemological distinction in knowledge creation and management between that which is analytic (science-based) from that which is synthetic (engineering based) and apply this to a case study comparing the synthetic knowledge output in the Skanian region with the hypothesized analytic knowledge output in the Saskatoon region. According to the authors, analytical knowledge is theory driven while synthetic is trial driven. These aforementioned definitions or categories of knowledge enrich the growing knowledge literature and provide a fundamental basis upon which to more rigorously examine management capacity.

Knowledge, no matter how it is defined or categorized, is created by humans. It is differentiated and, based upon the Malecki (1997) and Ryan and Phillips (2003) approaches, it would appear that it varies in terms of it transferability. It is also subject in various ways to economies of scale and scope (Sveiby 2001). At the firm level, Grant (2002) suggests that this leads to two types of knowledge based activity: knowledge generation or exploration and knowledge application or exploitation. Similarly, Cooke (2002) builds on these and distinguishes three knowledge related activities: 1) exploration knowledge that is based on fundamental research conducted in laboratories of universities and research institutes (as well as dedicated biotechnology firms); 2) examination knowledge which is 'feedback' knowledge resulting from the testing of new products; and 3) exploitation knowledge which is a blend of diverse knowledge and skills (e.g. scientific, technological, entrepreneurial, financial and legal) facilitating the introduction of innovations to the market. The nature of knowledge-based activities, combined with the complexities of sourcing knowledge represents challenges for the firm. The solution, according to Grant, lies in 'coordination' that "…permits individuals to apply their specialised knowledge to the production of goods and services while preserving the efficiencies of specialisation in knowledge acquisition" (Grant 2002: 136). Coordination, in this context, suggests that firms must identify sources of knowledge and strategically access that knowledge through licensing agreements, mergers, joint ventures or other collaborative arrangements.

In the past, knowledge management has been more broadly associated with 'paper management' or the use and management of data storage in organisations or firms. Knowledge management and the nature of knowledge production have taken on new and decidedly different meanings in the knowledge-based economy. In this context, Nonaka and Takeuchi (1995) examine knowledge transfer and knowledge management at the firm level and describe the knowledge-creation imperative as a dynamic, social and continuous process involving the acquisition, accumulation, creation and exploitation of new knowledge. According to the authors, knowledge management is a dynamic process interconnected with organisational learning.

Another significant contribution to the knowledge management literature is the work of Gibbons et al (1994). The phrase 'modes of knowledge production' is explored by the authors wherein they imply that a new mode of knowledge production (and management) is emerging in the knowledge-based economy. Gibbons et al distinguish between transdisciplinary ('Mode 2') research and development and more traditional ('Mode 1') research. According to Gibbons et al (1994), Mode 2 knowledge does not replace the traditional disciplinary structure of Mode 1 knowledge. Rather, it supplements and interacts with it. Without continued work in Mode 1, Mode 2 would not be able to exist, as the latter depends upon elements developed in the former. Although the authors validate the role of both modes of knowledge production, Mode 2 knowledge production is now gaining prominence over Mode 1. Mode 1 knowledge production holds as the ideal model through which basic research is carried out by universities or research institutes. Here, problems are identified, examined and solved in a context governed by the academic interests and codes of practice of a specific (often isolated) disciplinary community. This activity is curiosity-driven with individual, intrinsically motivated incentives for production. Mode 2 knowledge production, on the other hand, is driven by the search for things that are economically and socially valuable. Mode 2 knowledge production involves a heterogeneous set of practitioners and experts, working 'side by side' on a problem that is defined within a specific industrial and even localised context. Gibbons et al insist that this mode of knowledge production is more than just 'applied research.' Mode 2 knowledge production is shaped by a diverse set of intellectual and social demands giving rise to the creation of genuinely new knowledge, characterised by transdisciplinarity and social accountability.

Ryan and Phillips (2003) acknowledge the crossing of boundaries by highlighting the role of 'hybrid' activities and knowledge 'brokering' on the part of actors. The authors suggest that R&D systems require constant monitoring in order to respond to changes in the global market. Evolution in the market would require the formation of new or dynamic institutions in the pursuit of innovation.

2.1.2 The Drive for Innovation: establishing the context

Almost two decades ago, Drucker (1988) accurately predicted the role of knowledge in enabling sustainable competitive advantage. However, like most assets, knowledge is only valuable if it can be translated into socially and economically valuable goods and services (e.g. innovation).

The term 'innovation' originated in the 15th century and is defined in the Webster's Dictionary as "…to introduce something as or as if new." It is a dominant term and a defining paradigm driving most economic strategies in developed economies (e.g. Canada's Innovation Strategy). Twentieth century interpretations of the term grew predominantly out of Schumpeter's application of innovation to the field of the economy in the 1930s where he refers very broadly to it as the:

> "…[I]ntroduction of a new good…[or]…new method of production…The opening of a new market…[and] the carrying out of the new organisation of any industry…like the creation of a monopoly position (1934[9]: 66)."

The verb 'to innovate' takes a softer approach in Cooke's (2003) definition wherein he refers to innovation as a "social system" and the "…result of social interaction between economic actors" (p. 5). Lundvall sees innovation as 'ubiquitous', consisting of elements and relationships that interact in the production, diffusion, and use of new and economically useful knowledge (1992).

The definition of innovation has evolved over time and is categorised over five 'waves' by He Chuanqi (2005) spanning Schumpeter's early interpretation (outlined above) to a 21st century (fifth wave) focus on 'knowledge innovation'. Earlier 'waves' have been predominantly associated with new product development or enhancements to in-house manufacturing in order to increase margins. This includes second and third wave approaches to industrial innovation (e.g. Freeman 1982) and technological innovation (e.g. Abernathy and Utterback 1978; Kline and Rosenberg 1986). These latter terms are more economic-based conceptions of innovation and refer largely to the process of introducing new products or services to the marketplace or the adoption of new ways of making products or providing services (GoC 2005)[10]. Innovation systems, or the fourth wave of innovation, introduced the concepts of national and regional innovation systems (NIS and RIS respectively) in the 1990s. This 'wave' brought in concepts of the 'network' as a vehicle to organise technological innovation (Freeman 1987), the introduction of learning theories (Lundvall 1992) as well as comparisons

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[9] This Harvard edition of *The Theory of Economic Development* is a translation of the second German edition, published in 1926. Schumpeter rewrote the crucial second chapter of the 1912 German edition for that 1926 second edition.

[10] This definition is expanded further to include "… technical advances in how products are made or shifts in attitudes about how products and services are developed, sold and marketed" (GoC 2005).

of systems (Nelson 1993). Analogous to this, the Organisation for Economic and Cooperative Development (OECD) (2002) defines innovative activity[11] as:

> "…all of the scientific, technological, organisational, financial and commercial steps, including investments in new knowledge, which actually, or are intended to, lead to the implementation of technologically new or improved products and processes (18)."

The diversity of interpretations of the term and the nebulous nature of the innovation process itself has resulted in a certain amount of ambiguity both in its meaning and in its application in a policy context. The aforementioned definitions have a decidedly firm or profit based agenda driving them in terms of process, results and competitive positioning. However, the not-for-profit, social and public sectors are also consumers of resources and producers of output and these sectors are similarly being transformed by technology in the knowledge-based economy. A strictly economic slant of 'innovation' and innovative output lacks relevance within a strictly 'public good' context. More 'blended' approaches to innovation have evolved to include the interests and perspectives of a variety of institutional structures to accommodate change and diversity in a number of contexts. For example, the National Research Council of Canada (NRC) advocates for innovation within the region by supporting the establishment of technology clusters around NRC hubs (NRC 2002 & 2005). A primary objective to ensure this regional growth is to support small and medium enterprises (SMEs) in the commercialisation of knowledge (NRC 2005).

On this note, the past decade and a half has seen the rise of innovation in a systems context. A National Innovation System (NIS) has been defined as follows: 1) It is the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies. (Freeman, 1987); 2) It is the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge ... and are either located within or rooted inside the borders of a nation state. (Lundvall, 1992); 3) It is a set of institutions whose interactions determine the innovative performance ... of national firms. (Nelson, 1993); 4) It consists of national

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[11] This definition of innovation was outlined in the OECD's report on proposed standard practice for surveys on research and development (R&D) in The Frascati Manual (2002).

institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country (Patel and Pavitt, 1994) and; 5) It is that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies (Metcalfe, 1995).

According to innovation system theory, innovation and technological development results from a complex set of relationships among actors within the nation-state system. As stated by the OECD, these 'systematic approaches' give new insight into innovative and economic performance in developed countries (1997).

Distilling this concept down further, regional innovation systems (RIS) appear in the early 1990s (Cooke 1992, 1998, 2001) growing out of Lundvall's original concept of the 'innovation system' and its application to the Japanese economy in the late 1980s by Freeman (1987). Although the NIS approach highlights the importance of learning and nation-based institutions in explaining innovative performance, the *region* has been identified as the catalyst for innovative change. According to Coenen et al (2004), the region provides an important basis "for economic coordination and governance" between nation-state and local systems (2)[12] where, according to Phillips, innovation is considered "the driver for [regional] growth and development" (2002: 31).

Related to this, innovation clusters – more localised forms of the RIS – were popularised by Porter in 1990 who takes an industrial or managerial approach to innovation. He defines the cluster as the geographic concentration of competing and co-operating actors, including service providers, firms, government organisations and other institutions (Porter 1990).

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[12] According to Lundvall and Borras (1997), the region is the level at which innovation is produced through networks and cross-fertilizing activities.

This cluster-based lens to viewing innovation suggests that geographical proximity offers advantages in terms of competitiveness and access to localised and specialised labour.

The cluster phenomenon has been explored by a number of research-based and practitioner-supported entities from Canada's major collaborative research initiative on innovation systems to the Competitiveness Institute's (TCI) global network of 200+ economic developers and practitioners. The Innovation Systems Research Network is a five-year (2001-2005), $2.5 million study that examines the impact and importance of cluster-driven innovation in Canada. It investigates how local networks of firms and supporting infrastructure of institutions, businesses and people in communities across Canada interact to spark regional economic growth. The Competitiveness Institute's mission is to improve living standards and local competitiveness of regions across the world by enhancing cluster-based development initiatives—it has a Clusters Initiative Database, which consists of 81 identified clusters.

This collection of definitions and applications of the term innovation, in its entirety, suggests that the scope of the term is context-dependent and highly subjective. One thing that all definitions agree on is the importance of the role of knowledge in innovation and that the access to, creation, exchange and management of such knowledge is an inherently social process; one in which "place, people and … networks [of different actors] are essential" (Maxwell 2003).

Even in light of this seemingly universal pursuit for 'innovation', it is not evident that there are appropriate models for governing the process(es) that incorporate all of the necessary factors to maximise access and benefits sharing in the collaborative context.

The following section explores the notion of governing innovation. The term governance is examined along with the theories of institutions, new institutional economics and new growth theory. The theories of new public management and the firm are also explored as well as theories around proximity and social capital. Additionally, some practicable examples of collaborative models are reviewed in order to provide insight into current approaches to bring together public and private sector actors in R&D.

2.2 Governance and the Institution

Ensuring innovative performance requires the use of effective governance strategies employing structures and processes that lead to innovative output. Like innovation, the term governance can be vague. It is "…used in a variety of ways and has a variety of meanings" (Stoker 1998: 17). For example, the Institute on Governance suggests that it exists anytime a group of people come together to accomplish an end (2006). Consequently, the IOG outlines an even broader definition: 'the art of steering societies and organizations' (IOG 2006). Yet another interpretation of the term is "the use of institutions, structures of authority and even collaboration to allocate resources and coordinate or control activity in society or the economy" (Wikipedia 2006).

Regardless of how the concept is interpreted, scholars do agree that the term is most widely used in contexts where boundaries between public and private sectors have blurred (Stoker 1998: 17). Thus, exploring this concept and its affiliated theories is relevant to the context of knowledge management in R&D.

On this note, Stoker (1998: 18) outlines 'propositions' or theories of governance. According to Stoker, governance refers to collective action amongst networks of actors (government and non-government) that tackle complex social and economic issues. Stoker's views echo Gibbons et al (1994) view of Mode 2 knowledge production by a heterogeneous set of practitioners and experts working side by side. No single actor has the capacity (resources and otherwise) to undertake problems independently and this leads to the 'collaborative governance relationship'.

Governing collaborative-based institutions requires the consideration of a number of elements which will be reviewed in the following sub-sections. First, as covered in the first section, knowledge is an important resource for growth and wealth creation. Second, from an economic geography standpoint, proximity appears to play an important role in facilitating exchanges of particular sources of knowledge. Third, knowledge creation and exchange is a 0function of the social interactions between knowledge-agents or experts. Thus, the theory around social capital is also reviewed.

2.2.1 Institutions and Institutional Management

Collaborative arrangements in R&D are often comprised of both public (academic, research institutes) and private actors. How a collaborative arrangement performs or is structured is a function of the institutions or institutional mechanisms that support and govern it. Theories of new institutional economics, new public management along with theories of the firm provide the basis for exploring institution in a collaboration of public and private actors.

To begin with, one foundational theory under review here that complements the notions of 'knowledge', 'governance' and 'innovation' is the theory of institutional economics.

New institutional economics (NIE) grew out of Ronald Coase's fundamental insights about the critical role of institutional frameworks and transaction costs for economic performance (Coase 1937). Since then, other proponents of NIE (such as Williamson 1981 and North 1994) have criticised the traditional approaches to economics (outlined in more depth in Section 2.3) for their focus on the mathematical paradigm and the lack of consideration for more normative aspects of economic growth and change. New institutional economics represents a departure from traditional economics. It resists the positivist approach and embraces (economic) theories of non-market social relationships. NIE incorporates a complex set of methodological principals and criteria which address both efficiency (like traditional economics) and distribution (unlike traditional economics) issues. In the context of nation-state competitiveness in a rapidly changing global market, NIE represents a viable alternative to more traditional approaches in governing innovation and knowledge.

According to Smith and Katz (2000), institutions are integral in understanding the broader social organisation of research and the relationship between science, technology and society. Smith and Katz further qualify the role of the institution in that its size and geographical location can shape its collaborative profile or structure. North (1994) defines institution as any socially imposed constraint upon human behaviour. Similarly, Edquist and Johnson define it as "[a] set of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals and groups" (1997: 46). Although NIE often represents a decentralisation of nation-state power to provincial, state or municipal levels, it also elaborates on the role of the private sector in "…suppl[ying] collective services to citizens through various tools…such as contracts, quasi markets and franchises" (Osborne and Gaebler (1992) (as cited in Milward and Proven (2000: 239-240)).

Public private partnerships or collaborations are not new but are increasingly being used as a tool of government to achieve economic and social goals (Kettl (1993); Nagel (1992); Salamon and Elliot (eds) (2002)). Given the explicit role of both sectors, two other theories relevant in exploring collaborative models are new public management (NPM) and theories of the firm.

New public management theory grew out of traditional public administration, the latter of which constitutes an interdisciplinary blend of the theories of political science and public policy. Traditional public administration examines administrative practices and the implications of changes in government. However, evolving global markets and rapid technological changes launched institutional reform movements in the public sector. It is these new movements that are associated with new public management (NPM), or as Kaboolian refers to it, "new wine in old bottles" (1998: 189)[13].

NPM represents the institution of new governance models providing for separation of policy making and service delivery and by allowing for engagement between public administration and management. Primary objectives for the public sector actor are to "…maximise productivity and allocative efficiencies" by mitigating the constraints of bureaucracy (Kaboolian 1998: 190). Institutional reform movements associated with NPM advocate the use of administrative tools such as market incentives, deregulation as well as performance-

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[13] In its report *Achieving Excellence*, the Canadian government lays out innovation policy as it relates to academic research with a particular focus on universities and commercialisation. The policy indicates that public institutions would be expected to "manage" the public investment in research as a "national asset" through the implementation of targeted strategies for commercialisation. Partnerships, in particular, are viewed as vehicles to achieving commercialisable results. This commercialisation framework was developed in partnership with the Association of Universities and Colleges of Canada (AUCC). In it, commitments have been made to double the amount of research conducted in Universities and to triple commercialisation performance. This includes participation in a Statistics Canada biannual survey of university commercialisation that leads to a public report that demonstrates collective progress. Outcomes are measured, in this case, through accounting of IP-related revenues and expenditures, spin-off companies, disclosures, patent applications, patents awarded, new licenses, and revenues from IP. The approach has been criticized as downplaying the role of graduate students and training and other forms of industry-university collaborations such as consulting, consortia and contracts. (Langford et al 2005).

based contracting, borrowing from private sector business models or strategies to achieve such reforms. As such, the NPM movement advocates the view of government as 'steerer, not rower' in terms of its activities in the economy (a primary notion endorsed by the Organisation of Economic and Cooperative Development (OECD) (1995a 1995b)). According to this view, the state becomes merely one form of societal governance in that it encourages mechanisms such as 'contracting out' and the development of other forms of governance such as inter-group, public-private partnerships or networks (Steane and Carroll 2000).

The role of the private sector in such partnerships suggests that theories of the firm must also inform the analytical process. Under Romer's new growth theory (NGT) paradigm, any firm-based strategy for growth must endorse the role of private and public interaction all along the value chain continuum in order to access the needed knowledge for innovation (1998). According to Smith and Katz (2000), the main driver for firm involvement in public-private collaborations is "access to external resources" (5)[14]. The resource-based view (RBV) of the firm (a term coined in 1984 by Birger Wernerfelt) holds that firms can enhance and sustain returns if they have access to superior, well-protected resources. Contributions to the RBV approach began early with Penrose's argument that "…a firm is…a collection of productive resources…" the productivity of which is a function of the "administrative decision" that goes along with managing such resources which suggests that strategic management also plays an implicit role. Barney (1991) suggests that there are firm-level differences in strategic approaches to managing resources which can lead to competitive, sustained advantage in the market.

Taking this a step further, firm-based competitive advantage can no longer depend solely upon one resource. 'Resource', in traditional economics, is referred to as land, labour and capital. But with the advent of globalisaton and the new knowledge-based economy, the term

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[14] Access to external resources also includes strategic activities in terms of mergers and acquisitions. The agricultural biotechnology industry has restructured significantly over the past decade and a half. By the end of the third quarter of 1998, Monsanto alone had been involved in 18 acquisitions and had completed acquisitions overseas worth a total of $7.3 billion over a period of two years. Novartis, on the other hand, was formed with the merging of Sandoz and Ciba-Geigy. DuPont entered the market through joint ventures (~ 20) valued at over $5 billion (Lesser 1998).

has been adapted to include the resource 'knowledge'. Firms must therefore consider the complexities associated with specialised knowledge in that some resources (or knowledge) are dependent upon interactions or combinations with other resources (or knowledge). By introducing this concept of knowledge, more traditional RBV theories of the firm appear to have less explanatory power in the globalised, knowledge based economy. These limitations have lead to the rise of the knowledge based view (KBV) of the firm.

According to new growth theory, knowledge (access to and creation of) is the key driver to wealth creation and is considered an endogenous factor for growth. The knowledge-based view of the firm is about "…a set of ideas about the existence and nature of the firm" and, unlike more traditional approaches, emphasises the role of knowledge (Grant 2002: 135). From a firm-based perspective, Nonaka and Takeuchi (1995) propose an abstract definition in their book *The Knowledge Creating Company* and suggest that knowledge is a 'justified true belief'. Alternatively, Sveiby's (2001) take on the KBV of the firm sees knowledge as a 'capacity to act' and a resource that needs to be cultivated through action.

Together, theories of the firm and new public management along with foundational theories of the institution and new institutional economics enhance understanding of the structure for public-private collaborations. These theories illuminate the incentives for public and private sector participation in partnerships that access knowledge, funding and expertise. These collaborations have the capacity to bring together strengths from both the public and private sector. Properly governed, they can optimise efficiencies and innovation in private enterprise and can offer the public sector much needed capital to finance programs and projects. The public-private partnership or collaborative model is particularly important in research and development and in 'new-to-the-world' scientific and technological programs where knowledge is widely distributed – both nationally and internationally – and tapping into such knowledge can be extremely costly in terms of time and money.

As previously outlined, innovation has been identified as a social process, one in which "place, people and … networks [of different actors] are essential" (Maxwell 2003) in the creation and exchange of knowledge. Public-private partnerships are institutions that are structured to reduce transaction costs and to enhance the innovation process. Under this governance paradigm, knowledge and people are key resources. This would suggest that proximity among such resources could speed up the innovation process and facilitate growth and wealth creation. The following section explores the notion of proximity and its role in governing knowledge creation and exchange.

2.2.2 The Role of Proximity in Governing Innovation

As previously mentioned, the fourth wave of innovation (Chuanqi 2005) has seen the rise of the region and regional governance of innovation. Proximity has been identified as having a significant role in innovation and building competencies in theories of regional innovation and regional studies (Glaeser et al (1992); Anselin et al (1997); Glaeser (1999); Glaeser (2000)). Glaeser (1999 and 2000). This work particularly focuses on aspects of human-capital spill-overs, peer-group effects, social capital and altruism as they relate to spatial proximity.

The Italians have long since had an interest in the 'industrial district' as an engine of growth for the country. The 'Third Italy' arose in the late 1970s where groups of firms clustered together in specific areas to address the deep economic crisis of the time (Bagnasco 1977). Specialty areas in textiles, leather and ceramic tiles grew and prospered wherein firms were able to develop niche export markets and offer new employment strategies while being in close proximity to one another. Italy has become a hot-bed for social science research in efforts to understand models, theory and practice (Curzio and Fortis 2002). The positive effects of geographical proximity on innovation in Italy and in other regions throughout the world has been empirically tested through the work of researchers such as Henderson (1993), Feldman (1994), Anselin et al (1997), Audretsch (1998) and Baptista (2000, 2001).

Globalisation and, in particular, the mobility of knowledge has created alternative assumptions with respect to the value and role of geographical proximity. According to Morgan (2004), geography is more than physical space; rather it is socially constructed, relational space. Adjusting for this more 'virtual' space and its role in innovation, Boschma (2005) further suggests that proximity cannot be assessed in isolation. To support this, he outlines a typology of proximity dimensions ranging from geographical to cognitive, including organisational, social and institutional components. Boschma (2005) suggests that geographical proximity is neither a necessary nor a sufficient condition for learning and innovation. Rather, proximity facilitates interactive learning and enhances other dimensions of proximity such as social or organizational aspects. Boschma effectively challenges the overriding assumption that close proximity will result in higher learning and enhanced innovation capacity. He further suggests that there is an optimal balance between the extremes of too much or too little proximity.

Along the same lines, and in the R&D context, Smith and Katz (2000) suggest that proximity plays a secondary or tertiary role in innovation. According to Smith and Katz (2000: 29), "…scientists are more concerned with seeking out the most appropriate expert partners" no matter where they may be located. In the research arena, resources – human and otherwise – are likely to be more widely distributed. Therefore, governing public-private collaborations in advanced technology sectors requires input from experts across domestic and national boundaries in order to tap into relevant sources of knowledge. Thus, according to Asheim et al (2003: 53), limiting partnership models and their analyses in a strictly regional context would "…run the risk of constructing a wall around the region" and, thus, would neglect "important extra-regional linkages" amongst principals, secondary partners and trans-boundary collective activity. In the same vein as Boschma (2005), Uzzi (1997) suggests that there is an optimal balance of embedded and market relationships suggesting, from a regional sense, that both learning and trust-building are a function of flexibility (open-mindedness) and local relationships (transaction cost reducing) for cluster (or network) actors. In other words, regionally-based firms or actors acknowledge their interdependency and recognize that they must work together in order to address challenges or problems.

In emerging sciences or technologies, there is power in optimal proximity. Phillips (2005) suggests that location-based models (eg. clusters) offer great potential to lever the latent social capital in the Canadian research and commercial system and generate a "…wider range of institutional options to manage the creation and use of [knowledge] (29). Likewise, Coenen et al's (forthcoming) slant on knowledge bases and locational patterns can be interpreted to suggest that – as in the case of Saskatoon region – networks associated with Genome Canada projects are tapping into knowledge that spans a continuum between that which is synthetic (and based upon 'practice' knowledge or know-how) and that which is analytic (and based upon 'science' knowledge or know-what) constituting both global and local linkages. This is further validated through Phillips' (2002) entrepôt model which he applies to the Saskatoon canola research cluster, suggesting that proprietary knowledge is imported and combined with locally sourced germplasm and is then exported as raw or intermediate product to non-local markets.

These more fluid interpretations of the role of proximity in innovation suggest that knowledge access from a geographic perspective may be project-dependent. This challenges the dominant assumptions regarding the value of a strictly regional focus on innovation and suggests supra-regional networks may – from a bricks and mortar perspective – be anchored in a region but span geographical boundaries in terms of membership to tap into other required knowledge bases (eg. through 'communities of practice'). According to the 'new laws', knowledge production is a function of how much it is shared and knowledge use is a function of moving ideas into markets. Geographical boundaries no longer represent a barrier, in terms of knowledge and people mobility or in terms of access to markets. Based on this, effective management of knowledge requires a more dynamic view of the role of cross-boundary networks. Proximity matters. However, it is not yet clear what the optimal balance would be between local and non-local geographic linkages in a collaborative sense.

2.2.3 The Role of Social Capital in Mediating Knowledge Creation and Exchange

Examining proximity involves considering a number of important factors, such as access to expert partners, the notion of 'relational space' and, of course, social factors. Social capital has been identified as a driving factor for innovation and the impetus for knowledge development and exchange. According to Burt, many of the activities that take place at a regional level – such as partnerships – are forms of social capital (2000). Jane Jacobs (1965) defines social capital as networks of strong personal relationships that are developed over time and provide the basis for trust, cooperation and collective action. Similarly, social capital has been defined as social organisation, norms and trust that facilitate cooperation and coordination efforts for mutual benefit (Putnam 1993).

Fountain (1997) views social capital as a key enabler for innovation. One could suggest that social capital is a metaphor for advantage and is a powerful resource for productive social ties which underlie cooperative economic activity. Fukuyama (1995) sees social capital as "critical to prosperity and competitiveness" (355). Social capital, he suggests, emerges in the form of dense networks and is characterised by reciprocity amongst network agents or actors. Coleman (1998) takes this further:

> "Social capital is defined by its function. It is not a single entity but a variety of different entities having two characteristics in common: They all consist of some social structure and they facilitate certain actions of actors" (98).

Building upon this notion, Phillips (2007) grounds social capital in a technological-based context and characterises its scope within that context. In his forthcoming book *Governing transformative technological innovation: who's in charge?*, Phillips states that the notion of social capital is connected with "communities" that "span international boundaries" and share a set of "…normative and principled beliefs, shared causal beliefs, shared notions of weighing and validating knowledge…a shared technical vocabulary and a common set of practices associated with a specific set of boundaries" (online source: p.7, Ch. 8).

According to Putnam (1993) and Fukuyama (1995), an important factor underlying the development of this social capital is 'trust'. Trust enables economic actors to cooperate in circumstances where there may not otherwise be an incentive to do so. This is particularly relevant when geographical and institutional boundaries may impede cooperation. Similarly, Gibbons et al (1994) points to 'pluralisation' or multidisciplinary organisational formats (eg. networks) as creating new patterns of communication, cooperation and knowledge dissemination. As far back as the 1950s, the exchange of technical information or knowledge was viewed as a "social act" with an emphasis on "interpersonal relations" to mobilise knowledge (Shepard 1954). Gibbons et al (1994) echo this suggesting that access to knowledge is now more a function of networking than it is of institutional association (Gibbons et al 1994).

Despite this latter claim (Gibbons et al (1994)), social capital is still subject to and affected by the (formal and informal) institutions that precede, constrain or support collaborative or network-based activity. There are numerous types of networks or collaborative models currently employed in a number of contexts. In the following section, the collaborative concept is more fully outlined and examples of formalised collaborative models are reviewed.

2.2.4 Collaborative Models: Formal Governance Institutions

The capacity to access new knowledge has effectively blurred disciplinary, sectoral and geographic boundaries. Productivity has become contingent upon capacity-building across markets, governments, and communities. Innovation has effectively fallen into a category of collective-based activities wherein a number of actors operate on an iterative value chain in order to create new value in terms of knowledge for public good as well as for private profit.

This trend is characterised through the 'Chain Link Model of Innovation' proposed by Kline and Rosenberg (1986). The model builds upon the traditional linear model of product development from research to market. Kline and Rosenberg argue that the accumulation of knowledge necessary for innovation comes from complex and dynamic interactions amongst a number of actors. This model of knowledge creation and dissemination further emphasises the role of dynamic institutional models, such as public-private collaborations, to facilitate knowledge creation and exchange and to govern the innovative process.

There are numerous terms that represent the 'collaboration'. These span a continuum of institutional arrangements bounded formally and informally through a number of tools such as grants, contracts, memorandums of understanding and even handshakes or verbal agreements. Terms such as partnership, network or alliances are often used interchangeably in the literature. For example, the term 'collaboration' is often informally used in conjunction with the terms 'cooperation' or 'coordination'. As in the case of the 'innovation' term, this had lead to some conceptual ambiguity. According to Bruner, Kunesh and Knuth (1992), the development of clear definitions and operational languages are critical to research on collaborative arrangements.

Smith and Katz (2000) identify three specific models for collaboration: corporate partnerships, team collaborations and interpersonal collaborations. Sonnenwald (1999), on the other hand, proposes a collaboration-based typology that spans a continuum between 'complementary' and 'integrative' models of association of network agents or partners. A more specific term, the public-private partnership (PPP), is a formalised institutional or collaborative format that has been widely adopted in a number of nations. In Canada, the PPP model is specifically applied and intended to facilitate joint provision of infrastructure services. Industry Canada (2003) adopts the Canadian Council for Public-Private Partnership's (CCPPP) definition of PPPs as:

> "...[C]o-operative venture[s] for the provision of infrastructure or services…that best meets clearly defined public needs, through …appropriate allocation of resources, risks, and rewards."[15]

Going back into the literature, Gulati and Gargiulo (1999) define PPPs as "voluntary arrangements between organisations from different sectors, anchored by agreements, to promote the exchange, sharing, or co-development of products or programs". More broadly speaking, PPPs have been referred to as examples of the triple helix model – government, university and industry partnerships – wherein networked actors can collectively address issues and challenges associated with new technologies and globalisation (Leydesdorff and Etzkowitz 1997; 2003). In other contexts, these arrangements are also referred to as 'P3 privatisation models' and have been adopted by several countries throughout the world such as Norway, the U.K., and Australia[16]. Like Canada, Australia's PPP model is mostly applied to

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[15] The CCPPP outlines its compendium of 'meso-level' collaborative arrangements in highways, transportation and hospitals and health care facilities in its recent report entitled *100 Projects: Selected Public-Private Partnerships across Canada* (2005). According to the report, PPPs are posited as successful vehicles in the delivery of public services. To date, the PPP model has been applied in over 25 distinct sectors and at all levels of government in Canada moving beyond a nation-state application to the provincial and municipal based levels (CCPPP 2005).

[16] Similar triple-helix or P3-type models have been realised in other 'equity-coordinated' forms such as in the *keiretsu* system which has been a driving force behind Japan's industrial success or the *chaebols* of South Korea. These latter examples represent primarily 'macro' applications of a P3 model. What distinguishes lead countries such as the U.K. and Australia is that public-private collaborative activity in these countries is conducted through a comprehensive, overarching government program. For example, the U.K.'s Public Finance Initiative (PFI) in 1992 represented a break point in private sector involvement in public infrastructure. The PFI policy encouraged public sector authorities to consider contracting with the private sector for major capital assets and the services they provide as a combined package. There are currently over 400 PFI contracts in force with a value of over £100 billion. A further 300 projects worth about £16 billion are in the pipeline. This includes 26 hospitals and renewing and refurbishing 450 schools. The London Underground is also the subject of a major PPP.

infrastructure development. However, the federal government has endorsed the PPP model for its potential role in enhancing R&D in Australia, establishing of a number of programmes over the past decade or so including the Cooperative Research Centre (CRC) programme, Australia Research Council Linkage Grants and the Innovation Investment Fund (OECD 2004). Similarly, Canada has adopted the public-private collaborative model for research and development activity. For instance, the government established the Networks of Centres of Excellence (NCE) in 1987 to enhance partnerships between university and industry researchers. The NCE program, a collection of "…institutes without walls…", is supported and directed by the Canadian Institutes of Health Research (CIHR), the Natural Sciences and Engineering Research Council of Canada (NSERC), the Social Science and Humanities Research Council of Canada (SSHRC) and Industry Canada (NCE 2005). An integral part of Canada's Innovation Strategy, NCEs are "…aimed at turning Canadian research and entrepreneurial talent into economic and social benefit…" (NCE 2005)[17]. Genome Canada funded projects are examples of collaborative models which focus on bringing people together (from different sectors) to solve specific research problems. This type of institutional format differs greatly from corporate partnerships or joint ventures which, according to Smith and Katz (2000), focus almost solely on profit-based objectives.

Finally, another term often used interchangeably with collaboration, and referred to throughout this dissertation, is 'network'. Phillips (2005) defines the network as a differentiated set of actors – individuals or organisations – that represent both the public and private sectors. The 'network' has been largely adopted as a vehicle for managing knowledge. As with other collaborative models, R&D networks consist of actors or institutions that, more often than not, have competing interests or business models. The nebulous nature of networks leads to legal, managerial, social and economic challenges that affect how they operate or function and, thus, how knowledge can be properly managed.

Evidently, like innovation or governance, collaborative models or networks can vary in their interpretation and, most certainly, in terms of their application. Broadly referring to these

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[17] Currently, there are 21 networks funded through this program.

concepts aids little in understanding them, let alone revealing ways in which to govern such arrangements. Nevertheless, it is evident that collaborative models are widely adopted, growing out of the need for the private sector to tap into new sources of upstream knowledge and for the public sector's need to contribute to downstream commercialisation. Such collaborations may offer the institutional setting to combine knowledge and resources, to mitigate costs and to spread risk.

Despite the widespread adoption of these collaborative institutions in managing innovation, little has been done to explore how performance (or output) of such arrangements can evaluated. The following section reviews and compares several evaluation approaches currently used and also reviews the academic literature around such models.

2.3 Evaluating Performance: Limitations and Opportunities

Government, in large part, has leaned towards an 'input' based approach to management, measurement and evaluation focused upon control and use of government spending. The private sector, on the other hand, focuses on downstream outcomes and returns on investment in terms of realized outputs of a given investment. Bringing these two sectors together in a collaborative arrangement presents problems with respect to evaluating performance. It is not clear that there are appropriate evaluation models in place to monitor such projects. Issues concerning accountability need to be addressed. Based on these diverging management strategies and associated externalities, partnerships may not always operate optimally nor may they achieve desirable planned outcomes. How do these public-private collaborations balance the goals for innovation while monitoring performance and output in a fiscally responsible manner?

Understanding and employing performance measures requires an understanding of the various approaches that have been applied and the theories that underlie such approaches. Theories around economics and international political economy are fundamental while modern theories on knowledge, governance, networks and innovation (as previously outlined) add critical insights.

2.3.1 The Theoretical Backdrop for Measuring Performance

Traditional economic theory operates under a variety of prevailing assumptions. It assumes a dominant role for either the firm or the nation state. It assumes partial or full market equilibrium, emphasises price relationships and assumes that individual actors in the economy are rational optimisers operating under perfect information. Measures are limited to input and output in terms of productivity. Even the more modern economic approaches, such as Lucas' application of rational expectations hypothesis and his interpretations of policy evaluations (1972; 1976) wherein productivity rather than transaction costs is emphasised, are characterised by perfect competition, homogenous products and constant returns to scale.

Rapid changes in the world economy have challenged the traditional economic school of thought. Real world limitations of traditional economic approaches led to the development of new iterations that attempt to better explain or model economic and social patterns in the knowledge-based economy (for example, international political economy and new growth theory).

According to Strange (1988) and Gilpin (2001), the rise of the international political economy has radically changed the way in which the world communicates and trades and has subsequently softened the borders that once distinguished nations and communities from one another. Not only has this undermined the dominate role of the nation-state in analysis, but this economic change, marked by increasing returns to scale, which cannot be explained fully by traditional factors of production (land, labour and capital has led to new market structures and outcomes.

Also known as endogenous growth theory, NGT grew out of the more traditional Solow (1956) and Swan (1956) standard growth theory[18] and has laid out a number of important principles regarding the growth process. While the neoclassical model assumes a change in productivity from exogenous factors, new theories introduce the notion of endogenous technology change and its impact on growth. The foundation for the development of NGT

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[18] Output is deemed a function of the basic inputs of capital and labour.

stems from advances in knowledge and technological innovation which, as previously mentioned, lead to increasing returns to scale. Again, while the neoclassical economic model builds traditional factors of production and assumes technology or knowledge as exogenous factors, NGT assimilates knowledge and technological progress as endogenous factors. According to this school of thought, the absorption of knowledge can increase the productivity of both labour and capital.

Despite a blend of traditional and more contemporary economic theories, there are still limits to the ability for any one given theory (or even a blend of theories) to explain let alone quantitatively evaluate networks, innovation and public-private collaborations in specific contexts. For example, in most cases, theories have either a definitive nation-state or firm focus, to the neglect of the regional level or the local-global complexity as referred to above. Again, methodologies generally emphasise land, labour and capital as primary factors of production and do not account for knowledge in all its forms and uses. Additionally, most traditional economic approaches fail to account for measures for and the influence of social capital and the role of knowledge in enhancing innovative capabilities. Finally, most measures tend to be static – merely slices in time – with little or no consideration for the evolutionary nature of regional economies or for technological or institutional change. As Kline and Rosenberg (1986) suggest:

> "It would be a serious mistake to treat…innovation as…a well-defined, homogenous thing…entering the economy at a precise date – or becoming available at a precise point in time…[M]ost important innovations go through drastic change in their lifetimes…[which]…totally transform their economic [and social] significance…[S]ubsequent improvements…may be vastly more important…than the invention in its original form" (p. 283).

There have been attempts to measure innovation and/or performance utilising a blend of factors. The following sections outline a number of analytical approaches, including broader approaches at the nation-state level down to more definitive program-based strategies as well as discrete indicators used to measure performance.

2.3.2 Contrasting and Comparing Approaches to Performance Evaluation

The literature outlines several approaches used to evaluate performance. A broad based example is put forth by Stern, Porter, and Furman (2000). The *Determinants of National Innovative Capacity* is an empirical examination of the determinants of country-level research and development capacity and productivity taken across a sample of 17 OECD countries[19]. The study introduces the novel concept of 'National Innovative Capacity' (NIC) that integrates previous perspectives on sources of R&D productivity differences across countries and supports Romer's theory of ideas-driven growth (1996) and supporting theories of national competitive advantage based on clusters and innovation systems[20]. According to Stern, Porter and Furman, common innovation infrastructure, the innovation environment of its industrial clusters and the strength of the linkages between the two are the factors that drive a nation's innovative capacity. Upon deeper examination of the underlying theories, concepts and observable measures associated with NIC, it is evident that the measure is impacted by: R&D manpower and spending; national policies; the share of research performed by the academic sector and funded by the private sector; the degree of technological specialization; and the stock of knowledge. This assumes that NIC and R&D capacity are "amenable to governmental management" (OECD 1994; 9). According to the authors, productivity is higher when specific mechanisms or institutions migrate ideas from the common infrastructure into commercial practice (2000). Assumptions put forth in this approach presume a dominant role in building competitive advantage for the nation-state over the private sector and other economic 'regions' or 'agglomerations' in building competitive advantage. In the case of NIC, output measures are defined as commercially valuable innovative output per given year and represented by the number of international

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[19] between 1973 and 1996

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patents per given year[21]. Again, the Stern et al approach is limited as it is applied at the nation-state level.

Alternatively, social networking models or approaches have also been applied at the regional/local level (Procyshyn (2004); Procyshyn et al (forthcoming); Coenen et al (forthcoming)) and at the network level (Theodorakopoulous and Kalaitzandonakes (1999)). Centrality and density measures, as implemented through these models, appears to offer one set of efficacious metrics for examining networks or clusters of firms or organizations. Depending upon how they are constructed, they can take into account a number of dynamic elements, such as knowledge, social capital and an array of intermediate inputs and outputs related to the system. Each approach has its share of merits but none fulfills all of the proposed analytical dimensions. This is explored more fully in Section 2.4.

Table 2.3.2.1 lists these various approaches and compares them across a number of dimensions (unit of analysis, metric used, inputs and outputs, consideration for knowledge and social factors and whether the approach is dynamic or static in nature). This table highlights the incomplete nature of all approaches in terms of the aforementioned dimensions. The most compete approaches appear to be those employed by Coenen et al (2005), Procyshyn (2004) and Procyshyn et al (2005).

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[21] Number of patents granted to inventors from a country other that the US and sourced through the United States Patent and Trademark Office (USPTO).

Table 2.3.2.1 Typology of Innovation-based Performance Evaluation Approaches

Author(s) / Pub Yr	Coenen et al (2005)	Procyshyn (2004) and Procyshyn etal (2005)	Stern et al (2000)	Theodorakopoulous and Kalaitzandonakes (1999)
Unit of Analysis	Region / cluster	Region / cluster	Nation	U.S. & EU nation state networks
Metric	Centrality & density	Centrality & density	Regression	Betweenness centrality & density
Inputs	Publications & patents	Cluster based activities (services, research, funding, etc)	R&D $ / national policies / share of R&D / stock of knowledge / degree of tech specialization	# of joint projects / collaborations
Output Measure	centrality & density (publications and patents)	innovative index (firm) and density & centrality (region/cluster level by activity)	Patents	degree of activity and network positions
Parameters included				
• Knowledge	√	√	√	√
• Social capital	√	√	X	√
• other	√	√	√	X
Dynamic or static?	Dynamic comparative over intervals of years	Static	static	Static over several years

In examining more practicable applications of methods, a number of national approaches are contrasted and explored in the following paragraphs. Nation-state guidelines or programs have been implemented over the past couple of decades to support and encourage performance evaluation. For example, the United States made inroads in establishing fundamental performance guidelines with the passing of the Government Performance and Results Act (GPRA) in 1993. The legislation exercises pressure on Federal agencies to undertake economic impact assessments of programs and associated projects. The legislation was to mandate the collection of data and the estimation of outputs and outcomes. According to the directive of the GPRA, this is accomplished through regular reporting using a "limited set of generic and highly measurable indicators" (Tassey 2003: 3). The Program Assessment Review Tool (PART) was developed in 2002 by the Office of Management and Budget (OMB) and was designed specifically to R&D programs. PART identifies program strength and weakness to inform funding and management decisions. The approach examines program purpose and design, performance measurement, evaluations, and strategic planning; program management and program results. Theoretically, PART is structured to allow comparisons between similar programs and to illuminate improvements over time.

On the other side of the world, the Australian Cooperative Research Centre (CRC) program is considered a "flagship" of the country's research environment. It is through this program that collaborations are facilitated between the public and private sectors (Zhao and Dalrymple 2002: 1). The Program is designed to encourage high innovation and is thought to have "extensive monitoring and evaluation processes" based upon performance criteria and indicators such as cooperative arrangements, education and training, research applications, management and budget (Zhao and Dalrymple 2005:4). Formal processes include annual reports with audited financial statements, visitor appointments to each CRC and regular formal reviews at pre-arranged intervals (Zhao and Dalrymple 2002)[22].

Although formal legislation – such as the GPRA – has not been developed in Canada to mandate such evaluation measures, the Treasury Board Secretariat[23] has instituted the Management Accountability Framework. The framework ensures that governmental decision-making supports a 'results-based' approach to management and strategic planning. At provincial and local levels, performance management initiatives in Canada are more commonplace (eg. in Alberta and Nova Scotia[24]). These initiatives emphasise service delivery and, again, adopt a 'results-based' approach to management and budget development.

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[22] The Commonwealth government has established a number of guidelines to ensure accountability within the CRC structure and appropriate use of public funds.

[23] TBS is a central government agency that helps the Canadian government to manage its human, financial, information and technology resources.

[24] Many provincial governments had already provided models of what these government-wide performance plans might look like. For example, Alberta's *Measuring Up* is a series of annual reports that provides information on the government's progress in meeting social and economic goals (Alberta Treasury, 2004). Another example is the Nova Scotia government which has finalized and implemented a number of 'government-level outcome measures' (Nova Scotia, 1998). Canada and the United States would have been the first national governments to publish government-wide performance plans. However, neither government has produced a plan that comes close to these state and provincial models.

2.3.3 Comparing Performance Indicators

Moving from the overall federal governance frameworks to program specific evaluation protocols, Table 2.2.3.1 outlines a compendium of indicators that are either currently employed to measure performance. Institutions in select programs from Australia, the U.S. and Canada are contrasted and compared based on these indicators and/or statistical measures they each employ for their respective projects. For example, the Cooperative Research Centres (CRCs) in Australia employ formal evaluation processes using specific indicators that validate the role of public-private interactions, codifiable output, education and training of higher degree students, and downstream application of research. Similarly, the U.S. government assesses its fundamental science (eg. National Science Foundation (NSF)) and endorses a number of indicators of performance capacity such as patent, publication and citation counts, partnerships, and training and education. Cost-benefit analysis and internal rate of return measures are also counted as contributing to the performance evaluation process. Environment Canada's (EC) performance measurement strategy includes input and output measures with result-based management as a guiding principle. Yet, there is no explicit consideration for the use of patents, publications, etc. as indicators of innovation or productive output for EC initiatives.

Table 2.2.3.1 Comparison of Institutional Performance Indicators/Approaches Implemented across Select Countries[25]

Parameters of interest	Australia (CRCs)	United States (NSF)	Canada (Environment Canada)
Patents	√	√	n/a
Publications	√	√	n/a
Citations	√	√	n/a
Funding & Awards	√	√	n/a
# high degree students	√	√	n/a
Internal collaborative activity (eg. co-publish/patent)	X	X	X
Collaborative partnerships	√	√	√
Courses, seminars and presentations	√	n/a	n/a
Commercialised products / processes	√	n/a	n/a
Outreach activity	√	√	√
Milestones reached	√	√	n/a
Reporting	√	√	√
Internal/peer reviews (people and projects)	√	√	√
Long-term social impacts	n/a	√	√
Descriptive statistics and traditional measures	√	√	√
Results based management	n/a	n/a	√

√ = explicitly acknowledged; X = not acknowledged; n/a = unable to locate / or no evidence of

Data in this table was compiled through the following sources: Zhao and Dalrymple (2002); National Science Foundation (2005) and Environment Canada (2003)

Based upon the collection of parameters outlined and proposed, it appears that none of the approaches taken by the U.S., Australia and Canada are complete. Notably, the CRCs, the NSF and EC do not really monitor or validate the role of internal collaborative activity

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[25] Data in this table was compiled through the following sources: Zhao and Dalrymple (2002); National Science Foundation (2005) and Environment Canada (2003)

amongst principals or agents involved in projects. This would suggest that there is a valuable 'social capital' indicator missing from these approaches[26].

Although all approaches acknowledge the value of or encourage 'collaborative partnerships', there is no explicit measure for project-level collaborative activity (such as co-publishing) as part of performance evaluation processes. Each approach lacks the effort to integrative to measure performance drawing on more traditional descriptive statistics and including knowledge-exchange indicators such as co-patents or co-publications.

Despite the limitations of these analytical approaches for measuring performance or innovative outcomes, implementing or managing public-private collaborations is about managing both process (knowledge creation and exchange) and outcomes or output. Judge et al (1997) suggests that managing innovation involves the synthesis of multiple business models and diverging objectives that accounts for freedom and control, flexibility and focus, differentiation and integration, incrementalism and discontinuity. The authors also state that, due to these complexities, there are few cut and dry prescriptions for managing technological innovation.

Knowledge, proximity and social capital are three important factors in enhancing innovative output. However, knowledge is accessed not only through institutional mechanisms (eg. contracts, agreements), but it is also sourced from the 'heads' of individuals or experts (Gibbons et al 1994, 24). The 'social capital' factor complicates matters in terms of assessing performance of collaborations. Relationships or facilitating the 'know-who' and 'know-how' appear to be important in terms of enhancing the innovation process. The social network analysis model is not new, but its potential application in terms of this research is novel in that it can account for those 'softer' factors affiliated with knowledge creation and exchange. The tool and its current application in both academia and in practice are reviewed in the following section.

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[26] Ongoing personal email communications with Stuart Lee of Environment Canada suggests the agency's interest in pursuing social network analysis as a tool for evaluating projects.

2.4 Social Network Analysis

Measuring performance in genomics-based R&D projects is complex. Innovation moves beyond standard conceptions of invention when there is some form of social value extracted from it. People and expertise are important factors in terms of creating and exchanging all types of knowledge for innovation. The kind and quantity of interaction amongst actors or experts would appear to affect output. Yet, as previously outlined, resources and people are widely distributed both geographically and institutionally and developing appropriate governance models is challenging in such a context.

In considering all of these factors, it is not surprising that networks or public-private collaborations are extremely difficult to track and measure. In this case, the collaborative model may not amenable to traditional management approaches - it brings with it a whole new set of challenges. As previously outlined, innovation is a social process, one in which "place, people and … networks [of different actors] are essential" (Maxwell 2003) for the exchange of knowledge or associated collaborative activity. As outlined, important factors to consider when evaluating 'knowledge management' in this context are: knowledge, collaborative models, performance, proximity, social capital and the evolution of social capital over time.

In the R&D world, the 'network' is where actors can come together formally and informally to access, exchange and recombine knowledge. Thus, social networks analysis (SNA) holds promise as a diagnostic tool for collecting and analysing relevant data with respect to patterns of relationships among individuals involved in a given network.

2.4.1 The SNA Tool

According to Wellman, social network analysis (SNA) is a powerful method for "explaining variances in resources, social behaviour and socio-economic outcomes" (PRI/SSHRC/StatsCan 2004: 7). Social networks are defined as "a collectivity of individuals among whom exchanges take place that are supported only by shared norms of trustworthy behaviour" (Liebeskind, Oliver, Zucker, Brewer 1996). Networks are "political landscapes or roadmaps" (Krackhardt 2005). The related concept of 'communities of practice' is defined by what it is about, how it functions and what capabilities it produces (Wenger 1998). Wenger suggests that these communities of practice are vehicles for collective learning where common interests and associated social relations are pursued. Stuart Kauffmann highlights the complexities of exchange amongst networks of practice. He suggests that the outputs produced are, in fact, the same elements necessary as inputs for further expanding network output (1993). In other words, the social network is the vehicle wherein various types of knowledge is brought together in order to create new (types of) knowledge; thus expanding or sustaining the network and its output over time.

In its application, social network analysis identifies patterns of interaction of individuals or actors (hereafter referred to as 'agents') and knowledge flows within a network. SNA makes the invisible work visible (Mead 2001). It shows how knowledge intensive work is done or can illustrate complex communication channels within a network. As a tool for analysis, SNA views "actors and actions…as interdependent" units, acknowledges that "relational ties" between agents provide "channels for transfer or flow of resources" and can also create "opportunities for or constraints on individual action" (Wasserman and Faust 1994). Social network analysis can help to identify boundary spanners, gatekeepers, knowledge bottlenecks and as well as under and over-utilised individuals or organisations.

Network analysis can also be applied at multiple levels. Ego-centered network analysis focuses upon an individual agent and its relationships with others. This approach allows the researcher to paint a picture of an agent's 'sphere of influence'[27]. It determines agent contacts and qualifies the nature of those inherent relationships. This approach, focusing on the individual agent, is useful when boundaries are difficult to define in a large population (Wellman 1982; as cited in Mead 2001). Whole network analysis, alternatively, describes all of the agents and their relationships within a network. A whole network analysis approach is constructive when the boundaries are easily established within such structures as

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[27] ORA offers a way in which to measure the sphere of influence of principal agents in ego-centred networks.

organisations, departments or projects and when data can be collected from all members of a given network.

Network analysis has its mathematical roots in matrix algebra and graph theory but its application has moved between disciplines over time. Anthropologists adopted it in the 1950s and 1960s and sociologists took it on in the 1970s and have been dominating its use ever since. Network analytical capabilities improved with integration into computational practice in the 1980s. By the 1990s, the social network analytic methodology spread rapidly into every discipline and, more recently is linked with physicists in the 'new science' and examination of small world and scale free networks.

Social network analysis is fundamentally a multi-theoretical approach. It is distinctive in that it is most interested in "the relationship" between a dyad or amongst a set of agents. The relational ties can be characterised as kin-based, role-based, or may represent affective relationships (who likes whom). Agents within the network are connected by edges (undirected (or binary)) or arcs (directional). The capacity to incorporate weighted data to characterise edges or ties is software dependent. Correlations between agents not only include the discrete tie between a dyad (eg. two actors) but may also include the individual nodes' ties to other nodes or events. In terms of the data set, the latter is commonly referred to as two-mode data.

The relationships amongst agents make up what's known as the 'network structure'. This structure may vary from being quite dense with many connections amongst agents (relative to the total number of possible links) within the network, to being sparsely knit with few links connecting agents. From a structural standpoint, it is just as important to identify gaps within a network as it is to identify and quantitatively assess links. Structural hole theory (Burt 1998) explores the nature of network gaps and suggests that such gaps may, in fact, be a positive network attribute. Given this assumption, structural hole theory predicts a negative association between networks that are dense (without structural holes) and performance. Burt's Structural Hole theory reflects Granovetter's theory of 'the strength of weak ties'[28]

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[28] According to Granovetter's theory, a weak tie is "a (probably linear) combination of amount of time, the emotional intensity, he intimacy (mutual confiding), and the reciprocal services which characterize the tie" (1973: 1361).

(1973 and 1983). This latter supposition assumes that weak ties or gaps within a network structure provide opportunity for connection (or 'bridging') to outside sources and resources, helping the network to remain flexible and responsive to external changes and less likely to be constrained by 'group think'. According to Burt (2005), although higher density networks may result in higher information flows within the network, flows may be limited from outside the network (eg. constrained) (6). Burt's argument states that it is not tie strength that is important, but simply the existence of structural holes which suggests that an actor or agent would have non-redundant ties as a result. Weak ties tend to be non-redundant. Networks with structural holes consist of individuals that "…know about, have a hand in, and exercise control over, more rewarding opportunities" (10). According to Burt, 'brokers' bridge structural holes of networks, and provide links to extra-network contacts. This is similar to Granovetter's term of 'bridges' or 'bridging relationships' that can reduce path distance between networks or clusters (Burt 2005).Constraints, on the other hand, are associated with those networks that have a limited number of contacts, contacts that do exist are too interconnected or contacts that are connected inter-directly through a central person (eg. the network tends to be hierarchical in nature) (Burt 2005). Rosenthal (1997) investigated structural hole theory with a study of intra-organisational teams hypothesising that there must some sort of optimal point between productive structural holes and density. Her research indicated that teams whose networks extend beyond the boundaries of the team (and span these structural holes) are more likely to be successful.

Similarly, Valente et al (under review) explores density as it relates to community coalitions in health program delivery. According to the results of the study, too much density may be indicative of network-centric connections that "…do not provide sufficient pathways for information and behaviours to come from outside the group" (15) while low density leaves a network ineffective at mobilising resources for adoption of prevention strategies.

Network visualisation is an important component in the analytical process. The 'graph', generated through SNA software, is the symbolic representation of a network. Current network analysis software such as UCINET[29], InFlow[30] or ORA[31] utilise graph theory and algebraic constructs to analyse data in a mathematic sense. However, the mechanics of the software also offers ways (either alone or in combination with other software) in which to visualise networks. In addition to calculating metrics, the software enables the researcher to better identify subgroups in a given network, such as clusters of actors or individuals, or to pinpoint isolates or those agents or nodes that appear to be disconnected from the larger network. Such analyses also enable the characterisation of such networks into categories such as core-peripheries or emergent groups[32]. A core-periphery network structure is such that it can be partitioned into two sets: a core whose members are densely tied to each other and a periphery whose members have more ties to core members than to each other. An emergent group, at least at first, does not have clear boundaries or clear membership. They arise out of pair wise interactions and are informal structures (unlike classes or formal membership groups)[33]. Additionally, the flexible nature of SNA software allows practitioners to strategically impose changes to a given network and to view network impacts in light of such changes; a 'rewiring' of sorts, so to speak. Networks generated by software are never true representations of real life structures. The 'distance' is geodesic, an abstract representation of the ties that lie between actors or agents in the networks and extrapolated from the data outlined in the matrix.

In addition to providing a qualitative picture, SNA software generates a number of measures to quantitatively illustrate the nature of a given network that may be otherwise unobservable

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[29] UCINET (current version 6.0) is a comprehensive package for the analysis of social network data as well as other 1-mode and 2-mode data. Integrated with UCINET is the NetDraw program for drawing diagrams of social networks. In addition, the program can export data to Mage and Pajek for visualization of graphs (Borgatti et al 2002).

[30] InFlow performs network analysis AND network visualization in one integrated product (Krebs 2005).

[31] Organisational Risk Analyzer (ORA) (current version 1.54) is a network analysis tool that detects risks or vulnerabilities of an organisation's design structure. ORA utilizes over 50 measures categorized by which type of risk they can detect (Carley and Reminga 2004).

[32] An emergent group, at least at first, do not have clear boundaries or clear membership. They arise out of pair wise interactions, are informal structures (unlike classes or formal membership groups). Emergent groups are found through clustering algorithms that uncover patterns of interaction amongst network agents and events or activities.

[33] Emergent groups are found through clustering algorithms that uncover patterns of interaction amongst network agents and events or activities.

in the real social setting. One commonly used measure is 'centrality'. The concept of centrality refers to the importance of a particular actor and the hierarchical nature of an entire network. In general, centrality measures are used to "…describe and measure properties of 'actor location' in a social network" (Wasserman and Faust 1994, p. 169). Centrality, applied at the node level, is a family of measures each answering a different theoretical question.

'High degree centrality' refers to the capacity of a node for informal leadership according to the number of ties that the node has. In other words, the degree to which one individual or actor is connected to other network actors. Total degree centrality is defined as the actual number of linkages that one actor has to others within a given network population relative to the total number of possible links. It is the normalized sum of the degrees of the ties affiliated (both in and out) with a particular actor. This measure is zero for any actor that has no connections with other network actors. The total degree centrality is 1.0 if an actor is linked with every possible partner. The total degree centrality is the normalized total degree, td, of a node, x_i, where total degree is the sum of the in-degree – id - and out-degree – od - given by the following mathematically expressions:

$$\mathrm{od}(\mathrm{x}_i) = \sum_{j-1}^{N} \mathrm{x}_{ij} \text{ and } \mathrm{id}(\mathrm{x}_i) = \sum_{j-1}^{N} \mathrm{x}_{ji}$$

$$TotalDegreeCentrality = \frac{\mathrm{td}(\mathrm{x}_i)}{2 * (\mathrm{N}-1)}$$

'High closeness centrality' builds upon high degree centrality but also looks to the nature of the distance between nodes. In other words, closeness centrality calculates how many steps (on average) is takes one node to reach all other nodes in a network. The closeness centrality equation, according to Valente (1995) is as follows:

$$ClosenessCentrality = \frac{(n-1)}{\sum (d_{ij})}$$

(where d_{ij} is the number of edges, steps or ties between *i* and *j*)

'Betweenness centrality' or centrality betweenness identifies the critical route for flows in the network and the dominant node or agent that has more close relationships to other dyads. In other words, this measure calculates the degree that a network individual or actor lies between other network actors on their paths to one another. According to Valente (1995) centrality betweenness is a measure of how often an individual lies between the shortest path linking two other individuals or actors. Freeman (1979) outlines the equation as follows:

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

(where g_{ij} represents the number of ties linking i and j and $g_{ij}(p_k)$ is the number of these ties that contain individual k)

Power, in the network sense, is not just how many connections an agent or node has, but how central other actors or agents are that it is connected to. According to Bonacich, power is a function of centrality plus the centrality of others, weighted by the distance and number of links between the central node and other agents. The Eigenvector measure, one measure of power, provides useful insight into this. An actor or agent who is high in terms of Eigenvector calculates an actor's centrality relative to the sum of the degrees of the actors or agents they are connected to (Carley and Reminga 2004). The actor or node with high Eigenvector centrality is connected to many actors who are themselves connected to many actors, thus multiplying their risk and/or opportunity (eg. a power indicator) within the network.

Another important measure in SNA is network density. The density measure (applied at the whole network level) is useful for assessing the overall strength of activity or relationships within a network. The question to measure density (below) calculates the total number of links or ties within a network relative to the total ties possible.

$$Density_{Network} = \frac{L}{n(n-1)}$$

(where L is the total number of links or ties within a given network of *n* actors)

It is often assumed that dense networks are more productive networks, thus leading to overall improved performance. This is a common conjecture in communication based analyses wherein more and stronger ties between agents result in improved performance or capacity. Mead (2001) employs this approach and supports this assumption is his analysis of communication linkages in construction project networks. However, relying exclusively on density measures to examine one or even to compare two or more networks may not always be a good gauge of network capacity. For example, two networks comprised of 30 actors may have almost identical densities yet can be very different in terms of overall structure. Network structures may influence a number of outcome variables. One group may have connections distributed throughout the network with little clustering (e.g., core-periphery structure) while the other may have concentrated connections among several sub-clusters in the network (e.g., clique structures). Again, both may have identical densities, but the theoretical and practical implications of the structures may be widely different.

2.4.2 SNA Indicators for R&D

Social network analysis measures are only as good as the indicators or proxies employed. In the R&D world, Ryan and Phillips (2003) suggest that publications are a good indicator of scientific output (by the academic or public sector) while patents are a good indicator of technological output (may be public or private sector activity).

In terms of publications, bibliometrics – formally speaking – is a type of quantitative analytical method used to describe patterns in publication activity. It is commonly used to determine the influence of a single writer or, as it is applied in this methodological framework, to describe the relationship between two or more writers. According to a Statistics Canada report published in 1998 (Gauthier), bibliometrics act as important indicators of knowledge production and flows in science and technology at the institutional, municipal, regional, provincial, national and international levels. Publications have been endorsed as a measure of intellectual output (Holbrooke et al 2004)[34]. According to Smith and Katz (2000), bibliometric measures provide an indication of the patterns of collaborative activity.

To date, bibliometric analysis (often referred to as scientometric analysis) has been applied in a variety of analytical approaches. For example, bibliometrics has been used to examine clusters and innovation (Gaisford et al (forthcoming)), to analyze scientific and technological research in Canada (Gauthier (1998)) and as indicators for systems of innovation in Europe (Katz and Hicks (1998)).

Another important 'downstream' indicator of R&D activity and performance is patenting. Co-patenting activity, as represented through technometric analysis, has been used as an indicator for technological-based activity. For example, the L'Observatoire des sciences et des technologies (OST) use technometric indicators to evaluate patents granted by the USPTO to Canada's NRC institutes (OST 2000). As well, Debackere et al (2002) examine the application of technometrics in supporting the development of science and technology policy.

Despite the endorsement of technometrics, there is considerable debate amongst academics regarding the use of patents as measures of innovative activity. On one hand, Trajtenberg (1990) argues that:

> "…patents have long exerted a compelling attraction on economists dealing with technical change… The reason is clear: patents are the one observable manifestation of inventive activity having a well-grounded claim for universality."

Trajtenberg also suggests that patents are the best measure for effort. On the other hand, it has been argued that patents are instead better indicators of *input* to innovative activity. Rather than viewing patents solely as indicators of output, Scotchmer (1991) views patents as a significant part of the *incremental* innovative process reflecting the adage… 'standing on the

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[34] Publications, however, as a universal measure is imperfect. Publication practice is differentiated across disciplines.

shoulders of giants'. Scotchmer's approach suggests that patents may be *both* an input and an output measure of innovative activity[35].

Despite these endorsements and criticisms, it is evident that neither patents nor publications can stand alone as a performance indicator evaluating performance in public-private collaborations. Both parties need to achieve those knowledge creation goals as they are respectively validated. As Ryan and Phillips (2003) suggest, the private sector values technology-based knowledge in the form of patents and the public sector values science-based activities in terms of publishing.

2.4.3 Applications of Social Network Analysis

Many things are coordinated in networks including workplace environments, clubs and membership-based organisations. The process of network analysis appears to have almost universal application.

There are a number of examples of the use of SNA. It appears to be a fairly flexible tool that has been applied across a number of contexts through, as previously referred to, ego-centered analysis or whole network analysis. Both approaches have been employed in many fields including transportation[36] (Bell and Iida 1997), terrorist networks (Fellman and Wright 2004; Krebs 2002)[37], spread of disease such as HIV/AIDS (Rothenberg et al 1998), health and mental health (Provan and Milward 1995), development projects (Moore et al 2003), business transactions or relationships (Todeva 2002) and trends in international collaboration and co-publishing in areas of research in disciplines such as astrophysics, geophysics, soil science and virology (Wagner 2005).

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[35] Additionally, it could be argued that not all innovations are patentable thus such a measure would omit or invalidate some innovative activity.

[36] Transportation Network Analysis is concerned primarily with the spatial, but also the temporal, nature of the movement of people and freight across land, where the movement is channelled onto roads or railways.

[37] Modelling terrorist networks involves examining flows of money, information and materials in order to predict trajectories and to identify gaps or holes that may result in circumvention of future terrorist activities. Krebs 2002 analyzes *ex post* the network associated with the 9/11 high-jackings in September 2001.

In exploring collaborations or collaborative activity, most applications of social network analysis are limited to internal analyses of firm-based activities across teams within a given department. An example of this is the study conducted by Hewlett Packard Labs on how email flows through an organisation. Whole network analysis was used in this case in order to identify 'communities of interest' or specific individuals within a social network (company or department) that appears to develop into 'de facto teams of experts' (King, 2005). In other cases, the tool is used to explore the competency or capacities of cross-functional teams. Rosenthal (1997) studies extra-team firm-based relations by examining patterns of network ties of individual team members, the constraints caused by those ties and how those ties correlate with team performance in a Midwest manufacturing firm. Cross et al (2002) more broadly explore the notion of using social network analysis to graph intra-organisational collaboration amongst employees; in other words, to make the 'invisible work, visible' (25) (this phrase is also referred to in Mead's work (2001)).

Although commonly applied at the organization or team level, there are examples of SNA applied to the evaluation of firm performance based upon activities or links outside the firm boundaries. For instance, a two year project conducted out of MIT examines the role of social networks on productivity of 'head hunters' (Klein 2004). This approach utilises an ego-centered analytical approach. It focuses on task-level productivity and executive recruiters by examining the patterns of linkages inside and outside the company and how that correlates with the number of job placements made and revenue generated for the company that they 'hunt' for. Bulkley and Van Alstyne (2003), suggests that the extent to which information flows and the extent to which employees have established larger personal networks are highly associated with the ability to generate additional revenues. Externally focused social networks are more effective for landing new contracts; internally focused social networks are more effective for executing contracts.

Other examples of SNA applied in the business context include inter-firm collaborations and competition (Uzzi 1997; Ahuja 2000; Ouimet et al 2004). For example, Ouimet et al (2004) explore relationships between the network positions of firms in Quebec's optics and photonics cluster in order to assess whether such positions matter with respect to radical innovation. A broader approach is taken by Lee (2005) who uses case analysis to explore the relationship of social capital creation within the U.S. in the context of economic capital expansion in imperial nation-states such as China and Japan.

Another approach that is relevant for the R&D context, is one proposed by Theodorakopoulous and Kalaitzandonakes (1999). The approach incorporates knowledge and social capital into the methodology of examining networks in the plant biotechnology sector[38]. Using the tools of network analysis, Theodorakopoulous and Kalaitzandonakes map the national knowledge networks of the industry in the U.S. and the EU by analysing, comparing and investigating the impacts of the network structures – represented by public-private research agreements. According to the authors, the formation of national networks between the public and private sector promotes knowledge generation and transfer and influences national innovative capacity. The goal of the study is to measure the effect of the network position of each participant on innovation performance of the industry. Information is gathered on existing public-private research agreements in both the US and the EU. Both sets of knowledge networks (US and EU) are analysed separately using network analysis. Particular attention is paid to the density of each network and the measure of betweenness-centrality. According to the authors, this measure is important in ascertaining the degree of activity between various actors and institutions or in understanding how they are positioned relative to one another and in determining the power of the actors involved.

Another application of centrality and density measures, demonstrated through the work conducted by Procyshyn (2004), Phillips et al (2005) and Procyshyn et al (forthcoming), is applied to the Saskatoon regional innovation cluster. Causal relationships in this agricultural biotechnology cluster are explored using a blend of activity based analysis and social network analysis. The latter tool focuses on the activity based relationships between core or hub actors (n=8) in the cluster with other regional actors. Density and centrality measures are broken out by activity (eg. services, exchange of high quality personnel, research, financing, etc.). This unique combination of tools provides a more dynamic framework from which to analyse

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regional innovation activities. Procyshyn (2004) takes this a step further and develops an 'innovation index', a measurement of both past innovative capabilities and the future potential to innovate, and tests whether network position influences core actor's influence on innovative focus. Ryan, Pothier and Phillips (2003) use SNA to graph the evolution of pre-award collaborative activity amongst Genome Canada project actors, testing the notion that higher levels of collaboration over time would result in lower transaction costs in terms of achieving project milestones. This preliminary research suggests that, yes, this may be the case. However, the authors suggest that more in-depth analysis is required.

Regardless of application, the method and the theory behind SNA offer a useful way to conceptualise and analyse networks. Once a visual representation of a network is generated, patterns can be discerned and positions and linkages can be identified. However, the tool and the method does have its share of limitations. According to Krebs (2002), regardless of context, or the approach taken, there are three main problems associated with social network analysis: 1) Generally, the data is incomplete and there may be nodes that are completely overlooked; 2) there are often problems associated with fuzzy boundaries and not knowing, in advance, who to include or not to include; and 3) there is lack of recognition for the dynamics of the network phenomenon… networks are not static. One could assume that with input problems such as these, there would be limitations in terms of the efficacy of the outcomes of such analysis, particularly in a case where one is using such a tool to determine performance capacity of a given network. Finally, social network analysis has never been explicitly used to explore evolution of research and development collaborative networks.

2.5 Conclusion

Innovation and innovative output in R&D is difficult to predict and measure. Technology is rapidly evolving and the knowledge required to achieve desired outcomes is institutionally and geographically dispersed. Based upon the review of the literature, management of knowledge is an inherently social process; one in which "place, people and … networks [of different actors] are essential" (Maxwell 2003). In the case of most R&D projects, collaborative initiatives are developed amongst actors representing both the public and private sector that, presumably, have built relationships over time. These relationships progress based upon formal and informal interactions or linkages but all are initiated through some form of social interaction – either formally (eg. through contracts, co-granting initiatives, publications) or informally (through casual meetings, conferences or conversations).

Given the complexities of the R&D environment and based upon this literature review, a number of gaps arise:

1. People, place and institution matters when it comes to innovation, but these factors, collectively, are not necessarily considered in current performance evaluation approaches.

2. Current approaches to evaluating performance, both in theory and practice, come up short in terms of incorporating knowledge-based factors into measures. Overarching nation-state 'results-based' approaches are ambiguous and project indicators do not necessarily capture the nuances of knowledge, social capital and innovation. Literary-based approaches, on the other hand, are often not easily translated into practicable, models for real-world application, nor are they easily understood by the policy-maker.

3. Networks appear to be vehicles for innovation yet how their structure, in terms of network scale and scope, impacts performance in R&D has not been fully explored.

4. Assuming that networks build over time, little has been done to reflect how relationships grow over time. Applications in this area are often limited to mere 'snapshots' in time.

5. Social network analysis appears to offer the means to assess performance in R&D networks accounting for knowledge-based factors. However, there is a lack of consensus in the literary applications of SNA regarding the impact that density has on outcomes. This warrants further investigation.

Based upon the review of the literature, the overriding assumption that can be drawn here is that there is a positive relationship between the history of social exchange and structure of a given network of interest and its performance in terms of knowledge output and knowledge management capacity. This assumption needs to be tested. Developing a model or framework to address the gaps outlined above requires first an explicit recognition of the role of knowledge and the nature of collaborative activity that defines a given network of actors. Proxies for these factors are vast varying from publications and patents (knowledge creation) to the number of joint ventures or collaborative research projects that network actors participate in (collaborative activity). Again, given the dynamic nature of knowledge and its creation and diffusion, along with the nuances of innovation and innovative output, there also needs to be a consideration for the development of relationships over time. As Smith and Katz suggest, in the world of science "…collaborations begin informally and are often the result of informal conversation that then lead to increasing commitment to cooperate" (2000: 28).

Viewing public-private collaborations in R&D through the SNA lens offers a way in which address the gap between broader objectives for innovation and efficacious ways in which to evaluate performance and outcomes in such arrangements. Additionally, SNA may also permit one to view the historical evolution and overall structure of such partnerships over time. Identifying gaps or opportunities within networks may provide insight into the configuration and implementation of new, more efficient, organisational strategies.

Chapter 3

METHODOLOGY / MODEL

3.0 Introduction

Public-private partnerships in research and development represent a whole new institutional structure that requires more complex accountability systems in terms of how and which ones to support and how to govern or support them once in place. Innovation requires the right blend of the right people with the right knowledge or access to the right knowledge. Both people and knowledge are mobile resources for innovation and, therefore, the 'right blend' may not be confined to a specific region or locale or to a single set of institutions or organisations but, rather, may cross geographical and organisational boundaries. The best actors are not easy to identify. Also, these networks or communities of practice may develop over time, building upon informal linkages, formalising collaborations and establishing norms and trust over time. As Smith and Katz suggest, "…collaborations begin informally and are often the result of informal conversation that then lead to increasing commitment to cooperate" (28).

Based upon the review of the literature in Chapter 2, a number of gaps were identified that warrant further investigation. This dissertation operates on the assumption that enhanced network-based knowledge management capacity and optimal performance are a function of historical knowledge creation and knowledge exchange capacity (evolving social capital). Accounting for those gaps and to test this assumption, three conditional hypotheses are proposed:

1. A history of collaborative activity or institutional linkages amongst a set of actors of interest may result in self-organisation of said individuals into formalized research networks.
2. Self-organised research networks, as opposed to those that are imposed, may generate higher levels of knowledge creation and exchange over time.

3. How a network is structured – in terms of collaborative activities, organisational affiliations, research focus and the level of geographic dispersion of actors – may affect output and network-based knowledge management capacity.

The methodology outlined hereafter proposes to explore the relationship between networks and network structures and performance. It blends the tools of social network analysis (to conceptualise the network) with a combination of input and output measures to take into account the dynamics of knowledge flows over time. The methodology consists of a three part process to address these factors including the role that network structure plays on performance. Network structure, in this case, is categorized by examining not only the evolution of the network over time, the role of structure in terms of overarching program influence and the 'government hand' but also through the institutional, disciplinary or research foci linkages and geographical location of network actors or principals[39].

The framework proposes to test the relationship between social capital and performance in R&D networks. This approach rests on a number of assumptions: First, knowledge (various types) and people are key factors. Second, mapping historical collaborative activity (social capital) amongst principals provides a picture of the evolving network and its evolving structure over time. Third, the case study approach in this methodology provides the best way in which to explore the relationship between social capital and performance by contrasting and comparing networks that are presumed to be structurally diverse. The proposed framework tests the notion that a higher density of social or collaboration-based activity amongst network members of interest may lead to enhanced future performance and network capacity for enhanced knowledge management.

As public-private partnerships in research and development are comprised of a number of individuals across a number of organisations, it is conceivable that performance measures should somehow be tailored to incorporate social network analysis. However, as previously outlined, the literature does not explicitly connect social relationships or network density with

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[39] In part one of the analysis framework, the term 'actor' will be used interchangeably with 'agent' and refers to both individuals and organizations associated with the broader network of interest. Density measures are generated on both the actor-only matrices and the combined metamatrices.

project performance in public-private collaborations. Therefore, this framework offers a novel way in which to explore performance in research-based collaborative networks.

This dissertation uses a case-based approach to examine two Genome Canada funded research projects: The Functional Pathogenomics of Mucosal Immunity (FPMI) and the Functional Genomics of Abiotic Stress (FGAS). Both projects have been awarded through Genome Canada. As such, both projects are defined as formalized networks of actors or principals at point of award (2002 and 2001 respectively)[40]. As awarded projects, it is also assumed that there is implicit acknowledgement on the part of Genome Canada that both of these formalized networks will perform well and in keeping with the broader program objectives. From a quantitative network analysis respect, Genome Canada endorsement of the networks suggests that each is sufficiently dense and that each has appropriate centralisation levels. It is also assumed and that each network demonstrates a balance of local and global linkages and institutional representation to optimize performance.

3.1 An Overview of Targeted Case Studies

The FGAS and FPMI projects are identified as case studies in this dissertation for two primary reasons. First, both projects are geographically centered in the Saskatoon region. Second, each project exhibits a unique structure that was formally established and acknowledged at the point of award and is a function of historical collaborative activity amongst the network principals.

The FGAS project was originally submitted for funding under the Competition I through two letters of intent under two separate proposals led by two different networks of principals. The first proposal involved the exploration of proteins and genes involved in regulating wheat's response to low temperatures. The other proposal involved the study of canola's response to metal and nutrient stresses. Upon evaluation[41], Genome Canada determined that combining

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[40] The network boundaries (i.e. network actors) for each Project for the purposes of this research were defined by project managers during in-depth interviews.

[41] GENOME CANADA projects are selected /awarded following an in-depth evaluation process involving more than 150 international experts in each Competition.

the projects would offer a cost-effective and more favourable way to structure the Project. Thus, FGAS was only awarded once both groups agreed to collaborate to develop a unified proposal for consideration under Competition I. As a formalized network, FGAS appears to be more 'imposed' or 'inorganic' with a strong government hand in the structure of the network. Research foci, in this case, involve two crop varieties and alternate metabolic processes or pathways and are lead by principals that are often geographically and disciplinarily dispersed. It is assumed that a number of network principals have not had previous collaborative relationships, that there may be diverging research strategies and, as such, challenges to effectively managing such a large project (there are 20+ principals identified in the FGAS network).

The FPMI project, on the other hand, is considerably smaller in terms of scale and scope employing genomics techniques to understand infectious immunity, how immunity may be enhanced and how it may lead to new treatments and prevention strategies for both human and animal health. The formal project or network is comprised of eight network principals awarded after a standard submission process to Competition II round of funding. Unlike its FGAS counterpart, FPMI is deemed an 'organically' structured project, with minimal intervention regarding network structure on the part of Genome Canada at the point-of-award.

3.2 Analytical Framework

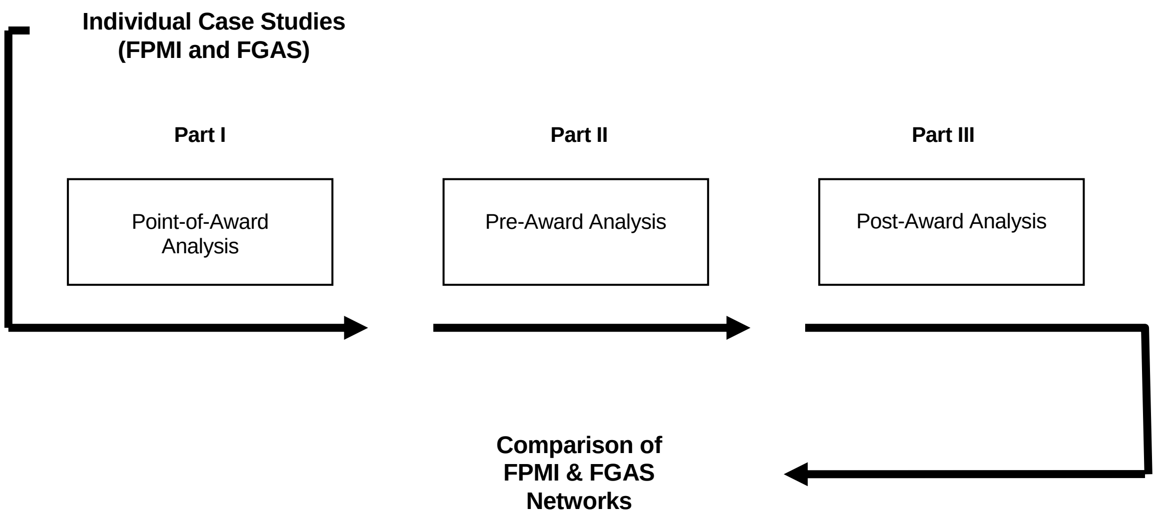
Based upon the outcome of the literature review and assumptions regarding knowledge management capacity, this dissertation will test the notion that a positive relationship exists between social capital and network performance.

To accomplish this, the history and structure of social exchange or social capital and performance in terms of current and future knowledge output and knowledge management capacity for a given set of individuals is assessed through a three part model applied to case-based data: point-of-award analysis, pre-award analysis and post-award analysis (See Figure 3.1).

The preliminary point-of-award analysis involves network based quantitative measures combined with qualitative data. Network based density and centrality measures are calculated to provide a picture of 'knowledge management capacity' for each network. Building upon this preliminary part of the analytical process, the framework then evaluates how the network of individuals associated with each of the projects (as they are currently structured under the formally awarded point-of-award network format) have evolved in terms of knowledge output and exchange over time. Part three quantitatively explores post-award output of each network.

Across this three-part analytical framework, graphs (illustrations generated through social network analysis software) are used to visualise network configurations and structures. The configuration of the network at the point-of-award establishes the structure upon which both pre-award and post-award analysis is conducted. Therefore, for each case, point-of-award analysis is conducted first, exploring the broader network (including those individuals and organisations that may not be formally linked to the given project) both quantitatively and qualitatively. Once this framework has been applied to both networks, results are compared to test knowledge management capacity and performance capacity within each network.

Figure 3.1.1 Genome Canada Public-Private Research Networks and Performance: An analytical framework



Data for the three-part analysis is collected through primary and secondary sources. First, data is collected through a survey instrument incorporating both qualitative and quantitative parameters. The survey instrument was developed and administered between 2003 and 2005 (see Appendix A). The instrument (administered to a total of five Genome Prairie projects) was designed to determine past, current and anticipated relationships related to the identified Genome Canada research projects in the Prairie region. Specifically, the instrument sheds light on the 3 stages in project development, focusing on search costs, negotiation costs and ongoing costs. Additionally, questions serve to highlight each project's intellectual property strategy and the costs incurred in the search, negotiation and monitoring of intellectual property rights and to outline commercialisation strategies (if any)[42].

The survey instrument is valuable as it illuminates the underlying power structures of each network and dynamics that may not be visible through secondary data. Also, some individuals or agents within the network or social system have power that cannot be measured or explained with traditional social science approaches. Thus, the survey instrument becomes the catalyst for assessing the system. These in-depth surveys are supported by subsequent additional personal interviews with Project Managers and Principal Investigators from both the FPMI and the FGAS projects. This also includes information gathered continuously through ongoing email exchanges and telephone interviews in order to capture data and information that may have been omitted in the original survey or to obtain more updated information. Of significant importance over the entire survey and interview processes was to identify and gather information on network principals or actors in both projects.

As previously mentioned the overall model/framework utilises a combination of descriptive and relational indicators and is broken down into three parts: pre-award analysis, point-of-award analysis and post-award analysis. Point-of-award analysis is initially descriptive in nature, involving analysis of the broader network to both qualitatively and quantitatively illustrate the institutional linkages that exist amongst a broad network of actors and organisations. This includes secondary and tertiary actors that may or may not be formally

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[42] Preliminary results from these interviews has been summarised, analyzed and presented at GENOME CANADA's symposiums (Ryan et al, 2004 and Ryan 2005).

associated with the awarded project. Qualitative data is supported by quantitative calculations of network density and centrality for comparative purposes to identify key actors or organisations that are affiliated with the network.

Pre-award analysis incorporates relational and descriptive indicators over time but applies this to a specific group of individuals that have been identified (through the interview process) as key players or as signatories of a given project. This group of key actors – referred to as 'principals' at this stage of analysis – are compared with the group identified in point-of-award analysis. Pre-award analysis continues on to examine network-based productivity and output over time (amongst network principals). Aggregate publications, patents and funding secured are used as indicators of knowledge creation capacity over time. Co-publications, co-patents and funding secured amongst two or more network principals[43] serve as relational indicators. The purpose of pre-award analysis is to identify trends in terms of collaborative activity amongst network principals and to illustrate the evolution of collaboration and knowledge creation over time.

Post-award analysis utilises primarily descriptive statistics as measures of output. Both scientific and technological output are relevant in this part of the analytical process. Thus, both publications (scientific output) and patents (technological output), among others, are used as short term output indicators within the framework. These performance indicators are normalized by network size for comparative purposes later on in the dissertation.

3.2.1 Framework Measures, Proxies and Terms

In this dissertation, higher performance is assumed to positively correlated with higher levels of historical collaborative activity (social capital). In pre-award analysis, both co-patenting and co-publishing activity will serve as important indicators for historical collaborative activity. Using these indicators also reflects the knowledge-based emphases of both the public (science-based) and private sector (technology-based) (Ryan and Phillips 2003).

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[43] The term "principal" is used interchangeably with "actor" or "agent" throughout the dissertation.

In both point-of-award analysis and pre-award analysis, two primary measures are employed to draw bibliometrics and technometrics into the network analysis process: density and centrality measures.

In point-of-award analysis, the density measure is used to quantitatively analyse the structure of the broader network of interest, giving insight into the nature of the connections between actors, affiliates and their location as well as research foci. In pre-award analysis, density measures are calculated based upon overall collaborative activity (eg. co-publications and co-patents) amongst principals of the formalized network or project. Similarly, the density measure is applied in point-of-award analysis to quantitatively assess the intensity of linkages amongst broader network actors and organisations. The density of the entire network "…is a proportion that is calculated as the number of all ties occurring in the matrix divided by the number of all possible ties" (Knoke and Kuklinski 1982: 45). The number of all possible ties (N) in this case is the aggregate number of co-publication or co-patent links for all network principals while L is the number of actual links amongst principals within the network. Additionally, the denominator (N*[N-1]) accounts for all possible permutations and combinations. Equation 1 outlines the density formula:

Equation 1

$$Density_{Network} = \frac{L}{N(N-1)}$$

Centrality measures are commonly used in social network analysis. Centrality is defined as the actual number of linkages (sum of x_{ij}) within the given network population, relative to aggregate output (N-1). In general, centrality would be zero for any actor or principal that has no connections with other network actors, while his/her centrality measure would be one if he/she was linked with every possible local partner:

Equation 2

$$Centrality = \frac{\sum x_{ij}}{N-1}$$

Centrality measures are employed in point-of-award analysis to identify dominant actors, institutions or research-activities within the broader network. In this stage of the analysis, centrality measures are administered at both the actor or agent level and the whole network level (termed 'centralisation' measures). In pre-award analysis, however, the measure is only employed at the actor or agent level to ascertain hierarchal configurations of principals (eg. central actors) in terms of specific activities for each network over time. In each of these stages of analysis, centrality measures will not only identify core actors (or principals) or activities but conclusions may also be drawn with respect to 'gaps' within each network. Such 'gaps' (or 'structural holes') may (negatively or positively) affect network capacity and performance.

The centrality measure is further delineated into three key measures of importance for the purposes of this analytical framework: Total degree centrality, betweenness-centrality and centrality Eigenvector[44] (See Table 3.1.1). Total degree centrality is defined as the number of ties that a given actor or agent within a network has to other network actors (Carley and Reminga 2004). The trouble with degree centrality is that two actors or agents may have the same degree (measure), but one actor is connected only to people who are relatively disconnected, while the other actor may be connected to other actors that are highly connected. Centrality Eigenvector calculates an actor's centrality relative to the sum of the degrees of the actors or agents they are connected to (Carley and Reminga 2004). Betweenness-centrality measures the level to which an actor connects subgroups within a given network (Carley and Reminga 2004). In other words, an actor or agent with a higher betweenness-centrality measure usually 'brokers' between other actors or agents within the network. This actor or agent is assumed to have the power to make or break connections or flows within the system or network.

These centrality measures are generally applied to the node or agent level. However, as previously mentioned, these measures will also be applied to the whole network level in both point-of-award and pre-award analysis. These whole network measures will facilitate network to network comparisons which will be explored later in the dissertation. Terminology, in this case, is revised to reflect whole network analysis with the term 'centralisation' (vs. centrality)

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[44] Centrality Eigenvector is a centrality measure developed by Phillip Bonacich (1972).

to distinguish between both measures. Application and distinguishing terms of the three key centrality measures are outlined in Table 3.1.1.

Table 3.2.1 Typology of Centrality Measures

Centrality Measure	Meaning	Actor Level Application	Network Level Application (centralisation measures)
Total degree centrality (TDC)	An actor or principal with higher TDC is identified as a "hub" or "connector" within the network	To identify central actors or principals (those that are more highly connected) in terms of position and activity; those actors or principals that are 'in-the-know'	To determine the overall intra-network connectedness and determine, to what degree, the network revolves around one actor or principal
Centrality Eigenvector (CE)	An actor or principal with higher CE has multiple connections with others with multiple connections	To identify those central actors or principals that have more connections to other highly central actors or principals; those actors or principals with 'influential power'	To determine the overall level of cohesiveness of the network and, to what degree, the network revolves around actors or principals that are connected to other central actors.
Betweenness-centrality (BC)	An actor or principal with high BC is identified as a "broker" or "bridge" and can connect or disconnect groups within the network	To identify those actors or principals with the capacity to facilitate or break knowledge flows within the network; those that link sub-groups within the system; those actors or principals that have 'potential influence'	To determine the overall knowledge flow capacity within the network and, to what degree, the network revolves around an actor or principal that connects and disconnects network sub-groups

At the whole network level, centralisation describes the manner in which a network or graph revolves around one particular actor or principal. Centralisation measures are calculated through the sum of the differences between the centrality of the most central actor (either Betweenness-centrality, Centrality Eigenvector or Total degree centrality) and the centrality of all other actors in the network divided by the maximum possible. Denoted as they are – these measures will operate as proxies to determine network structures and capacities in terms of intra-network connectedness, overall cohesiveness, and network-based knowledge flow capacity. These measures will be employed later on in the dissertation to contrast and compare knowledge management capacities of each network.

The broader Genome Canada goal (in the most recent stage of the Program) is to commercialise knowledge. Thus 'commercially valuable output' is of significance in any performance measure as applied in this context. Thus, a set of proxies to represent post-award network performance or knowledge output needs to be delineated that will reflect the activities and objectives of R&D. Economic value, in the Genome Canada context, means that inventions or innovations need to reach the marketplace in order to realise social value. In the case of genomics research, such end-use is not expected to be realised for some time (beyond the time limitations associated with the actual term of an award). However, it is important to be able to project the future potential of innovations or inventions derived through these Genome Canada funded projects. Measuring or quantifying commercialisable output at this early stage is not necessarily feasible. However, *potential* for such output may be proxied within the window of the project award.

A new typology for output as it relates to measuring performance in Genome Canada projects or other R&D projects is outlined below. As previously stated, a "…long[er]-term research agenda (20 to 50 years) is key" (GoC 2003) and performance evaluation approaches need to somehow incorporate long-term considerations. This new typology is outlined as follows (See Table 3.2.2). Technical output which includes all short term output (3-5 years) which includes publications, provisional patents, number of trained graduate students, seminars, presentations, tools for discovery and spin-offs. Economic outcomes are medium term outcomes which could include all of the aforementioned parameters but also patents. An added analytical process that could be included at this point would be citation analysis, testing the quality of both patents and publications that arise out of projects. Of significant important yet difficult to predict are long-term social impacts which include products, processes or services that are available in the market or for consumption as a public good.

Table 3.2.2 Typology for Research Project Output

	Time Frame	Indicators	Analytical Options
Technical Output	3 – 5 years	• Publications • Provisional patents • Patent applications • Trained personnel • Seminars/Presentations • Tools for Discovery • Spin-offs	• Limited to aggregate output measures normalised by network size
Economic Outcomes	5 + years	• Patents • Publications • Commercialised products or processes • Spin-offs • labour force • income per worker • exports • GDP/employed worker	• Citation analysis (Patent or Publication) • Cost benefit analysis • Input or output Analysis • Industrial structural analyses (eg. share analysis) • ROI
Social Impacts	20 + years	• Social welfare • Standard of living • Per capita income levels • Composition of the labour force (LFS) • GDP/capita • Unemployment rates	• Macro modelling (e.g. Stern et al)

The ultimate goal of Genome Canada, and its mandate for projects, is to achieve commercialisable output. Social value is derived from short term technical output as well. Publications and patents, as disclosed in the public sphere, are considered a 'public good' (although not necessarily consumable, in the layman's sense). Yet, these 'products' are utilised to create further innovations, in other words 'standing upon the shoulders of giants' (Scotchmer 1991) to create further innovative output. Thus, in the case of this dissertation, employing short term or technical output measures such as the number of provisional patents and publications in combination with other factors is both feasible and valid. Such measures can provide an indication of the potential for future economically and socially valuable output of a given network.

3.3 Case Study Application of the Analytical Framework

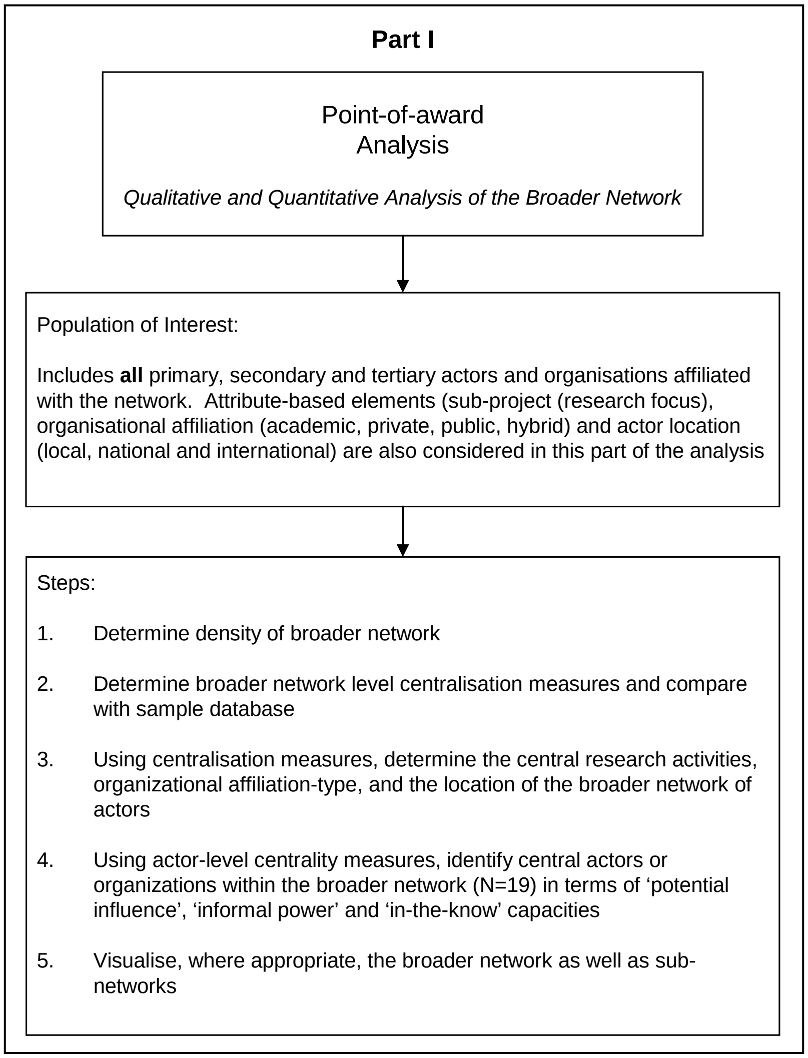
The following sections (3.3.1 to 3.3.3) details the three part framework that serves as the foundation for analysis of the genomics based R&D networks and includes the approach taken for measuring project or network-based output. Section 3.4 outlines the approach taken to compare networks, the final step that capstones the analytical process.

3.3.1 Part I: Point-of-Award Analysis

This part of the analysis uses social network visualisation (as a tool for broader network analysis), descriptive and quantitative measures to provide a 'picture' for each network, including the secondary and tertiary linkages. Point-of-award analysis serves as the precursor for pre-award and post-award analysis. It is a form of institutional or relational analysis, so to speak. As Smith and Katz state, understanding the [structure of the] institution [including formal and informal linkages] is essential in understanding the broader social organisation of research and the relationship between science, technology and society (2000). At this point of analysis, the broader network is the target. Capturing as many linkages to actors or organisations (including secondary and tertiary links to the principals) that are formally associated with the project network (eg. those actors that are identified as either signatories or key principals for the given network) will provide a more expansive view of the R&D network of interest.

Through the preliminary interview process and in subsequent interviews, qualitative information is collected on both the FPMI and FGAS projects. Linkages amongst individuals and organisations in this part of the analysis are compiled through these sources as well as through secondary data (eg. FPMI and FGAS websites). Figure 3.1.1.1 provides a detailed illustration of the Point-of-Award Analysis step.

Figure 3.3.1.1 Point-of-Award Analysis



Part I

Point-of-award
Analysis

Qualitative and Quantitative Analysis of the Broader Network

Population of Interest:

Includes **all** primary, secondary and tertiary actors and organisations affiliated with the network. Attribute-based elements (sub-project (research focus), organisational affiliation (academic, private, public, hybrid) and actor location (local, national and international) are also considered in this part of the analysis

Steps:

1. Determine density of broader network
2. Determine broader network level centralisation measures and compare with sample database
3. Using centralisation measures, determine the central research activities, organizational affiliation-type, and the location of the broader network of actors
4. Using actor-level centrality measures, identify central actors or organizations within the broader network (N=19) in terms of 'potential influence', 'informal power' and 'in-the-know' capacities
5. Visualise, where appropriate, the broader network as well as sub-networks

Step one of point-of-award analysis consists of the development of an agent x agent matrix using a combination of programs including Excel, UCINET and ORA (Organisational Risk Analysis). 'Agent x agent' is a term formally used by the ORA program and refers to an actor to actor relationship matrix. The ORA program and its measures[45] have been employed to analyse a variety of social environments, including informal networks such as friendship linkages, web-based or email networks, business networks social networks, etc. An in-

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[45] ORA generates up to 75 measures to analyze a given network or organisation.

program sample database of these different social environments is used in point-of-award analysis to compare FPMI and FGAS network level centralisation measures with database means. Excel and UCINET are used to input and 'house' datasets which are then exported to the ORA program for 'visualisation', metric analysis and report generation. Throughout the dissertation, all relationships or linkages are assumed to be binary (eg. acknowledged by both parties) and, therefore, all matrices developed and generated through the software are symmetrical. A value of either one or zero is used to indicate the presence or absence of a link or relationship. As outlined in section 3.2.1, a collection of metrics (including centrality and density measures) are used to analyse the broader network with results generated through the ORA reporting function.

In this stage of analysis, additional matrices are also developed for each network wherein additional linkages between actors and attributes, referred to as 'agent x attribute' by ORA, are illustrated. Building upon agent x agent matrices, links between network actors and attribute-based factors or elements are defined (actor research focus (by sub-project), actor affiliations (public, private, academic and hybrid) and actor location (local, national or international))[46].

In combination, these multiple matrices make up what is defined as the individual 'meta-matrix' for each of the broader networks of interest. Measures and calculations for point-of-award analysis are generated on not only the agent x agent matrices but also on the combined 'meta-matrix'. The former takes into account only the relationships or links amongst network actors (individuals and organisations). The latter includes these relationships plus broader network actor links with attributes as outlined above. Density measures are generated on both the agent x agent and the meta-matrix. The ORA program is then used to graph these relationships amongst the broader set of network actors as well as between these same actors and the attributes defined (above). Attribute-based networks are also graphed to visualize and

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[46] To factor in attribute or descriptive factors into the network analysis process, the ORA software defines three matrix-based elements and or analytical processes which may be used in meta-matrix analysis: "knowledge", "resources" and "tasks". For the purposes of this dissertation, these elements are adapted to represent or proxy those attributes of interest for this framework: 'knowledge' refers to affiliation-type, 'resources' is equivalent to geographic location and 'task' is used to proxy research interest or focus (sub-project).

identify broader network actor links to key activities, institutional affiliations and geographic location.

Of importance in this part of the analysis is the reporting feature that the ORA program offers. It is utilised to generate both program-defined 'Intelligence' and 'Context' reports. The former reporting mechanism uses a pre-defined set of measures to analyse the central actors and groups in a network. The top actors and groups are ranked, and then an overview of the key characteristics of the organisation as a whole is presented. The Context report, on the other hand, compares the given network to the sample ORA-based database of known social networks.

Following the aforementioned steps, broader network level analysis is complete for point-of-award analysis. The final step in this stage is actor level analysis. Here the most central actors (individuals or organisations) are identified and ranked within the broader network using centrality measures. Centrality betweenness is used to isolate the top five actors that have the greatest level of 'potential influence' in the broader network. The centrality eigenvector measure is employed to identify those actors with the most 'informal power' while the total degree centrality is used to identify those actors that are 'in-the-know'. In part two, this group of key actors will be compared to the defined set of principals as laid out or outlined for pre-award analysis.

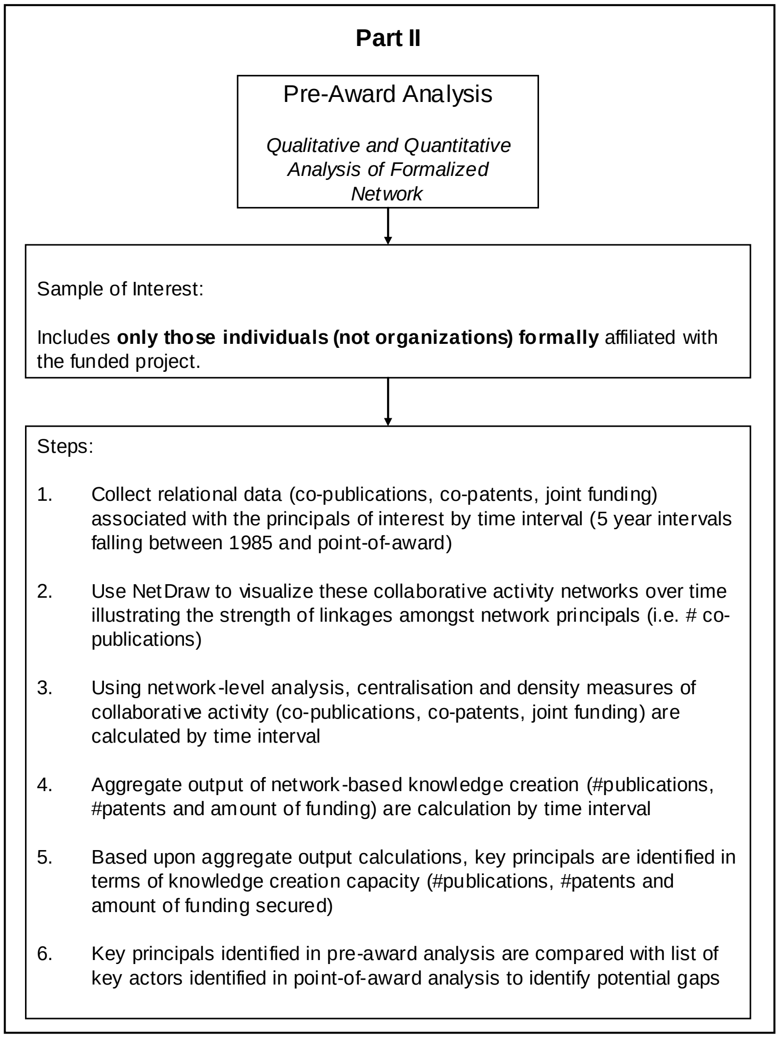
Based upon network analysis of a broad network (including actors that are affiliated with the formal project and organisations), conclusions are drawn with respect to key network actors identified in part I of the framework. Network boundaries are narrowed in part II of the analysis to only those key actors or 'principals' identified as signatories to the project in question. Comparing the identified list of key network actors in point-of-award analysis with those that are considered to have 'self-identified' for Genome Canada application process (in pre-award analysis) may help to identify gaps in the given network.

3.3.2 Part II: Pre-Award Analysis

The pre-award analysis examines historical collaborative activity amongst principals over time (in 5 year intervals from 1985 to point-of-award) using co-publications, co-patents and joint grants or funds as relational indicators for such activity. Such interactions amongst network principals constitute the flow of knowledge between two or more individuals and are defined as indicators of knowledge generation capacity for the given network. A combination of software packages are used to analysis this historical collaborative activity. UCINET is used to house matrices (for each time interval from 1985 to point-of-award) and is exported into NetDraw in order to visualize the networks. The ORA software is not used at this point as it is not currently capable of taking into account the level of activity amongst principals (eg. the 'weight' of linkages). Pre-award analysis employs these analytical software programs to analyse and illustrate the structure of each project network over four time intervals (1985-1989; 1990-1994; 1995-1999 and 2000-to point-of-award). This stage of analysis uses co-publications, co-patents and co-funding initiatives as proxies for collaborative activity and/or knowledge exchange over time.

As linkages between network principals can be direct or indirect and can grow geometrically over time, the boundaries of a network (eg. the set of network principals) are established first, before data collection begins in pre-award analysis. Figure 3.1.2.1 illustrates the framework for pre-award analysis. As previously mentioned, network boundaries are narrowed in this part of the analysis to those actors (identified as 'principals' here on in) that are formally affiliated with the project of interest (eg. are signatories to the awarded project).

Figure 3.3.2.1 Pre-Award Analysis



Part II

Pre-Award Analysis

Qualitative and Quantitative Analysis of Formalized Network

Sample of Interest:

Includes **only those individuals (not organizations) formally** affiliated with the funded project.

Steps:

1. Collect relational data (co-publications, co-patents, joint funding) associated with the principals of interest by time interval (5 year intervals falling between 1985 and point-of-award)
2. Use NetDraw to visualize these collaborative activity networks over time illustrating the strength of linkages amongst network principals (i.e. # co-publications)
3. Using network-level analysis, centralisation and density measures of collaborative activity (co-publications, co-patents, joint funding) are calculated by time interval
4. Aggregate output of network-based knowledge creation (#publications, #patents and amount of funding) are calculation by time interval
5. Based upon aggregate output calculations, key principals are identified in terms of knowledge creation capacity (#publications, #patents and amount of funding secured)
6. Key principals identified in pre-award analysis are compared with list of key actors identified in point-of-award analysis to identify potential gaps

Data collection for this stage of analysis involves primary and subsequent interviews with key network actors[47] in combination with a collection of secondary data. An important strategy behind the administration of preliminary interviews is to define the narrowed scope of actors (principals) associated with the funded project. This differentiates the network of interest in this pre-analysis from the broader set of actors defined in point-of-award analysis. Firm network boundaries are required in pre-award analysis in order to conduct bibliometric and

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[47] Project manager and targeted network principals.

technometric data collection and analysis. Bibliometric and technometric (or secondary) data, in pre-award analysis, are the number of co-publications and co-patents amongst principals which are gathered through the ISI Thomson Web of Science database and the United States Patent and Trademark Office (USPTO) database respectively. Data is collected in 5 year intervals from 1985 through to time of Genome Canada funding award (2002 for FPMI; 2001 for FGAS). Searches of SSHRC, NSERC, CFI and CIHR databases are also conducted based upon principals and their capacity to generate and collaborate in terms of funding over time. Again, the time intervals of interest here begin at 1985 and continue in five year intervals to time of award.

As previously outlined, network structures or graphs of collaborative activity (for both FGAS and FPMI over each time interval) are generated using a combination of UCINET, NetDraw and ORA (Organisational Risk Analysis) programs. A collection of metrics are generated through ORA and are used to analyse pre-award networks. Again, UCINET is used to 'house' datasets which are then exported to NetDraw[48] for 'visualisation' and ORA for metric analysis and report generation. ORA's reporting feature, employed to a lesser extent than in part I of the analysis, is utilised only to generate density measures. Density measures of collaborative activity across all intervals are also recorded.

NetDraw is effective for use in this part of the analysis. Although the ORA program offers some dynamic features, it cannot account for nor visualise the value of the linkages (eg. weight of linkages) in terms of collaborative activity (co-publications, co-patents, joint funding) amongst principals. The program (at this point of its development[49]) can only generate a graph indicating whether a link exists or not (binary). NetDraw is employed in this part of the analysis to address this gap. The evolutionary analysis of historical collaborative activity needs to not only visualise whether or not a relationship exists between principals, but

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[48] NetDraw is used specifically when the weight of edges or links needs to be considered. In the case of this thesis, NetDraw is used to illustrate the number of collaborative arrangements (eg. patents or publications) between actors or principals.

[49] The developers of ORA (CASOS at Carnegie Mellon University) are continually upgrading the software's capability. New versions are released on a monthly basis. A graph-generating element of ORA, which also include strength (value) of linkages, is currently being developed.

it must also further quantify that relationship by providing a visualisation of the value of that relationship. The NetDraw visualisation program has this capability.

Although relational indicators are of considerable interest in this part of the analysis, descriptive statistics, in terms of aggregate publications, patents and grants ($CDN) by network and by principal, will also support this relational data. Aggregate grants (SSHRC, CFI, NSERC and CIHR) are compared with individual output (patents and publications) by network principal over time[50]. In combination, these descriptive statistics (both aggregate and relative) will be employed as output (performance) measures of network activity and density over time to compare networks (FPMI vs. FGAS) later in the dissertation.

In combination, density, centralisation and descriptive measures provide a historical picture of each network as it evolves over time to the point-of-award. In the latter part of the dissertation, these results are normalised by network size to compare productivity by network. Tangential to this, but of additional interest to this dissertation, is the relationship of collaborative activity to proximity. In addition to elements or measures of density and centrality, the extent of geographic dispersion of a given group of network actors speaks to its structure. As Coenen et al (forthcoming) indicate in their comparative analysis of publication and patenting activities across the Saskatoon and Scanian (Sweden) regions, collaborative generation of synthetic knowledge or knowledge that is associated with more downstream activity (eg. patenting) appears to be more proximity-dependent than co-publication activity (epistemic knowledge). This notion is tested as it relates to both the FPMI and FGAS projects, in all activities of interest: co-publishing, co-patenting and capacity for securing funding.

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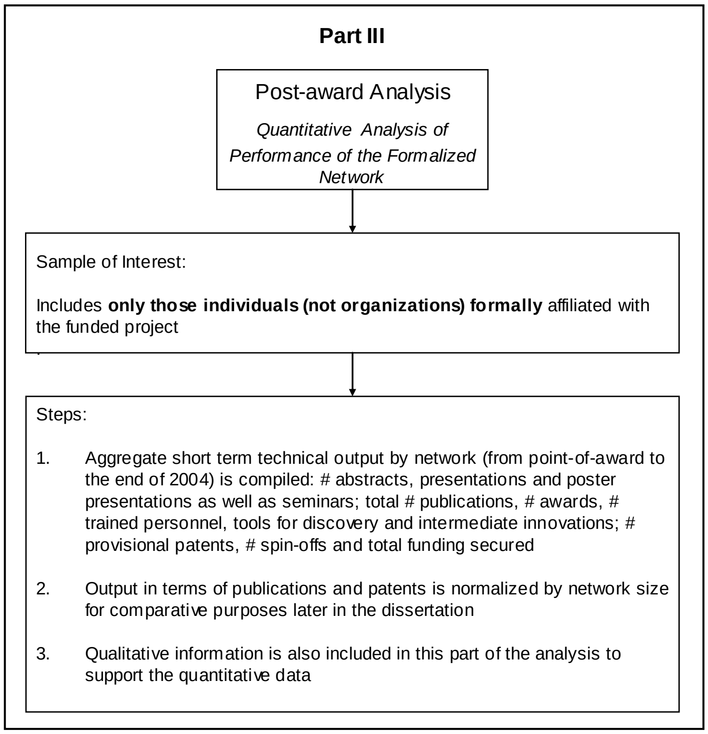
[50] The social capital (or, in this case, aggregate output in terms of publications, patents and grants) of individuals "aggregates to the team on which they serve" (Burt 2005: 34). Thus, collecting descriptive statistics on each individual of the defined network is important in determining the overall effectiveness of the network. Also, it provides comparatives between what activities or outputs are exclusive to the network compared with those that are extra-network in nature.

3.3.3 Part III: Post-Award Analysis

Descriptive statistics are used primarily in this part of the analysis to determine preliminary (short term technical) outputs of Genome Canada funded public-private networks. This post-award period represents the time period from the award date to present for each network. As identified in Table 3.1.2, descriptive statistics and output measures - in terms of short term technical output) includes a combination of: publications, provisional patents, seminars, presentations, tools for discovery, spin-offs, number of trained personnel (post-docs, technicians and graduate students) and new project applications. Once gathered, these outputs are normalised according to network size in order to compare networks later on in the dissertation.

Figure 3.3.3.1 Post-Award Analysis



Sample of Interest:

Includes **only those individuals (not organizations) formally** affiliated with the funded project

Steps:

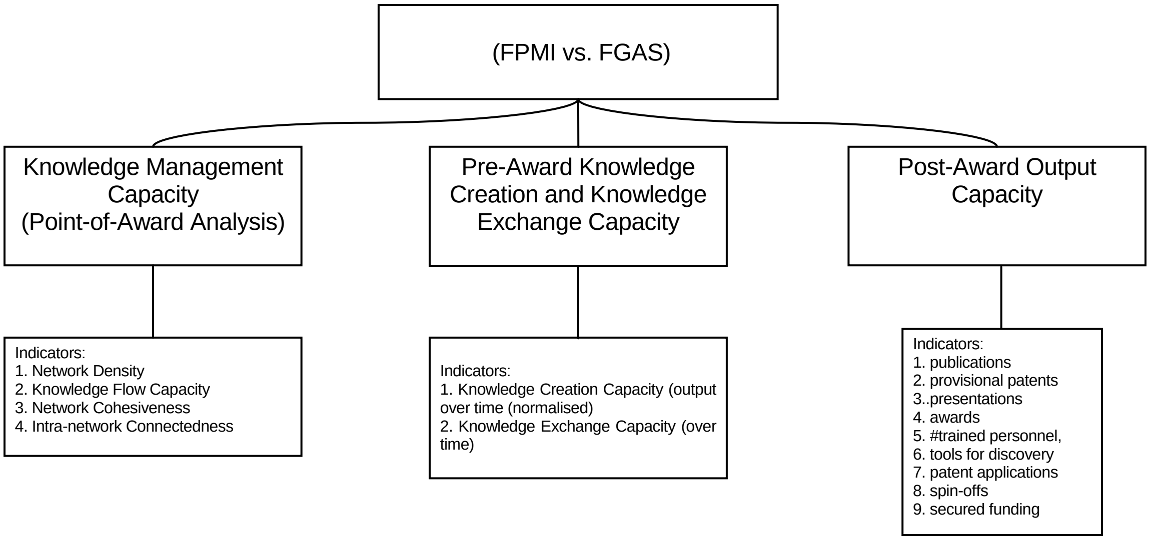
1. Aggregate short term technical output by network (from point-of-award to the end of 2004) is compiled: # abstracts, presentations and poster presentations as well as seminars; total # publications, # awards, # trained personnel, tools for discovery and intermediate innovations; # provisional patents, # spin-offs and total funding secured
2. Output in terms of publications and patents is normalized by network size for comparative purposes later in the dissertation
3. Qualitative information is also included in this part of the analysis to support the quantitative data

Applying this framework to a case study, in isolation, offers little in terms of understanding network based performance. Therefore, once all the data has been collected and analysed for each network across the preliminary three-part framework, they are compared.

3.4 Comparing Networks

In the absence of a benchmark, results from the application of the three-part framework offer little in terms of understanding individual network capacity. Thus, at this preliminary level, the only way to test framework efficacy and to determine network capacity is to apply the model across two or more case studies (see Figure 3.4.1 for outline of comparative framework).

Figure 3.4.1 Framework for Network Comparisons



This part of the overall analytical model proves to be the most integral to the dissertation. Here, the FPMI and FGAS networks are compared in terms of:

1. Their respective knowledge management capacity (based upon key proxies for centralisation, density measures and the nature of individual network structures).

2. The hierarchy of sub-network level attributes including sub-project (research focus), network level affiliation with a specific organisation type (academic, public, private and hybrid) and by location (local, national and international) for each network.

3. Overall knowledge exchange capacity (density of activity) and creation capacity (output measures normalized by network size) for each network is compared.

4. Key principals identified in part II of the analytical process for both networks are revisited and a synopsis of 'key actor' knowledge creation (publications, patents and funding) output is contrasted and compared to determine the concentration ratios of key actor (n=3) activity for each network.

5. Concentration ratios are summarised by activity (publishing, patenting and funding) for the top 50% of principals and compared across networks.

6. Finally, post-award performance across each network is compared drawing on the descriptive statistics outlined in part III of each of the network analyses. These descriptive statistics are normalized by network size in order to effectively compare networks' performance.

In step one, networks are compared at point-of-award through proxies for 'knowledge management capacity'. The assumption here is that enhanced knowledge management capacity is a function of the high levels of knowledge flow within the broader network, a higher cohesiveness of the broader network (in other words, how well connected network actors are) and a higher degree to which the broader network revolves around a single actor (i.e. leader, either an individual or organisation). Proxies for each of these three factors are used and correspond to a group of centralisation measures to calculate or determine overall knowledge management capacity by network. Each of these proxies is defined and connected to specific centralisation measures taking into account how that measure is defined in literature and applied in real world analysis:

1. Knowledge Flow Capacity = centralisation betweenness
2. Network Level Cohesiveness = centralisation Eigenvector
3. Intra-network Connectedness = total degree centralisation

As in part I of the analysis, each of the aforementioned network-level measures is compared with a sample database of measures provided through the ORA software. Overall density measures of each network at point-of-award are also compared.

The network structure is also considered in this step of the comparative process. The results of comparisons can be used to infer the capacity for network structure to impact performance capacity. The 'organic' structure (FPMI) is compared with the 'imposed' network structure (FGAS).

Step two explores and compares the sub-network-level hierarchy of attributes using network level centralisation measure to determine dominant research activities, dominant affiliation-type trends and location-based attributes. Affiliation type and location-based attributes associated with each network provide pictures of the balance of local-global activity or linkages and the fluidity of organisation-type boundaries in project structure. Are there dominant attributes associated with each network that may influence productivity or performance?

Step 3 goes into network level capacity for knowledge creation and exchange across both projects over time. Capacity for knowledge exchange is proxied through density of collaborative activity (co-publication, co-patent, and joint funding). These measures are supported by knowledge creation capacity measures which are represented by total output (publications, patents and joint funding) normalised by network size. Density and output measures for each collaborative activity (publications, patents and funding) by time interval are combined for both networks and are graphed for comparative purposes to support and draw conclusions from this part of the analysis. Network level capacities for both knowledge exchange and creation are summarised and compared across each project.

Next (step 4), key network principals that were identified in part II of the analytical process for both networks are revisited and a synopsis of key actor knowledge creation (publications, patents and funding) is contrasted and compared to determine the percentage of activity carried by each identified key principal in terms of activity (publishing, patents, funding) for each network. Conclusions can be drawn about the level of activity that is carried by the top three key actors that were identified in part II for each network.

In step 5, concentration ratios of knowledge creation activity (publishing, patenting and funding) for the top 50% of each of the network of principals are outlined to, again, explore and contrast, the ‘carrying’ capacity of top knowledge producers in each network.

Finally, in step 6, post-award output (project performance) – normalised by network size – is compared across the two networks of interest. These results are compared with each network’s capacity for knowledge management (point-of-award analysis) and knowledge creation and exchange (pre-award analysis).

The results from the three part analysis and the comparatives will not only test the manner to which historical collaborative activity leads to self-organisation on the part of research networks but will also explore the overall effect that network structure either by nomenclature (organic or imposed) or according to attributes (research focus and organisational affiliation and geographic distinctions) has on future performance. Tangentially, conclusions will be drawn on the capacity for social network analysis to predict performance in terms of overall knowledge management, in particular, the model introduced in this dissertation.

Chapter 4

CASE STUDY #1 – FUNCTIONAL PATHOGENOMICS OF MUCOSAL IMMUNITY (FPMI)

4.0 Introduction

The Functional Pathogenomics of Mucosal Immunity (FPMI) was funded by Genome Canada in 2002. The overall objective for the FPMI project is to provide new information about the processes of disease and innate immunity to microbial pathogens. Results enable researchers to gain an increased understanding of how the mucosal surfaces of bovine, chicken and human hosts respond to the presence of infectious agents and to the adjuvants, immuno-modulators and vaccines designed to combat these agents. FPMI project objectives include: to characterize, using epithelial and lymphoid cells, the host gene expression responses to pathogens including the development of microarray platforms; to generate afull genome chicken microarray; to characterize host gene expression responses in enteric and respiratory animal infections; to determine the influence of adjuvants, immuno-modulatory agents including antimicrobial peptides and vaccines on host gene expression; and to study the influence of pathogen genetics on the host response.

According to the project manager, over the latter funded period the FPMI project involved – directly and indirectly – over 25 research assistants, 18 technicians, 8 post-docs, 12 graduate students, 4 bioinformatics specialists, 4 undergraduate students and 2 project managers[51].

A part of the Genome Canada funding requirement is that funded projects must secure matching funding from alternate sources such as the provincial government or from the private of public sector. In the case of the FPMI network, matching funding came across through multiple sources including in-kind contributions through the University of Saskatchewan and commitments by Pyxis Genomics.

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[51] Ongoing interviews and email correspondence with Dr. Paul Hodgson (Project Manager) and Bernadette Mah (Project Manager).

4.1 Point-of-Award Analysis of FPMI Network

The broader FPMI network that is of initial interest in this part of the analysis is relatively small and is comprised of 8 local, national and internationally based organisations and firms as well as 11 individuals geographically located primarily in the provinces of Saskatchewan or British Columbia (BC)[52] (i.e. N=19). This population of actors was identified through primary (interviews) and secondary sources (website and other publicly available information).

The network, in its entirety, at point-of-award is illustrated in Figure 4.1.1 (Appendix B provides a complete listing of FPMI actors, affiliates / affiliate type and location). In addition to illustrating the relational links amongst identified FPMI actors within the network (N=19), Figure 4.1.1 also includes other attribute based nodes illustrating FPMI actor links to affiliation-type (academic, public, private and hybrid), sub-project or research interest (in this case - bioinformatics, animal models or pathogenomics[53]), affiliation type (public, private, academic or hybrid) and actor location (local, national or international[54]). As outlined in the methodology, this latter data supplements the foundational agent-by-agent adjacency matrix (N=19) through the addition of multiple adjacency matrices in the aforementioned categories. Organisational Risk Analysis (ORA) software is used to illustrate this 'meta-matrix' network structure (see Figure 4.1.1) and also to generate density and centrality measures for the network of interest (agent x agent) and to determine measures for underlying sub-networks (eg. sub-project or research interest, affiliation-type or geographic location). For point-of-award analysis of the network, all agent to agent relationships are assumed to be binary and, therefore, matrices are all symmetrical. The relationships defined in this part of the analysis are institutional in nature. Links between agents, agents and project-types, agents and organisations and agents and location signify a linkage that represents qualitative or affiliation-type linkages. For example, agent North works with Inimex which is a private-sector, Canadian-based organisation. Both North and Inimex are affiliated with both the

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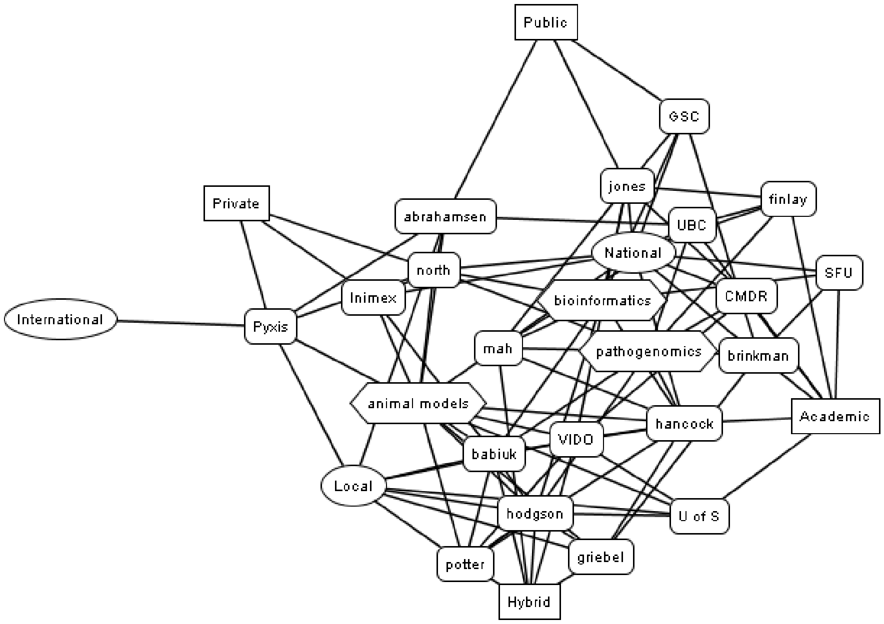
[52] With the exception of one FPMI actor who works out of the University of Minnesota in Minneapolis.

[53] Subprojects or research interests are differentiated across both case studies and, of course, are case dependent according to project and disciplinary focus.

[54] Saskatoon-based firms or organisations were deemed 'local' while any other Canadian-based ones (outside of Saskatoon) were categorized as 'national'.

pathogenomics and animal model FPMI sub-projects. Therefore, links amongst this individual, the organisation, the sub-projects, location (national) and sector-type (private) are identified and illustrated[55]. Figure 4.1.1 employs various shapes to distinguish between nodes that are individuals or organisations and those that are attribute-based nodes (eg. location-oriented nodes (ovals), sector-type (rectangular) and sub-projects (irregular hexagon)).

Figure 4.1.1 FPMI Point-of-Award Network Structure



Created with CASOS SocialInsight

Based upon ORA Intelligence and Context reports, agent x agent (individuals and organisations) density for the FPMI network is 2.4% while the larger meta-matrix (including sub-project, affiliations, location) is 2.8%. The Intelligence report uses a pre-defined set of measures to analyse the central actors and groups in an organisation. The top actors and groups are ranked, and then an overview of the key characteristics of the organisation as a whole is presented. When a comparison report is generated, the percent change between organisations is also displayed. The Context report compares the given organisation to a random network, and a database of known social networks, for a selected set of measures (the

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[55] Sub-projects for the FPMI network were defined through the interview process.

ORA database consists of a sample of 20 representative organisations or networks). The ORA reporting system allows for a comparison of network measures against a database of existing networks that are part of the software resources. Average centrality measures for the agent x agent network (N=19) are outlined in Table 4.1.1 along with ORA database mean measures for comparative purposes.

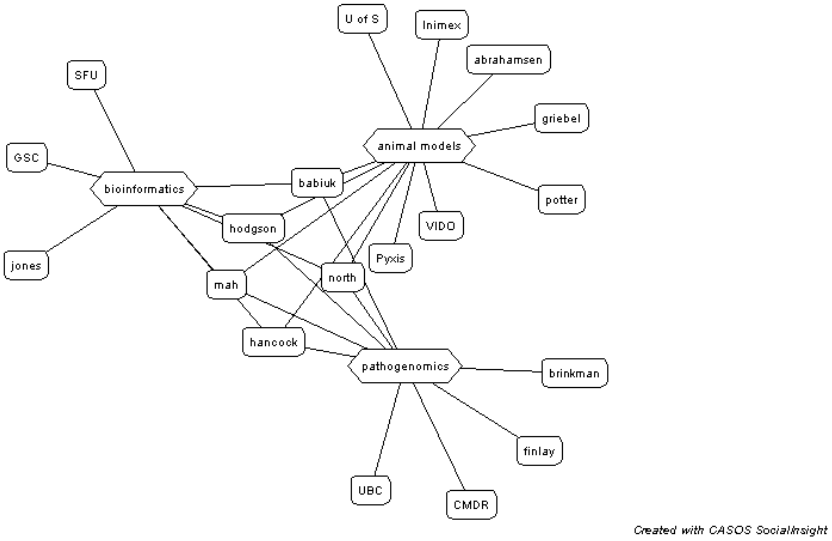
Table 4.1.1 FPMI Agent x Agent Network Centrality Measures

	FPMI Network (average across all agents / N=19)	Sample ORA Database Mean	Results from ORA
Centralisation Betweenness	0.1039	0.0472	MIN = 0.0000 MAX = 0.4031 STDDEV = 0.1004
Centralisation Eigenvector	0.4538	0.1652	MIN = 0.0696 MAX = 1.0000 STDDEV = 0.2820
Total Degree Centralisation	0.4094	0.2842	MIN = 0.1389 MAX = 0.6944 STDDEV = 0.1494

According to the results, as compared with other networks in the ORA database, the FPMI network is more cohesive than other networks (centralisation Eigenvector), it has more paths by which information can get from one actor to another (betweenness-centralisation) and, on average, FPMI actors have more connections to other network agents than is typical (total degree centralisation). However, standard deviations suggest higher variability in terms of the Eigenvector measure (network cohesiveness).

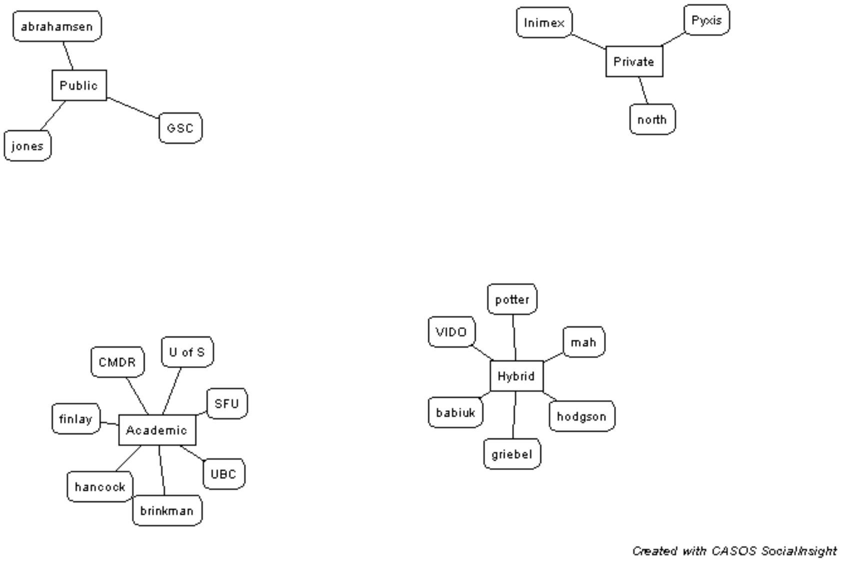
To simplify the FPMI network further, attribute-based sub-networks are segregated out of the larger meta-matrix and illustrated below. Figure 4.1.2 shows FPMI network actors (individuals and organisations) and their links to FPMI sub-projects which include bioinformatics, animal models and pathogenomics.

Figure 4.1.2 FPMI Sub-project Network



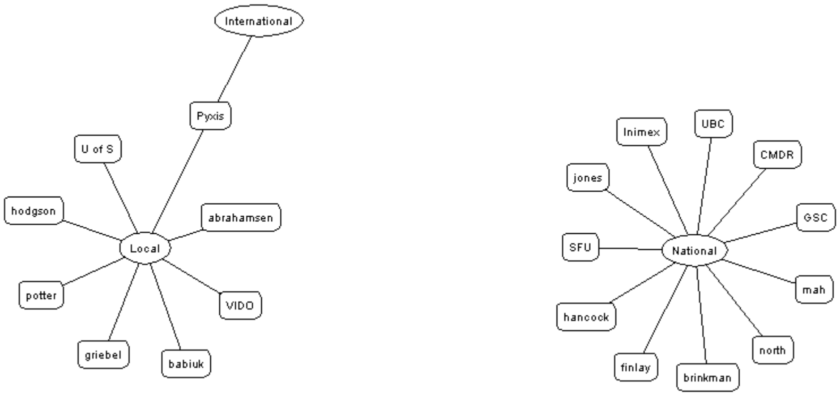
Next, Figure 4.1.3 illustrates the sub-networks which link FPMI actors to their affiliation-type: academic, hybrid, private or public institutional parameters.

Figure 4.1.3 FPMI Affiliation Networks



Finally, the FPMI network is structured according to agent location. The location-based network is illustrated in Figure 4.1.4 and links actors as to attributes that define them as either locally, nationally or internationally situated. In some cases, agents may be linked to one or more parameters (for instance, Pyxis which has local and international connections).

Figure 4.1.4 FPMI Location Networks



Created with CASOS SocialInsight

Although the aforementioned figures clearly illustrate dominant attributes, the sub-networks are quantitatively analysed with centralisation measures for each sub-network of interest presented in Table 4.1.2.

Table 4.1.2 Comparison of Centrality Measures by Location, Affiliation/Organisation Type and Project Type

Sub-Network of Interest	Degree Centralisation	Results from ORA
Sub-Project		
Bioinformatics	0.4444	AVG=0.5370 STDDEV=0.0944
Animal Models	**0.6667***	
Pathogenomics	0.5000	
Affiliation/Organisation Type		
Academic	**0.3889***	AVG=0.2639 STDDEV=0.0992
Hybrid	0.3333	
Private	0.1667	
Public	0.1667	
Location		
International	0.0556	AVG=0.3704 STDDEV=0.2328
Local	0.4444	
National	**0.6111***	

Results suggest that the 'animal models' subproject is the most central activity for the FPMI network. Bioinformatics appears to be a tertiary activity which would follow the assumptions that this sub-project works in as supportive capacity to the overall FPMI project. Additionally, there appears to be a higher level of academic-based activity within the network, suggesting that most actors (individuals and organisations) are defined as or are members of academic institutions. Hybrid-type organisations also rank relatively high in terms of centralisation measures for attribute-based institutional affiliation. However, in most cases, 'hybrid' actors that are illustrated in Figure 4.1.3 are directly associated with VIDO (identified as a 'hybrid' actor[56]). Network actor Mah appears to be the exception. However, as one of the Project Managers of FPMI (Hodgson is the other[57]) Mah has been categorised as a 'hybrid-based' actor as she is affiliated with both the FPMI project and with the University of British Columbia. Private and public sector-based affiliations are significantly lower for the FPMI network. However, public sector affiliations (in particular the University of Saskatchewan) may be disguised under the dominant network actor VIDO that is defined as a hybrid in terms of organisational type. Finally, with respect to location, most agents are nationally based (Canadian and non-local) or have links to nationally based organisations, institutes or firms. However, there is still a high level of locally situated activity. International linkages or affiliations are significantly lower. Of note, the non-local nationally based affiliations are located in and around the University of British Columbia.

The ORA program generates statistical data for comparative purposes (see Table 4.1.2). FPMI principals are assumed to represent the entire population of interest. However, a comparison of ORA results with those generated on the FPMI network indicates that the FPMI values for 'international' are significantly lower than those of the ORA database results. This would suggest that in terms of this location factor, there is a lack of individuals or principals representing areas outside of Canada.

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[56] VIDO covers both private and academic activities.

[57] Hodgson's affiliation, like other FPMI broader network actors were defined early on in the research. At that point, Hodgson had not yet been appointed as Project Manager. He was defined as a network actor directly affiliated with VIDO.

Key actors are of particular interest in this dissertation. Therefore, calculating centrality measures at the actor-level (as opposed to the network level) highlight influential leaders within the broader FPMI network. Calculations are based upon binary agent x agent relationships. This takes into account all agents within the network including individuals, organisations or firms along with the linkages identified with the other sub-groups (FPMI sub-projects, affiliation-type and location). Results of measures of centrality betweenness, centrality Eigenvector and degree centrality of the broader network of FPMI actors and agents are outlined in Table 4.1.3.

Table 4.1.3 Summary of Point-of-Award Centrality Measures by Key Network Principals (N=19)

Rank	Centrality Betweenness "Potential Influence"	Centrality Eigenvector "Informal Power"	Total Degree Centrality "In-the-know"
1	Finlay (0.1089)	Babiuk (1.0000)	Babiuk (0.5000)
2	Babiuk (0.0964)	Potter (1.0000)	Potter (0.5000)
3	Potter (0.0964)	Finlay (0.9766)	Hancock (0.4444)
4	Brinkman (0.0915)	Hancock (0.9693)	Finlay (0. 4444)
5	VIDO (0. 0915)	Brinkman (0.9665)	Brinkman (0. 4444)

Of the 19 actors included in the broader meta-matrix, only 6 are ranked within the top five positions in terms of all three centrality measures (Babiuk, Finlay, Potter, Hancock, Brinkman and VIDO). Babiuk leads both in terms of Eigenvector centrality and in total degree centrality. The former measure calculates an agent's centrality to the extent that the agent's neighbours are central. Total degree centrality, on the other hand, identifies those agents that are 'in-the-know'[58]. Therefore, the results suggest that Babiuk has a high number of ties with other central agents or principals within the FPMI network, he holds a significant amount of informal power and he is assumed to be a leader for the network.

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[58] This term is employed by ORA to qualify or explain total degree centrality.

Potter also ranks within the top three in all three centrality measures. Based upon their overall centrality, it appears that both Potter and Babiuk hold a significant amount of power within the FPMI network. The two have a significant history together, particularly in terms of the development and management of VIDO. Respectively, Babiuk and Potter hold the positions of Director and Associate Director of the organisation.

In terms of centrality betweenness, Finlay is identified as the overall leader (relative to other actors). This would suggest that Finlay is on a critical route for flows within the network and assumed to be 'potentially influential'[59] in terms of how knowledge is generated and how it flows throughout the network.

Of the group of key network actors (n=6; individuals and organisations) identified through centrality measures (Table 4.1.3 above), three are nationally-based (non-local but Canadian) while the remaining three are situated locally (Saskatoon). Of those six actors, three are deemed to be hybrid (VIDO) or have hybrid type affiliations (Babiuk and Potter). In terms of sub-project or research interest, two core agents are affiliated with animal models, two are affiliated with pathogenomics and two (Hancock and Babiuk) are linked with all three. No obvious leader or central actor exists for solely the bioinformatics sub-group within the identified core group. Again, as this sub-project operates in a supportive capacity to the larger FPMI project, this latter observation appears to be accurate.

Although 11 individuals (scientists and managers) and organisations are identified in this part of the analysis, this number has been narrowed to just eight primary actors (hereafter referred to as 'principals') for the second part of the analysis. This latter group of individuals is delineated according to their respective key roles in the FPMI project. They are the formal signatories of the original proposal and are formally designated on the subsequent Genome Canada award. It is the output and collaborative activity of these key principals that are of interest for the next part of the analysis.

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[59] This term is employed by ORA to qualify or explain betweenness centrality.

4.2 Pre-Award Analysis of FPMI Network

Pre-award analysis is conducted on the network structure as it is organised under the currently funded FPMI project. Therefore, the actors or the principals number 8 and, as previously indicated, are geographically distributed in Saskatoon, Saskatchewan, in B.C. and in Minnesota (1 actor) (principals of interest for this part of the analysis are those that have * by their name in Appendix B).

Relational data amongst principals, including co-publishing and co-patenting, is collected and network structures are illustrated later on in this chapter. The period of interest for pre-award analysis falls between 1985 and 2004 with intervals broken out as follows: 1985-1989; 1990-1994; 1995-1999 and 2000 to point-of-award. Point-of-award, in the case of the FPMI project is 2002. However, data on patents is collected and categorised by time interval according to 'date of award' and not by 'date filed'. Given the lag period assumed between publications and patents, co-patenting activity from 2000 right up until 2004 is also included within the parameters of pre-award analysis (provisional patents or patent application activity from point-of-award (2002) to 2004 is considered under the parameters of post-award analysis Section 4.3). NetDraw is used in pre-award analysis to visualise the collaborative activity amongst network principals has the capacity to illustrate weights of linkages (representing volume of output). ORA, however, is still used to generate reports and conduct calculations to quantitatively support the visualised agent x agent networks.

As outlined in the methodology chapter, of additional interest to this dissertation is the exploration of network-based collaborative activity with respect to publishing, patenting and securing funding activity as it relates to proximity. This notion, as it relates to the FPMI project and associated principals, is explored in relevant sections throughout this chapter..

4.2.1 Co-publishing Activity

Each time interval of co-publishing activity amongst FPMI network principals depicts a disconnected graph consisting of one or more sub-works structured as clique(s), dyad(s), and /or triad(s) amidst, in most cases, a high proportion of principal with no linkages whatsoever (i.e. isolates). The figures below (4.2.1 to 4.2.4) show the graphs generated by NetDraw. Links between network principals are weighted to represent value-based data.

Figure 4.2.1FPMI Network Co-publishing Activity by Time Interval 1985-1989

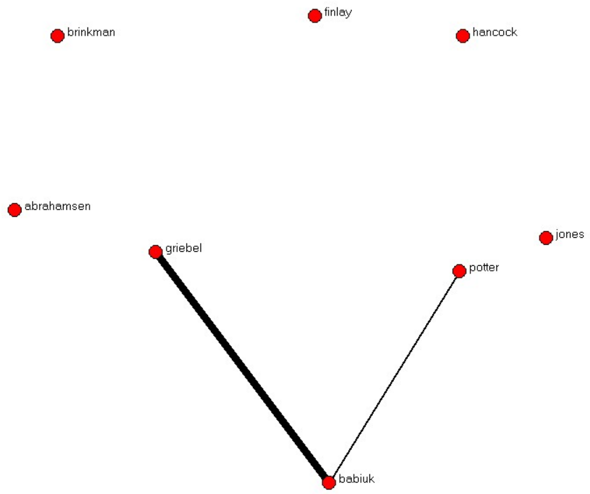


Figure 4.2.2 FPMI Network Co-publishing Activity by Time Interval 1990-1994

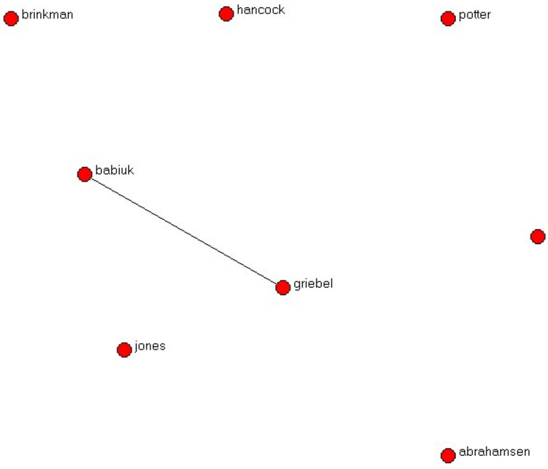


Figure 4.2.3 FPMI Network Co-publishing Activity by Time Interval 1995-1999

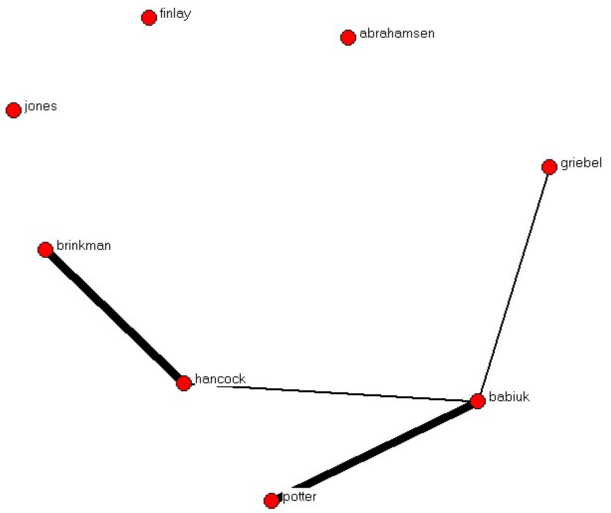
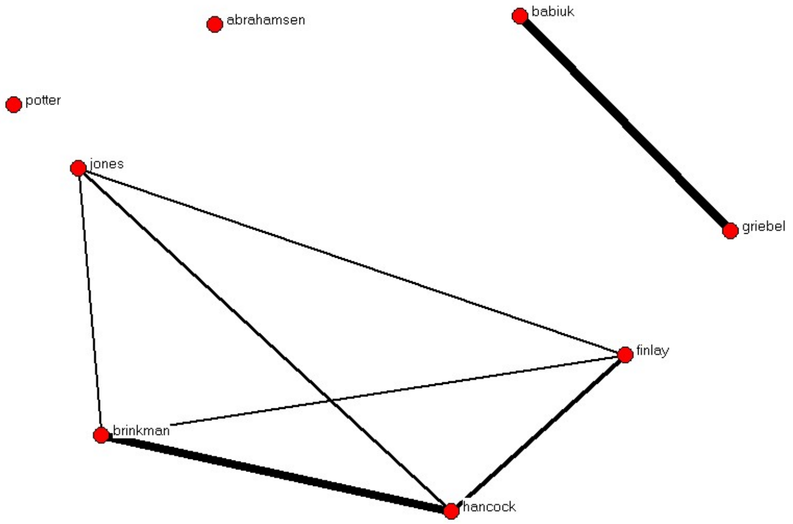


Figure 4.2.4 FPMI Network Co-publishing Activity by Time Interval 2000-2002



Based upon the results from these graphs, the FPMI network appears to develop over time evolving from a single open triad with several isolates in the first time interval (1985-1989; Figure 4.2.1) to a closed clique and a dyad with only two isolates in the latter time interval (2000-2002; Figure 4.2.4). A closed clique is a maximally complete sub-graph wherein every node is connected to every other node (there has to be > 3 nodes or actors).

To support these qualitative visuals of the FPMI network, whole network density and centralisation measures in terms of co-publishing activity by time interval are outlined in Table 4.2.1.1 along with the sample ORA database centralisation means with which to compare results. Centralisation measures in Table 4.2.1.1 are calculated with value-based input data (eg. actual number of co-publications is incorporated into dataset) rather than assuming merely a binary relationship between agents.

Table 4.2.1.1 FPMI Network Co-Publishing Centralisation and Density Measures by Time Interval

	Total Output (# co-pubs)	Centralisation Betweenness	Centralisation Eigenvector	Degree Centralisation	Density
1985-1989	7	0.0060	0.2688	0.2500	7.1%
1990-1994	2	0.0000	0.2500	0.0714	3.6%
1995-1999	6	0.0476	0.4456	0.2143	14.3%
2000-2002	21	0.0000	0.3596	0.7500	25.0%
Sample ORA Database Mean		0.0472	0.1652	0.2842	

Co-publishing activity amongst network principals, in terms of betweenness-centralisation measures, suggests that on average there are fewer links between network principals over time relative to the sample means in the ORA database. Across all time intervals, higher Eigenvector centrality measures suggests that the co-publishing networks are significantly more cohesive than average. Finally, based on degree centralisation measures, network principals have fewer connections to other members than is typical in the first three time intervals (1985-1989; 1990-1994; 1995-1999) but in the latter time interval the degree centralisation measure is significantly higher than average, even with the shortened time period (2000-2002). Echoing the interpretation of graphs above, the results of the combined centralisation and density measures suggest that the FPMI network evolves in terms of co-publishing activity (other than the nominal drop in some values between 1990 and 1994), with principals collaborating more and more over time.

What role does proximity plays in terms of co-publishing activity? Re-examining co-publication activity over time shows that those principals involved in co-publishing activity in the first two time intervals are all locally based (Griebel-Babiuk-Potter & Griebel-Babiuk). By the 1995-1999 time interval, collaborative efforts have increased significantly yet such activities are still proximity based. The exception is Babiuk who assumes a central role, mediating between locally and non-local based publishing activities. By the final time interval, Hancock-Jones-Finlay-Brinkman have formed a closed clique of activity which, according to the currently defined FPMI network structure, is based in and around the region of Vancouver and Burnaby. Babiuk and Griebel continue with a collaborative relationship in this latter time interval building upon the linkages that are graphed for time interval one (1985-1989).

4.2.2 Co-patenting Activity

A search of patents on the USPTO (by award date) in the time intervals of interest finds no co-patenting activity amongst FPMI network principals. This is unusual as one might assume that a relative density of co-publishing activity would lead to co-patenting activity as well. However, FPMI principals *do* patent their inventions. As previously mentioned, an assumed lag period would exist between point of invention and the patent award date. Therefore, the pre-award analysis (including analysis of key principals' patenting activity in Section 4.2.4) will also include those patents awarded between point-of-award and 2004 (again, provisional patents from point-of-award (2002) to 2004 are considered under the parameters of post-award analysis in the following section). Patent output for the FPMI network in the pre-award period is outlined in Table 4.2.2.1.

Table 4.2.2.1 Patenting Output of the FPMI Network by Time Interval

	Total patents by network principals	Overall distribution of patent activity
1990-1994	6	16%
1995-1999	12	31%
2000-2004	20	53%
Total Patents	38	

Although the results indicate that there is no collaborative activity with respect to patenting in the pre-award period, the overall patent-based output appears to grow over time, with the final time period of 2000-2004 accounting for over 50% of total activity. Patent application activity from time of award (2002) to 2004 for the FPMI network is explored in section 4.3 post-award analysis.

4.2.3 Network Capacity for Securing Funding

The ability to secure funding for research is an important skill for academics and researchers alike. Such funding provides important resources for hiring graduate students and post-docs (expanding the network), for stocking laboratories and purchasing capital equipment and to fund new ideas and innovations. Such funding can be sourced from a number of federally based programs. Those of interest to this dissertation and, of course, the analysis of the FPMI network are: CFI, NSERC, CIHR and SSHRC.

A preliminary search of the SSHRC database identified no links to any principals associated with either the FPMI or the FGAS projects. Therefore, with respect to this case study, data collection was limited to CFI, NSERC and CIHR. Commencement of data varies between agency of interest as some have more recent inception dates. While NSERC was established in 1978, the CFI was not established until 1997. The CIHR, on the other hand, was initiated in 1999. Although NSERC was established well over two decades ago, a search of the database did not return any results for FPMI network principals until after 1990. Therefore, results of the analysis begins with the second interval (1990-1994) up to point-of-award

(2002). Table 4.2.3.1 outlines total grants and awards (including scholarship monies) by funding agency and time interval.

Table 4.2.3.1 FPMI Network Grants and Awards by Funding Agency and Time Interval

	CFI	NSERC	CIHR	TOTAL $		Funding $/principal
1990-1994	n/a	$7,018,041	n/a	$7,018,041	19%	$877,255
1995-1999	n/a	$6,398,872	$5,599,656	$11,998,528	31%	$1,499,816
2000-2002	$6,315,197	$1,767,526	$10,873,190	$18,955,913	50%	$2,369,489
	$6,315,197	$15,184,439	$16,472,846	$37,972,482		

* Note: CIHR funding windows varied and were often longer than those of NSERC or CFI ranging from 1999-2000 to 1999-2005. Thus, CIHR values were segregated in this analysis by time interval based upon the starting year of the award.

According to the results, FPMI network principals secured a total of $37,932,482 in funding between 1990 and 2002. Fifty percent of funding was secured in the latter period of 2000-2002, a significant proportion of that attributed to funds secured through CIHR. Over 40% of total funding was obtained through this agency.

Of interest to this dissertation is, of course, collaborative activity amongst network principals. A search of the CFI and NSERC funding databases indicated that there were *no* grants awarded jointly to FPMI network principals. However, there were collaborative grants secured through the CIHR during the final time interval (2000-2002). Of the $10.8 million awarded to network principals by the CIHR, $2.6 million (24%) of that was secured by two or more FPMI network principals in collaboration. Babiuk-Potter-Griebel obtained a grant in the amount of $1.6 million while Jones-Brinkman obtained another in the amount of $1.2 million. The density for securing joint funding for the time interval 2000-2002 was 16%.

Based upon the results some general conclusions can be drawn with respect to the relationship between geographical location of FPMI principals and collaborative activity with respect to securing funding. Close geographical proximity appears to matter. In both cases, the collaborations are amongst principals in close proximity to one another. Jones and Brinkman are located in and around Vancouver. Similarly, the collaboration of Babiuk-Potter-Griebel represents a proximate group of collaborators as all are located in Saskatoon. While this latter group works together at VIDO, the former cross organisational boundaries in order to secure funding as each principal represents a different organisation (Genome Sequencing Center (GSC) and Simon Fraser University (SFU), respectively).

Individual capacity in terms of securing funding is explored in the following section.

4.2.4 Key Principals in FPMI Network Activities

Although collaborative effort in terms of tapping into new resources and generating new knowledge (eg. securing funding, publishing or patenting) is critical, it is also important to understand the impact of 'individual' capacity for output. This will help to identify potential leaders in terms of activity and to understand the structure of network in question. As Katz et al (2000) suggests, scientists will seek out the most appropriate expert partners, reflected by reputation and linked to quality and quantity of individual output (eg. publications and/or patents). Although organisations or research institutes are frequently important attractors, it is often the individual actor or expert that is associated with these organisations that proves to be the primary draw[60]. Therefore, this part of the analysis will examine individual output in the pre-award period. It includes not only principals' capacity to secure funding but also individual capacity to publish and to patent over time in the pre-award period.

A review of funding sources (CFI, NSERC and CIHR) obtained by FPMI network principals finds that all but one principal (Abrahamsen) secured funding at some point(s) over the pre-award period. This result makes sense as Abrahamsen is located in the United States and likely secures funding from U.S. based sources.

In terms of nationally and locally-based agents, the top five performers in obtaining funding (Hancock, Babiuk, Finlay, Jones and Potter (in that order)) secured 99% of total funding ($38 million). Almost 80% of that funding, over $29 million, was secured by Hancock and Babiuk alone (See Table 4.2.4.1). Average funding per network actor was calculated at $4.7 million. These normalised values are used for comparative purposes in Chapter 6.

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[60] For instance, in personal interviews regarding the evolution of the NRC-PBI, two [anonymous] former PBI researchers indicated that Wilf Keller was the most powerful draw for them to come to the Saskatoon research community in the early 1990s.

Table 4.2.4.1 Key Network Principals in Sourcing Funding (1990-2002)

	Funding Secured 1990-2002 (CFI, NSERC & CIHR)	Per Cent Funding Secured by Principal
Hancock	$15,081,567	40%
Babiuk	$13,938,739	37%
Finlay	$5,335,890	14%
Jones	$2,636,719	7%
Potter	$556,033	1%
Average funding $ per network actor	$4,746,560	
Total funding by network principals	$37,972,481	

In terms of individual publication output, FPMI network principals accounted for a total of 681 articles during the pre-award period (1985-2002). Publishing activity was fairly evenly distributed across all time intervals. However, 1995-1999 was peak in terms of aggregate output representing 35% (n=238) of total publications.

Table 4.2.4.2 outlines the top five FPMI network performers in terms of publication output: Babiuk, Hancock, Finlay, Potter and Abrahamsen (in that order). The top five accounted for well over 90% of total output for the entire network. The top three - Babiuk, Hancock and Finlay - accounted for over 80% (500+ articles) of this activity. Overall, Babiuk appears to be a leader in publication activity (publication leaders across all time intervals are highlighted). Babiuk leads in all intervals with the exception of the 2000-2002 time interval where Finlay leads. In terms of publication output, Abrahamsen appears on the radar only in time interval 1990-1994. However, little or no collaborative activity with other network principals (in all activities) over the pre-award time period suggests that Abrahamsen's role with the currently structured FPMI network may be linked, instead, with other activities. Further investigation shows that Abrahamsen's link with other FPMI principals is a more recent occurrence. Abrahamsen is the Chief Scientific Officer for Pyxis Genomics U.S.A. The nature of his role in the project and Abrahamsen's history with project principals is outlined further in section 4.3.

Table 4.2.4.2 Key Network Principals in Publishing Activity by Time Interval (n=650)

	1985-1989	1990-1994	1995-1999	2000-2002	Total
Babiuk	**62**	**59**	**79**	35	235
Hancock	43	37	60	40	180
Finlay	19	24	57	**53**	153
Potter	6	17	15	7	45
Abrahamsen	0	6	17	14	37
Average output (publications) per network principal	17.1	18.6	30.0	21.8	
Total publications by top five network principals	130	143	228	149	n=650

With respect to patent output, the window for this type of knowledge generation activity is short for networks principals. A search of the USPTO patent database finds no patents awarded to FPMI network principals until after 1990. Therefore only those time intervals from 1990 onward are considered in this part of the analysis. As previously mentioned, an assumed lag period would exist between point of invention and the patent award date. Therefore, the pre-award analysis will also include those patents awarded between point-of-award and 2004 (again, provisional patents from point-of-award (2002) to 2004 are considered under the parameters of post-award analysis in the following section).

Although there was no co-patenting activity recorded amongst FPMI network principals in the pre-award period (section 4.2.2), several network principals were named on a number patents in the pre-award period. A total of 38 patents were awarded to FPMI network principals between 1990 and 2004. Of those, over half (20) were awarded in the latter time interval of 2000-2004. Twelve were awarded in the previous time interval (1995-1999) and six were awarded between 1990 and 1995. Of the 8 network principals associated with the formalized project, only 4 were involved in patenting activity: Babiuk, Potter, Hancock and Finlay. Babiuk and Hancock account for 87% of all patenting activity with 17 and 16 patents awarded respectively to each. Table 4.2.4.3 outlines the top key principal actors in terms of patent output by time interval.

Table 4.2.4.3 Key Network Principals in Patenting Activity by Time Interval

	1990-1994	1995-1999	2000-2004	Total	Lead Applicant
Babiuk	4	6	7	17	2
Hancock	0	5	11	16	14
Potter	2	1	1	4	4
Finlay	0	0	1	1	1
Average output per network actor	0.75	1.5	2.5		
Total patents by network principals	6	12	20		
Overall distribution of patent activity	16%	31%	53%		

Another observation of this analysis is that within the group of 38 patents awarded in the pre-award time period, FPMI principals were named as lead applicants (Hancock, Potter, Babiuk and Finlay). Normalised data/results from this case study will be used in chapter 6 for comparative purposes. See Appendix C for a listing of the FPMI network inventors, associated patent numbers, award dates, assignees and other related information.

4.3 Post-Award Analysis of FPMI Network

Descriptive analysis and output measures are used in post-award analysis. The time period of interest here is from the time of award onward (2003-2004). The post-award period is short and performance indicators are limited in terms of applicability in this part of the analysis. However, in interviews with network principals across both projects of interest, the following parameters were suggested to be good indicators of short-term post-award output: seminars, presentations, publications, provisional patents/patent applications, spin-offs, trained personnel and tools for discovery. The FPMI network output is outlined in Table 4.3.1.

Table 4.3.1 Post-Award Output for the FPMI Network (2003-2004)

Short-term Indicator	Network Output
abstracts/posters/seminars	23
presentations	44
publications (total)	152
publications (network based)	17
awards	29
trained personnel	45
tools for discovery / intermediate innovations	Open source pipeline, model infections, library and products
provisional patents / patent applications (total)	30
network-based patent applications	9
spin offs	2
funding secured	$29,611,245

In the post-award period, FPMI network principals generated a total of 152 publications, 17 of which were network-based publications and represented collaborative activity. Network-based publications are those that are formally recognized as project-related articles as listed on the FPMI website. The FPMI network generated an additional 67 other 'know-why' knowledge-related output which included conference, poster and seminar presentations as well as abstract submissions. FPMI network principals were recognised through twenty nine awards in the post-award time period[61]. These awards included post-doctoral fellowships, industry leadership and innovator awards, graduate student awards provided for through various national institutions and organisations such as CIHR, NSERC, the Canadian Animal Health Institute as well as the National Institute of Health (NIH) in the United States. Over the course of the post-award period, the FPMI project trained a total 45 individuals including 8 post-doctoral fellows, 11 graduate students and 26 undergraduate students.

In terms of 'know-what' or synthetic-based knowledge, the FPMI network generated a total of 30 provisional patents in the post-award period. Appendix D provides a detailed listing of post-award provisional patents. Of these 30 post-award provisional patents, 9 involved two or

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[61] This number represents those publications from 2003-2004 as outlined on the FPMI Publications website, available online at: http://www.pathogenomics.ca/publications.html.

more FPMI network principals. In twelve of the total (30), FPMI network agents or principal investigators were listed as lead inventors. Of the 9 network based provisional patents, 4 listed were lead by network actors. In one case, Finley and in the remaining three, Hancock was the lead inventor. On average, the provisional patents listed 4.2 inventors per application. Of the total of 30 provisional patents, only 10 explicitly listed an assignee. In all cases, assignees were academic actors (either UBC or U of S).

Additionally, the FPMI project resulted in several tools for discovery and intermediate innovations. This includes a web-based, semi-automated, open source pipeline "ArrayPipe" which was developed by the FPMI bioinformatics group at Simon Fraser University. This tool is used for the initial pre-processing of microarray data. Several bovine and chicken model infections have also been developed. A library of 10,000 random Pseudomonas aeruginosa lux transposon mutants has been developed and sequencing is completed on 3200 PCR products.

In terms of spin-offs, two have been identified as resulting from the FPMI project. Inimex Pharmaceuticals was founded in 2001, with the anticipation that the organisation would be used as a commercialisation tool for new discoveries associated with the pending FPMI project. Inimex proprietary technology involves the understanding of genomics associated with the up-regulation and control of innate immune response to provide for new therapeutic strategies for disease and infection treatments. A peptide patent, co-invented by FPMI principals Finlay and Hancock, served as a foundational innovation for the establishment of the organisation.

Pyxis Genomics USA was originally established as Anagenomics in 2000. The Canadian counterpart was established in the Saskatoon region in conjunction with the FPMI project in 2002. Thus, Pyxis Canada is included as a spin-off of the FPMI project. The link between Pyxis and the FPMI project began with a serendipitous conversation and cab ride between Lorne Babiuk and a Burrill and Co. executive. Babiuk had been attending a Scientific Advisory Committee meeting in the San Fransisco bay area in 2001. The cab ride to the airport turned fortuitous when Burrill executive referred Babiuk to Pyxis USA, when Babiuk had outlined the Project and the need for matching funding. The Burrill executive had previous investment dealings with Pyxis USA at the onset of its development in 2000. A connection was made immediately between Babiuk and Pyxis USA executives and Mitch Abrahamsen (CSO of Pyxis) came on board with the FPMI project. Pyxis Canada grew out of this partnership[62].

The amount of funding secured in the post-award period is assumed not only to reflect the capacity for the FPMI project and its principals to attract funding but is also considered a definitive output of the project. In total, FPMI network principals secured $29.6 million in funding in the post-award period of 2003-2004. Sixty five percent ($19.3 million) was sourced through the CFI while another 31% ($9.3 million) was secured through CIHR. The remaining $987K was sourced through NSERC. Almost $30 million in post-award funds represents a 56% increase from the previous time interval (2000-2002). Also, there is a notable shift in sources by funding agency in the post-award period. In the 2000-2002 time interval most funding was secured through CIHR (57%) while, in the post-award period, most was sourced through the CFI.

4.4 Summary

The FPMI network was defined early in this dissertation as one that is 'organic' and whose structure grew out of self-organisation of network principals that have collaborated over time. Given this, one would expect that, historically, there would be a higher level of collaborative activity amongst network principals than a network that is 'imposed' in terms of its structure. Although this notion can only be fully tested by comparing networks (this will be covered in the chapter 6), a few observations can be made at this point about the FPMI network:

Network Structure: Point-of-award analysis suggests that the FPMI network consists of a balance of actors that are located either in Saskatoon or in and around Vancouver, B.C. Also, there appears to be one dominant research activity or focus (animal models). Similarly, there

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[62] As Pyxis Canada was unable to raise much needed capital, the relationship between FPMI and Pyxis dissolved in early 2004. Pyxis Canada has since gone into receivership as of early 2005. Although not entirely a standalone firm (a satellite of an existing firm) and, as it turned out, it failed to remain solvent, Pyxis Canada is characterised as a spin-off of the FPMI project.

is a balance of actors representing both academic and hybrid organisatons. As VIDO has been identified as a hybrid organisation and that most actors are affiliated with either VIDO or a university (U of S or UBC), these results are anticipated. There is little private and public sector representation within the FPMI network.

Knowledge Exchange Capacity: Although there is no co-patenting activity amongst FPMI principals in the pre-award period, the network does appears to evolve from a single open triad with several isolates in the first time interval to a closed clique and a dyad with only two isolates in the latter time interval with respect to co-publishing activity. In intervals one, two and three, locally-based Babiuk, Griebel and Potter collaborate with respect to publications. In the fourth interval, however, principals from the Vancouver area (Hancock and Brinkman) link in with locally based principals. Over time, proximity appears to matter less with respect to collaborative activity (publications).

Knowledge Creation Capacity: In point-of-award analysis, the clear leaders are identified in terms of their centrality actors within the network: Babiuk, Potter, Finlay, Hancock and Brinkman (in that order). Comparing the list generated through institutional analysis (the subjective process of point-of-award analysis) and those identified through more quantitative, objective methods (pre-award analysis using bibliometrics and technometrics), it appears that four of these five central actors are repeatedly listed as central actors in terms of publication, patent and funding related output. Babiuk and Hancock are consistently listed as leaders across all forms of knowledge output. Other than funding secured, Potter and Finlay are listed as third and fourth position. Overall, the results from point-of-award analysis are consistent with pre-award analysis of knowledge creation activity.

Chapter 5

CASE STUDY #2 – FUNCTIONAL GENOMICS OF ABIOTIC STRESS (FGAS)

5.0 Introduction

The Functional Genomics of Abiotic Stress (hereafter referred to as FGAS) is significantly more complex than the FPMI network both in terms of structure and scale. This project was originally submitted for funding under Competition I through two letters of intent under two separate proposals and led by two different networks of principals. The first proposal involved the exploration of proteins and genes involved in regulating wheat's response to low temperatures. The other proposal involved the study of canola's response to metal and nutrient stresses. Upon evaluation[63], Genome Canada determined that combining the projects would offer a cost-effective and more favourable way to structure the project. Thus, FGAS was only awarded once both groups agreed to collaborate to develop a unified proposal for Competition I.

As of 2004, the FGAS project was described as exploiting a "…range of genomics and proteomics technologies to decipher the genetic mechanisms that underlie the plant response to various abiotic stresses" with crops of interest being wheat and canola[64] (FGAS 2005). This would appear to be a rather broad set of objectives. However, the Project size and its structure as imposed by Genome Canada's funding requirements forced a combination of the objectives as originally set out in the original two proposals.

The broader FGAS network, as it is analysed in point-of-award analysis, is a large network involving 20+ principals geographically dispersed across five provinces. At peak performance, the structure of the project consisted of 25 principal investigators, 16 research assistants, 34 technicians, 8 post-docs, 11 graduate students, 4 bioinformatics specialists, 5 undergraduate

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[63] GENOME CANADA projects are selected /awarded following an in-depth evaluation process involving more than 150 international experts in each Competition.

[64] FGAS uses the plant *Arabidopsis thaliana* as a model plant for its experimental systems.

students, 1 project manager as well as more than 20 other individuals (Appendix E outlines actors either formally affiliated or informally connected with the network).

The complex structure of the network is further illustrated in terms of funding/monetary discrepancies across regions. In terms of matching funding, the FGAS project partners in Quebec are fully matched. However, as of 2004, matching was incomplete in Saskatchewan. According to an interview with FGAS Project Manager Elizabeth Nanak[65], the matching issue came up after the award when 'Rules for the Project' changed. According to Nanak, incongruities (money, geographical, and research foci) amongst principals created discrepancies in terms of output across regions and led to tensions that also affected project work.

Given the fragmented nature of the FGAS project as it is currently structured, one might assume that an exploration of the historical evolution of the network leading up to award would point to two disparate networks. This assumption will be tested in this chapter. As with the FPMI project, co-publications, co-patents and co-funding are used to proxy interactions or collaborations amongst principals for the pre-award period. First, however, point-of-award analysis is conducted to obtain a picture of the broader FGAS network of interest.

5.1 Point-of-Award Analysis of FGAS Network

The broader FGAS affiliation and partnering network is comprised of 31 local, national and internationally based organisations and firms as well as 26 individual scientists (N=57). The network, in its entirety, is illustrated in figure 5.1.1 and includes the 21 network principals (of interest to this dissertation) as well as other key individuals (Crosby, Haughn, Nanak, Pelcher and Ross)[66]. Appendix E lists all FGAS actors, their affiliation types as well as their locations.

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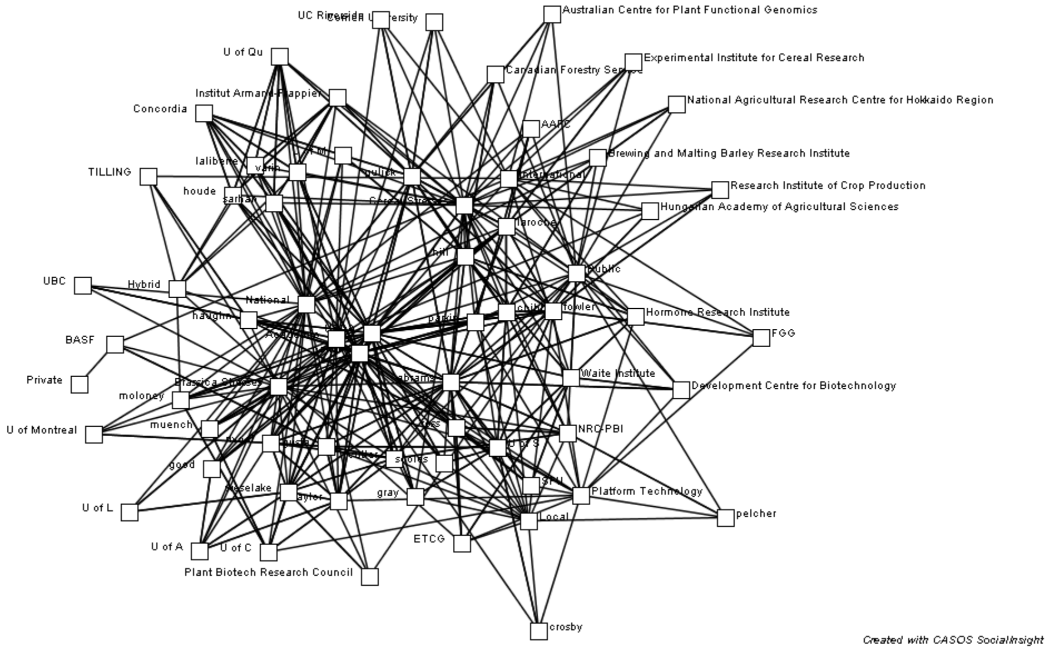
[65] Personal Interview: April 3, 2005.

[66] Early on in the research, a preliminary list of 21 principals was put together based upon interviews with the original project manager and a brief review of publicly available FGAS documents. At this point, the future project manager (Nanak) and platform technology team (Crosby, Haughn, Pelcher and Ross) were not considered in the data collection process and, unfortunately, are not included in pre-award analysis data. However, these individuals are all for accounted in this section of the dissertation.

The network shows the relational information such as agent or principal links to affiliations and partners and sub-project or research interest in terms of the FGAS project (Brassica stresses, cereal stresses or platform technology), affiliation type (academic, public, private or hybrid) and organisational or firm location (local, national or international)[67]. As with the analysis of the FPMI network, Organisational Risk Analysis (ORA) software is used to illustrate the meta-network structure (which includes attribute-based elements: sub-project or research focus (in this case, brassica stresses, cereal stresses and platform technology), affiliation-type (academic, public, private and hybrid) and geographic location (local, national and international), to generate network-level density and centralisation measures and to calculate measures and develop graphs for the underlying sub-networks (see Figure 5.1.1).

Figure 5.1.1 FGAS Point-of-Award Network Structure



Created with CASOS SocialInsight

Overall density for the broader agent x agent FGAS network is 9.5%. Nodes included in this latter density measure include the 57 individual scientists, firms and organisations both

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[67] Network agents and principals were compiled through interviews and through information obtained in the FGAS List of Collaborators. This latter document is available online at: http://www.genomeprairie.ca/abioticstress/Collaborations.pdf.

formally and informally connected with the FGAS project. The network density for the meta-matrix (which includes the attribute based nodes: sub-projects, location and affiliation or sector type) is 13%. As in the previous case study, the ORA reporting system is used to calculate centralisation measures which are compared against the means of a database of existing software-based networks. Centralisation measures for the broader FGAS network are outlined in Table 5.1.1 along with ORA database mean measures for comparative purposes.

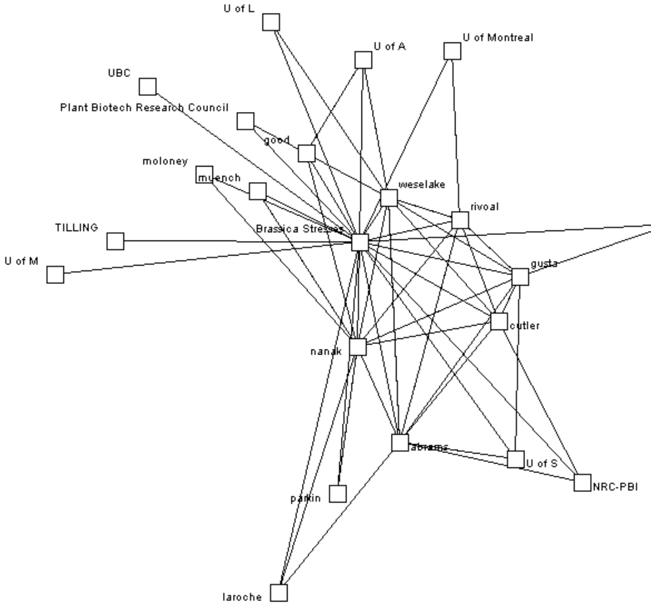
Table 5.1.1 FGAS Agent x Agent Network Centralisation Measures

	FGAS Network (average across all agents / N=57)	Sample ORA Database Mean	Results from ORA
Centralisation Betweenness	0.0291	0.0472	MIN = 0.0000 MAX = 0.2462 STDDEV = 0.0567
Centralisation Eigenvector	0.2010	0.1652	MIN = 0.0120 MAX = 1.0000 STDDEV = 0.2274
Total Degree Centralisation	0.3311	0.2842	MIN = 0.0179 MAX = 0.4846 STDDEV = 0.0679

According to the results, as compared with other networks in the ORA database, the FGAS network is slightly more cohesive (based upon the Eigenvector centralisation measure), it has slightly fewer paths by which information can get from one agent to another (betweenness-centralisation) and, on average, agents in the network have more connections to others than is typical. However, as in the case with FPMI, standard deviations relative to means of centralisation measures suggest that there are very high levels of variability in statistical results across all centralisation measures.

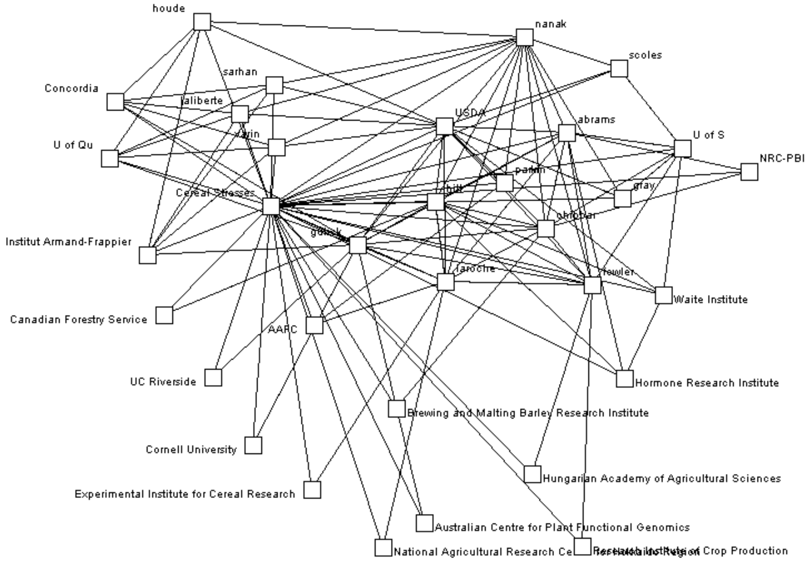
To simplify this network further, sub-structures or sub-groups are identified and graphed. Figures 5.1.2 through 5.1.4 illustrate network sub-projects (cereal stresses, Brassica stresses and platform technology) along with associated actors (individuals and organisations).

Figure 5.1.2 FGAS Brassica Stresses Sub-network



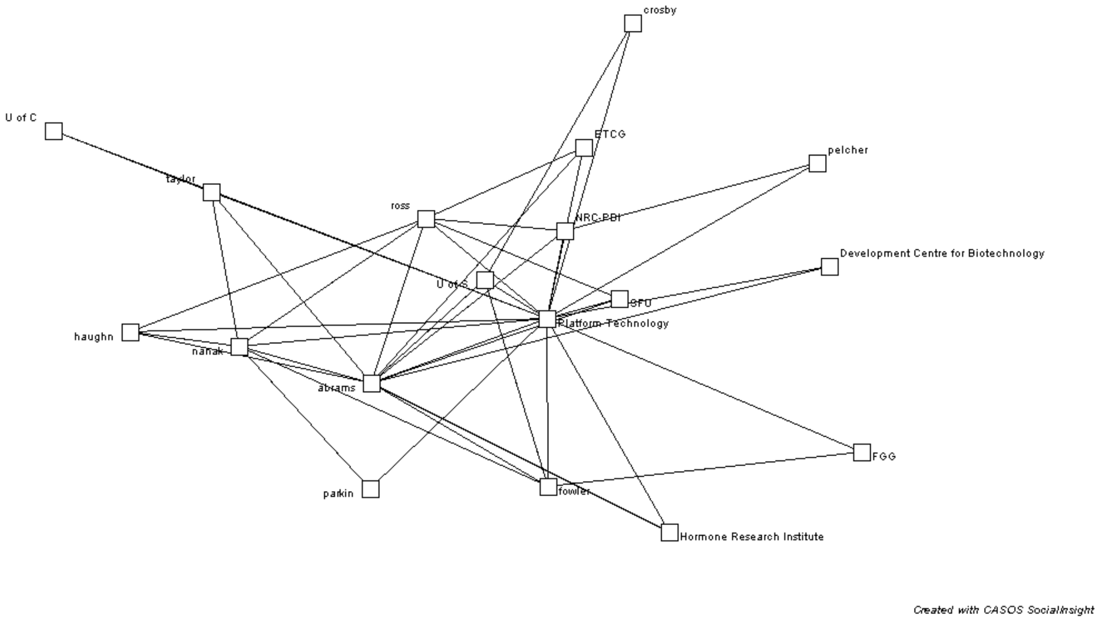
Created with CASOS SocialInsight

Figure 5.1.3 FGAS Cereal Stresses Sub-network



Created with CASOS SocialInsight

Figure 5.1.4 FGAS Platform Technology Sub-network



Figures 5.1.5 through 5.1.7 illustrate affiliation type sub-groups (public, academic and private).

Figure 5.1.5 FGAS Public Sector Affiliates

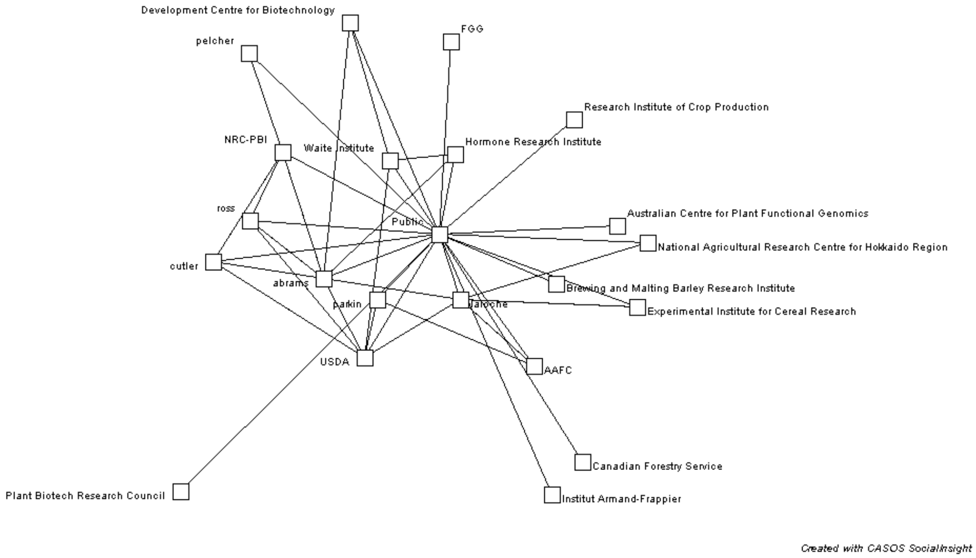


Figure 5.1.6 FGAS Academic Sector Affiliates

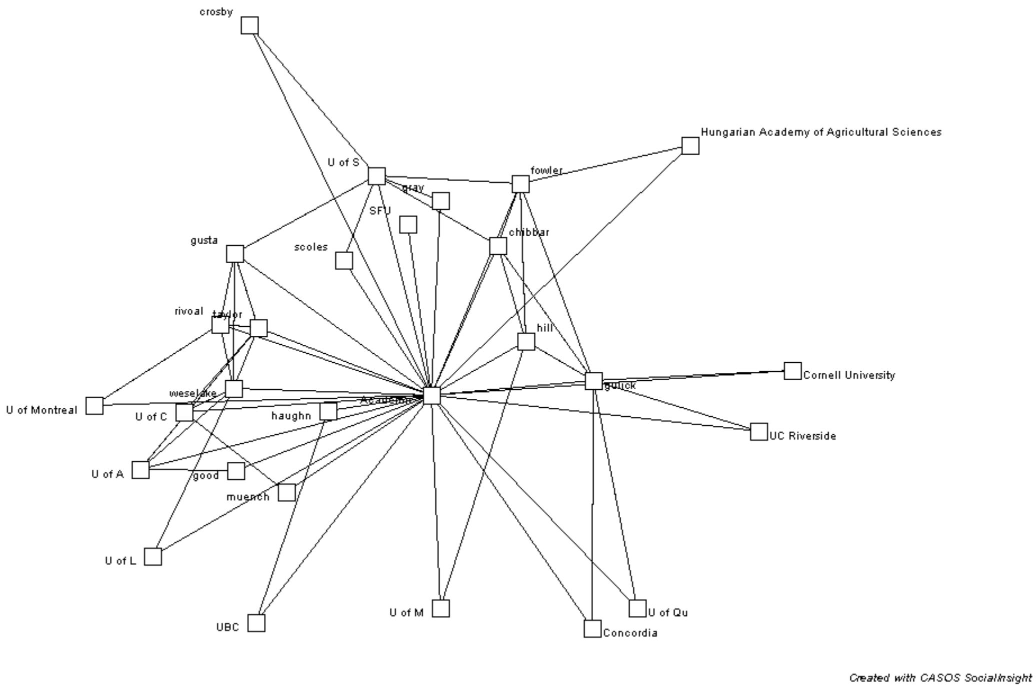
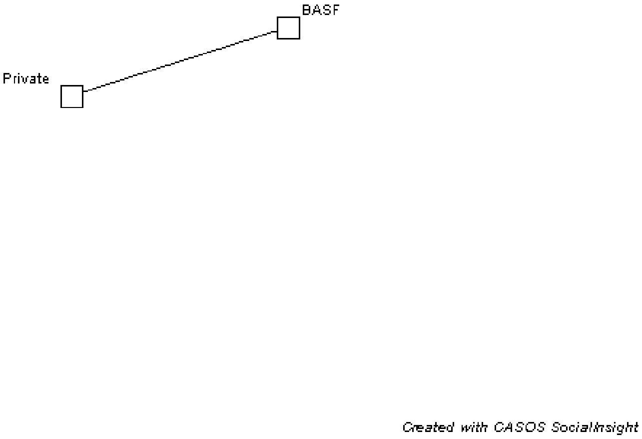


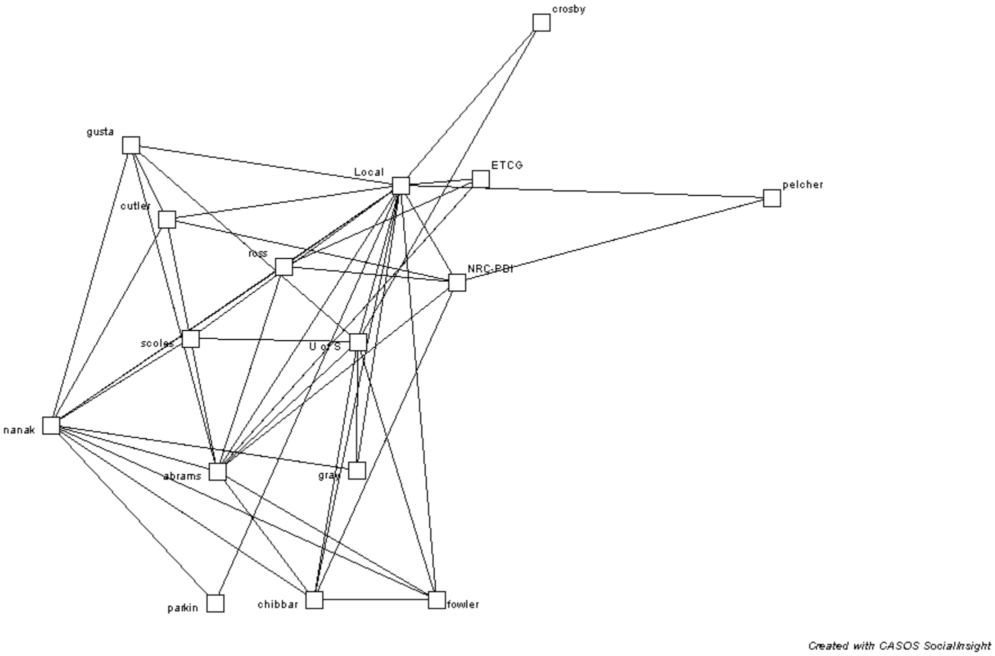
Figure 5.1.7 FGAS Private Sector Affiliates



Those organisations identified as 'hybrids' for the broader FGAS network are: TILLING and ECTG. The former, an acronym for a method (Targeting Induced Local Lesions IN Genomes), is linked with the organisation, the Seattle Tilling Project (STP). The STP is funded by the National Health Foundation and is a collaboration of the Fred Hutchinson Cancer Research Center (FHCRC) and the University of Washington (UW). The Enhancing Canola through Genomics (ECTG) group, like FGAS and FPMI, is a Genome Canada funded project that operates out of the National Research Council's Plant Biotechnology Institute in Saskatoon. As with FGAS and FPMI, the ECTG has been identified as a hybrid organisation as it operates across organisational boundaries (University of Saskatchewan and NRC-PBI) (a graph for the hybrid sub-network was not generated[68]).

Figures 5.1.9 through 5.1.11 illustrate the location-based sub-networks (local, national and international).

Figure 5.1.9 FGAS Local Sub-network



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[68] However, centralisation measures are calculated for this sub-network and are outlined in Table 5.1.2.

Figure 5.1.10 FGAS National Sub-network

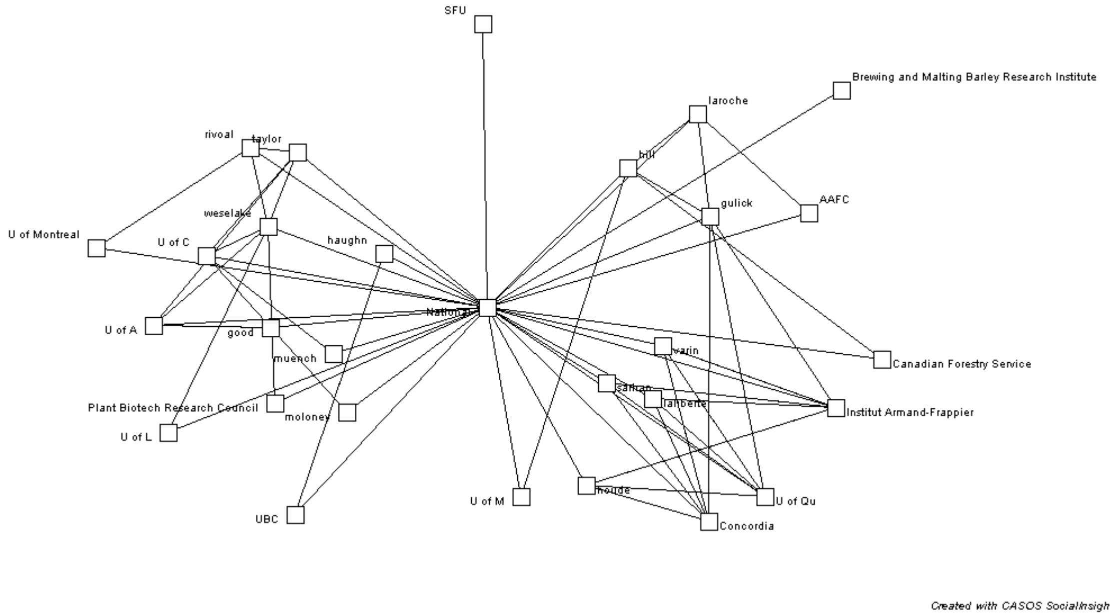
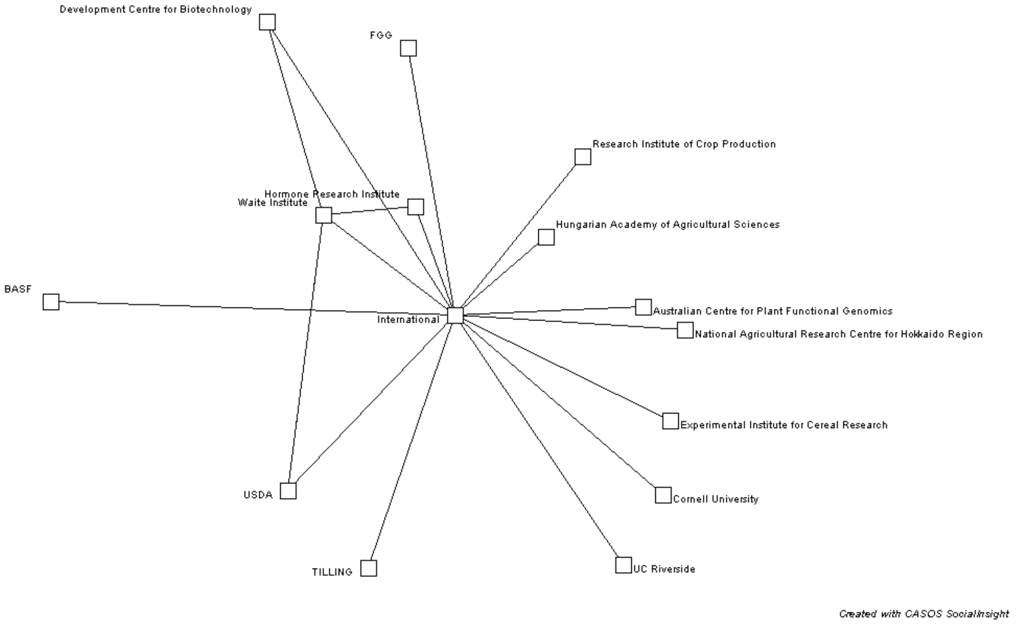


Figure 5.1.11 FGAS International Sub-network



Quantitative measures to support these illustrations for each sub-group or sub-network are outlined in Table 5.1.2.

Table 5.1.2 Comparison of Centralisation Measures by Location, Affiliation/Organisation Type and Project Type

Sub-Group of Interest	Degree Centralisation	
Sub-Project		
Brassica Stresses	0.3929	AVG=0.4167 STDDEV=0.1179
Cereal Stresses	**0.5714***	
Platform Technology	0.2857	
Affiliation/Organisation Type		
Academic	**0.4821***	AVG=0.2545 STDDEV=0.1836
Hybrid	0.1429	
Private	0.0179	
Public	0.3750	
Location		
International	0.2500	AVG=0.3327 STDDEV=0.1562
Local	0.2679	
National	**0.5000***	

Results suggest that the cereal stresses sub-project is the most central activity for the FGAS network. As in the case of the FPMI network, there appears to be a higher level of academic-based activity within the FGAS network, suggesting that most agents are associated with or are members of academic universities. There is only one private firm associated with the network (BASF)[69]. Finally, most agents are nationally based or have links to nationally based organisations, institutes or firms, as in the case of the FPMI network.

As in the case of the FPMI, principals are assumed to represent the entire population of interest. However, a comparison of ORA results with those generated on the FGAS network indicates some statistically significant results. Degree centralization for sub-project type 'platform technology' lies outside parameters of the standard deviation generated by ORA.

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[69] Advanta, Aventis and Pioneer also play a role in the FGAS network. Unfortunately, at the point of gathering data, these agents or private sector organisations were not included on the original list. The International Triticeae EST Cooperative (ITEC), the International Triticeae Mapping Initiative (ITMI) collaboration and NSF Wheat Project are other organisations or collaborations also have not been included. This oversight illustrates the problems associated with social network analysis in terms of incomplete data.

This would suggest that this particular sub-project may not be as well represented within the FGAS network. Additionally, centralization values for institutional affiliation indicate that the 'private' sector is significantly underrepresented within the network. As in the case of the FPMI network, the FPMI network appears to lack international representation.

Calculating actor-level centrality measures for influential leaders within the network helps to identify central actors or leaders within the broader FGAS network. Calculations are based upon agent x agent relationships and take into account all actors within the network including individuals, organisations and firms along with the linkages identified with the other sub-groups (sub-projects, affiliation-type and location-based attributes). Results of measures of centrality betweenness, centrality Eigenvector and degree centrality are outlined in Table 5.1.3.

Table 5.1.3 Summary of Point-of-Award Centrality Measures by Key Network Principals (N=57)

Rank	Centrality Betweenness "Potential Influence"	Centrality Eigenvector "Informal Power"	Total Degree Centrality "In-the-know"
1	USDA (0.2462)	Nanak (1.000)	USDA (0.4286)
2	Nanak (0.2190)	USDA (0.9242)	Nanak (0.4107)
3	Abrams (0.2044)	Abrams (0.8976)	Abrams (0.3482)
4	Gulick (0.1600)	Gusta (0.5767)	Gulick (0.2321)
5	Fowler (0.1130)	Chibbar (0.5530)	Fowler (0.1964)

Of these rankings, there are a total of 7 principals or agents listed as central actors of the larger FGAS network. The top three agents or actors are: the USDA, Nanak and Abrams. The USDA ranks within the top two of three centrality measures, having higher 'potential influence' within the network and a higher capacity for being 'in-the-know'. According to the definition of centrality betweenness, the USDA's higher level of 'potential influence' relative to other actors' suggests that although this organisation may not be connected to all network agents, it may be close (in terms of geodesic distance) to more pairs of individuals. In most cases centrality betweenness is, in fact, a good predictor of the power of an organisation or individual within a network.

Even without the actor-level calculations of centrality Eigenvector, Nanak may be assumed to have a great amount of 'informal power' due to her central role as FGAS Project Manager[70]. Here, she is identified as having high levels of 'informal power' within the broader network. Nanak maintains communication with project principals or leaders on a regular basis and assuming day-to-day administrative tasks associated with the Project. An important skill that Nanak brings to the network is bilingualism. This skill enables her to bridge communication barriers across Quebec and Saskatchewan. Abrams, who ranks next in line to Nanak, is the Principal Research Officer for Plant Metabolism at PBI and has several collaborative based linkages with a number of the other network agents which would position her centrally within this network. In the context of the FGAS project, Abrams works with the plant hormone ABA (abscisic acid) and the development of analogues for use as a germination inhibitor and for improving drought tolerance has served as foundational technology for functional genomics research in Brassicaes.[71]. Nanak and Abrams rank high (2nd and 3rd) in terms of total degree centrality (in-the-know) relative to the USDA. The USDA is ranked number one.

Gusta, Gulick, Chibbar and Fowler also all rank within the top five of within one or more of the centrality measures. Evidently, these key individuals assume a higher level of centrality within the FGAS network relative to other actors. Overall, the results suggest that – like the USDA, Nanak and Abrams – they have more connections with other central actors through fewer paths. Interpreting this further, Gusta, Gulick, Chibbar and Fowler's connections are relatively more efficient and effective than others within the network.

It is important to note that within this most central group of actors (n=7) there is a split in terms of affiliation-type. Three of the actors represent the academic sector while another

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[70] Nanak assumed the role of project manager in September 2004. At the time of point-of-award, Amit Shukla was the project manager.

[71] A recent development in plant functional genomics research is simultaneous profiling all the signalling molecules, or plant hormones, that regulate growth and development. Plant hormones are chemically diverse low molecular weight natural products and include auxins, cytokinins, abscisic acid, gibberellins, jasmonic acid, brassinosteroids and ethylene. Abscisic acid (ABA) is involved in everything from seed development and composition to germination and the structure of the plant. ABA is an effective germination inhibitor of wheat embryos. Long-lasting ABA analogs developed at NRC-PBI have been shown to reduce transpiration and improve drought tolerance. They have been used to understand how ABA works in plants in regulating gene expression and in physiological studies. These hyper-ABA analogs were designed to be resistant to the enzymes that turn ABA over in plants. The application of these compounds as plant growth regulators for a broad range of physiological processes is being investigated.

three represent the public sector. Nanak is the only agent within the group that has a hybrid-type affiliation (FGAS). Most of these most central actors are situated locally in and around the Saskatoon region (5 out of 7). Of the seven, five are identified as having some or total involvement in the cereal stresses sub-project. Abrams and Gusta are the only actors within this most central group that are linked to the brassica sub-group. Nanak and Fowler each cross sub-project boundaries and are identified as being involved in some capacity in two or more project sub-groups.

The USDA is the only organisation listed as a key network actor in terms of the selected centrality measures. The remaining actors identified are all individuals. NRC - PBI and the University of Saskatchewan are two actors or organisations that are noticeably missing from these centrality rankings. Given their explicit role in the FGAS project (institutional homes to the projects and/or project principals), it would be assumed that they would be central actors within the network. Yet, in point-of-award analysis, they only show 15 and 21 links (respectively) to other agents within the network.

5.2 Pre-Award Analysis of FGAS Network

The pre-award analysis process is based upon the network structure as it is formally organised under the currently funded FGAS project. Through the interview process, actors of interest (hereafter referred to as 'principals') are identified for the FGAS network and are considered key scientists, researchers or partners for the FGAS network. Thus, the original group of actors identified in point-of-award analysis (N=57) are narrowed down to n=21. These project principals are geographically dispersed and represent a number of institutional types (public, private or academic[72]) (Appendix E's listing asterisks the 21 principals of interest for pre-award analysis).

Relational data amongst FGAS network principals, including co-publication and co-patenting activity, was collected and network structures are illustrated in the following sections. As with FPMI, the periods of interest here fall between 1985 to the current date and are broken out as

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[72] None of the principals are formally affiliated with a hybrid organization or firm.

follows: 1985-1989; 1990-1994; 1995-1999 and 2000-2001. Data on patents and co-patents is collected and categorised by time interval according to 'date of award' and not by 'date filed' for comparative purposes[73]. Given the lag period assumed between publications and patents, co-patenting activity from 2000 right up until 2004 is also included within the parameters of pre-award analysis (provisional patents or patent application activity from point-of-award to 2004 is considered under the parameters of post-award analysis Section 5.3).

As in the case of the FPMI network, publishing and patenting collaborative activity as it relates to proximity is important in terms of exploring collaborations. This thesis is tested as it relates to the FGAS project and its principals. Again, research foci is of interest here and it is assumed that the FGAS network will illustrate the evolution of two networks over time with clusters of co-publication and co-patenting activity related to research foci or interest (eg. Brassica or cereals) and there are little, if no, convergence in terms of technological interest.

Proximity factors (eg. the geographic distribution of principals), the evolution of the FGAS network over time in terms of key activities and other qualitative factors provide a picture of the network structure. Again, the assumption is that structure may affect performance. Understanding the FGAS network structure through qualitative and quantitative analysis assists in the understanding of the relationship between these two variables.

5.2.1. FGAS Network Co-publishing Activity

Figures 5.2.1.1 through 5.2.1.4 illustrate co-publishing activity amongst network principals over the time intervals of interest. Generally, the illustrations depict a disconnected graph or network consisting of cliques, dyads, or sub-groups amidst a high proportion of isolates. The 1985-1989 time interval shows two sub-groups of collaborative activity which evolves to four sub-groups in the second time interval (1990-1994), four again in the third time interval, and

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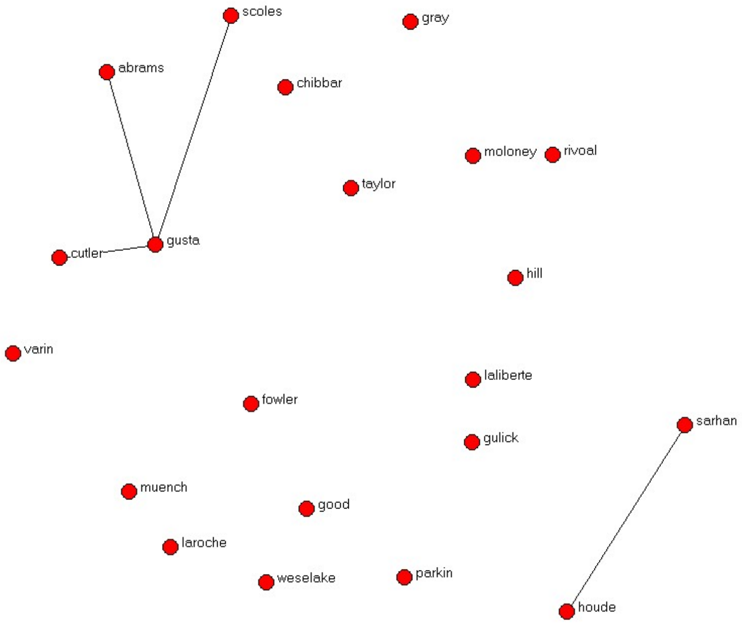
[73] Please note: In the case of the FGAS project that although patent applications began in the late 1980s, no patents were awarded until the early 1990s. Therefore, in terms of co-patenting activity, this analysis only considers the time intervals beginning from 1990 onwards.

decreasing to two for the final pre-award time interval. Links are weighted and illustrate the level of collaborative activity between principals[74].

Figure 5.2.1.1 FGAS Network Co-Publishing Activity by Time Interval 1985-1989



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[74] As with analysis of the FPMI network, NetDraw is used as a graphing tool in that the software has the capability to illustrate the strength (in terms of a weighted line) of links amongst network principals.

Figure 5.2.1.2 FGAS Network Co-Publishing Activity by Time Interval 1990-1994

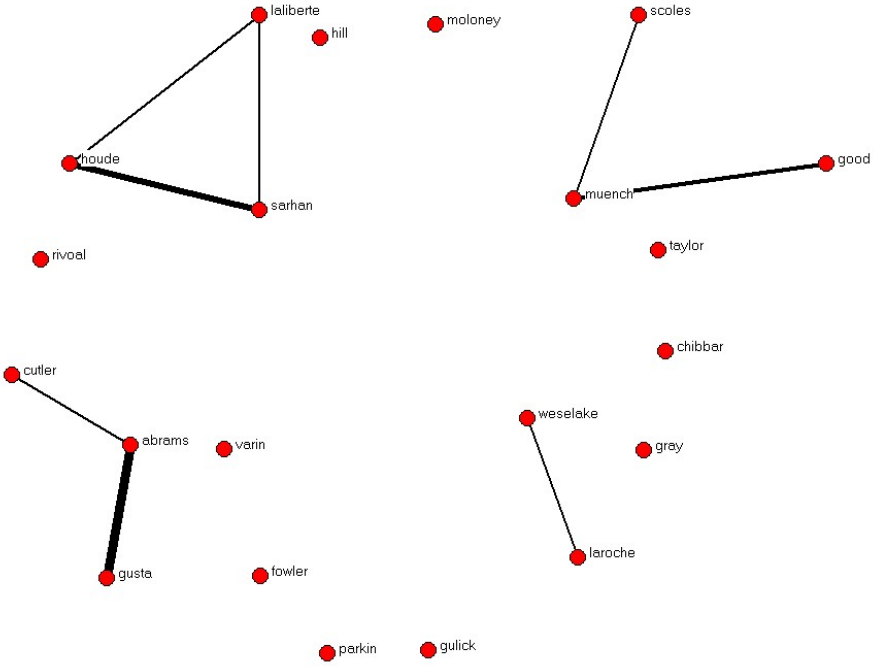


Figure 5.2.1.3 FGAS Network Co-Publishing Activity by Time Interval 1995-1999

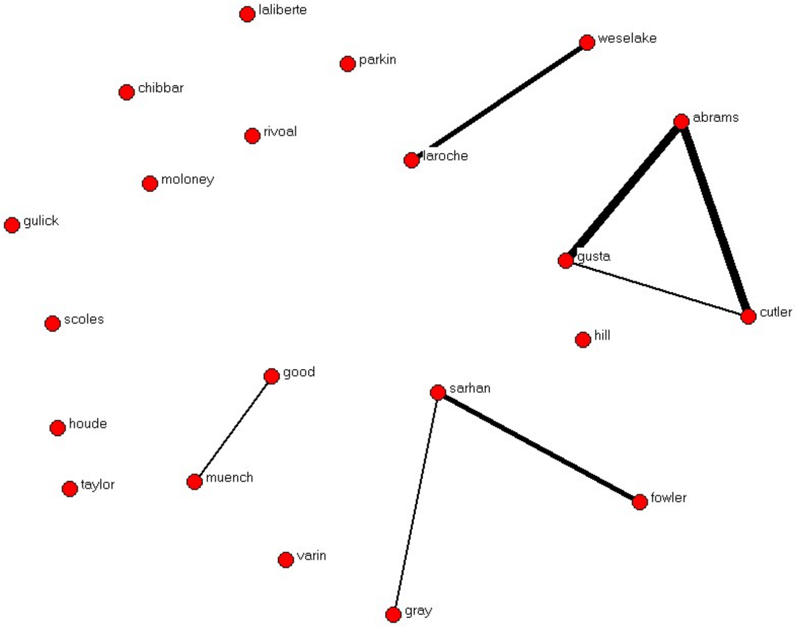
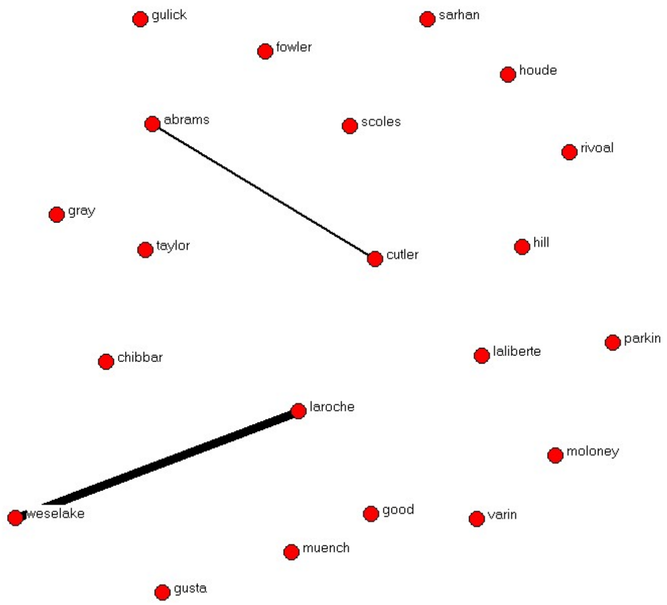


Figure 5.2.1.4 FGAS Network Co-Publishing Activity by Time Interval 2000-2001



To quantify this qualitative data, agent x agent density and centralisation measures[75] of each time interval in terms of co-publishing activity is outlined in Table 5.2.1.1 along with the sample ORA database mean with which to compare values.

Table 5.2.1.1 FGAS Network Co-Publishing Centrality and Density Measures by Time Interval

	Output (#co-pubs)	Centralisation Betweenness	Centralisation Eigenvector	Degree Centralisation	Density
1985-1989	8	0.0008	0.1301	0.0190	1.9%
1990-1994	25	0.0005	0.1429	0.0381	3.8%
1995-1999	20	0.0003	0.1429	0.0333	3.3%
2000-2001	6	0.0000	0.0952	0.0286	1.0%
Sample ORA Database Mean		0.0472	0.1652	0.2842	

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[75] All measures are generated based upon value-based data (eg. actual number of co-publications are incorporated into dataset) rather than assuming merely a binary relationship between agents. Value based data (as opposed to binary) appears to only affect the Eigenvector and total degree centrality measures (in this case only nominally). Betweenness centrality and density measures remain unchanged when value-based data is replaced with binary based data.

These values indicate significantly lower than average centralization relative to the means of the ORA database. This is particularly evident in terms of centralisation betweenness. According to its definition, the FGAS network appears to have extremely low levels of linkage amongst groups of principals or sub-networks over time relative to the sample means in the ORA database. Similarly, the low values for degree centralisation indicate that the FGAS network does not revolve around one particular principal relative to the ORA database means (there is no clear leader amongst all principals in terms of this activity). The Eigenvector measure, however, for the 1990-1994 and 1995-1999 time intervals are somewhat closer to the mean of the sample database (slightly less so for 1985-1989 time interval) suggesting that these two time periods are moving towards an average level of cohesiveness activity in publishing. More specifically, these results suggest that the FGAS network has a slightly below average level of bridging activity amongst its principals. In other words, there are few principals within the network that are linking sub-networks or groups of individuals.

The 2000-2001 time interval is significantly shorter than others. This may account for the (significantly) lower than average centralisation and density measures for this latter time interval.

Proximity and research foci are factors that appear to affect co-publishing activity within the FGAS network. Throughout all time intervals, there is little overlap in terms of publishing activity amongst principals in terms of research foci or sub-project (cereal stresses, Brassica stresses or platform technology). Collaborative activity as illustrated in the various sub-groups suggests the principals network according to research interest and predominantly seek out and collaborate with those with similar research interests (eg. Brassica or cereals). For instance, the two distinct subgroups illustrated in the first time interval each represent divergent research interests. With the exception of Scoles, the first group (Abrams, Gusta and Cutler) hold research interests in Brassica while the second smaller group (Houde and Sarhan) have interest in cereals. It appears that the former predominantly-based Brassica sub-network evolves over time within the context of the greater FGAS network structure. In time interval two, the core-periphery structure (as illustrated in time interval 1) breaks off into two distinct sub-groups. Scoles appears to 'bridge', from a proximity-based perspective, by breaking off from the original sub-group and engaging in a new sub-group with Muench and Good (also with cereals interest). By time interval three, Cutler, Abrams and Gusta have 'closed' their linearly structured sub-group into a clique[76] (with maximal density and minimal geodesic distance) amongst principals. Co-publishing activity for Scoles with other network principals discontinues for the remaining time intervals. Like the Cutler-Abrams-Gusta triad (Brassica), the Laliberte-Houde-Sarhan sub-group (cereals) forms a 'closed' clique by time interval two. These latter two occurrences are the only two incidences of triad cliques throughout all time periods.

Sub-groups, across all time intervals, consist of principals with related research interests. There is an incidence of a relationship contrary to this, however. In the second time interval (1990-1994), Laroche and Weselake – each assumed to have different research interests – do collaborate in terms of publishing. This relationship continues throughout the remainder of the time intervals with regular co-publishing activity occurring between these principals. This relationship represents the only incidence of what could be considered collaborative convergence between principals with diverging research interests.

For the FGAS network, proximity among principals appears to be an important precursor to collaborative activity, during the earlier time intervals. For instance, in time interval one, each of the two distinct sub-groups consist of principals that are geographically proximate (eg. Saskatoon, Saskatchewan or Montreal, Quebec). However, as early as the second time interval (1990-1994), principals are crossing (some) geographic boundaries with Scoles (located in Saskatoon) co-publishing with peers from Alberta. From 1995-1999, the cereal-based subgroup (previous network-based collaborative activity associated with principals from Quebec) has crossed a larger geographical divide with Sarhan co-publishing with Saskatoon-based Fowler and Gray. Proximity appears to be a significant precursor to co-publication for Abrams, Cutler and Gusta as this sub-group collaborates frequently from 1985 to the point-of-award (2001). Throughout the entire time period, this latter sub-group conducts no

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[76] In a clique, every node is connected to every other node but there has to be greater than or equal to 3 nodes or actors to qualify as a clique.

collaborative activity with non-local principals as defined by the boundaries of this project network[77].

5.2.2. FGAS Network Co-patenting Activity

Unlike its FPMI counterpart, the FGAS network principals do participate in collaborative activity with respect to patenting in the time period of interest (1990-2004[78]). Similar to co-publishing activity, each time interval for co-patenting sub-networks depicts a disconnected graph consisting of cliques or dyads amidst a high proportion of isolates. Figures 5.2.2.1 through to 5.2.2.3 illustrate the network graphs for co-publishing activity amongst FGAS principals.

Figure 5.2.2.1 FGAS Co-Patenting Activity by Time Interval 1990-1994

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[77] The geopolitical divide between principals in Quebec and others deteriorated somewhat over the course of the post-award period. For example, matching funding was easily secured in Quebec yet principals in Saskatchewan had great difficulty in obtaining provincial support. Principals in the FGAS network were expected to achieve common goals yet they were subject to differentiated transaction costs. This lead to a break down in communication, particularly between Quebec and non-Quebec principals. A bi-lingual Project Manager (Nanak) certainly helped to mitigate some of these problems. However, this was not enough to overcome all the problems (Nanak 2005).

[78] As is the case with FPMI, patenting activity for network principals (either with network principals or with non-network principals) does not occur until after 1990. Therefore, the time period of interest for analyzing collaborative patenting activity begins at 1990.

Figure 5.2.2.2 FGAS Co-Patenting Activity by Time Interval 1995-1999

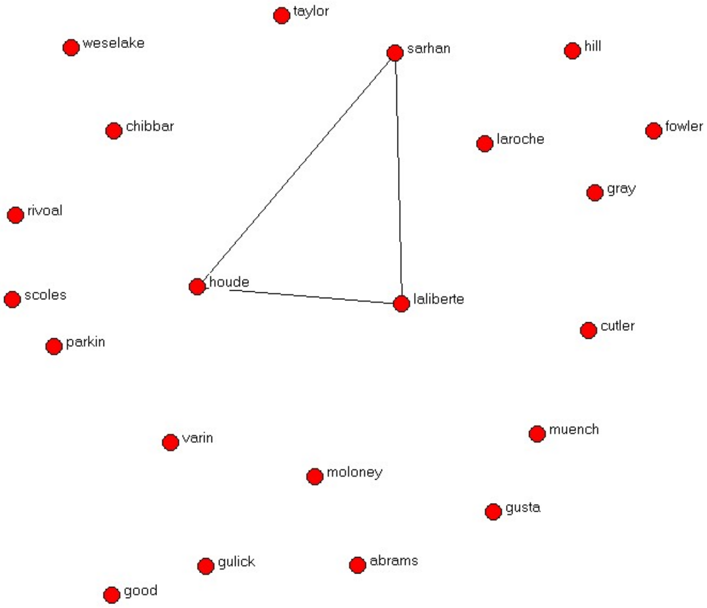
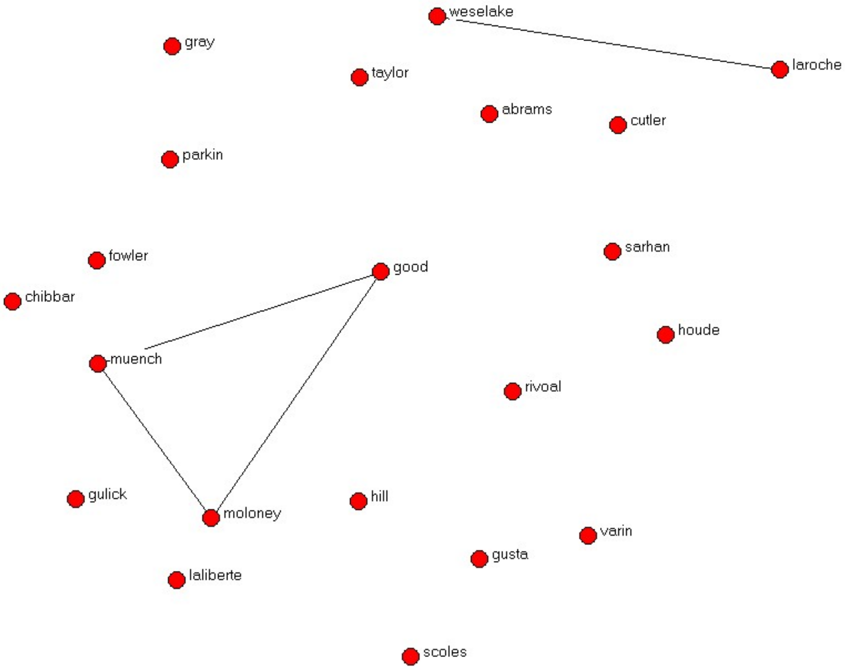


Figure 5.2.2.3 FGAS Co-Patenting Activity by Time Interval 2000-2004



According to the graphs, there are no core-periphery sub-groups depicted in any time interval. The 1990-1994 time interval sub-network illustrates a singular dyad (Abrams-Gusta). In the next time interval (1995-1999) a new triad of co-publishing activity amongst Laliberte, Sarhan and Houde develops. The two latter sub-groups represent different geographic regions, one is locally based (Abrams-Gusta) while the other clique (Laliberte, Sarhan and Houde) consists of principals from Montreal, Quebec. In keeping with the methodological framework, co-patenting data for the FGAS network is also considered for the entire interval of 2000-2004 to accommodate for lag times between patent filing and award dates (patent co-application is explored more fully in post-award analysis in Section 5.3). Activity in this latter interval is assumed to be part of the pre-award time period. From 2000-2004, no co-patenting activity occurs amongst those cliques identified in the previous two time intervals. Rather, new sub-groups emerge including the triad of Moloney-Good-Muench and the Weselake-Laroche dyad. Although institutionally dispersed[79], these latter two sub-groups of co-patenting activity are geographically based in Alberta (principals operating out of Edmonton, Calgary or Lethbridge).

In terms of research focus (either in Brassica or in cereals), even less collaborative activity would be expected amongst network principals and this is evident in the graphs for each time interval. The lone exception is the collaborative activity between Weselake and Laroche (2000-2004). However, based upon the co-publishing evidence, it appears that proximity (both principals are from Lethbridge) may play a more significant role than research focus in terms of the relationship between these latter two principals.

In terms of overall aggregate output of patents, 13 patents were awarded to FGAS principals over the time period of interest (see a listing of these patents in Appendix F). Table 5.2.2.1 breaks out patents by time interval.

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[79] Moloney represents the private sector (Calgary) while Good and Muench are affiliated with the U of A and U of C respectively. Weselake and Laroche are both from Lethbridge, however, Weselake is with the U of L while Laroche is with AAFC.

Table 5.2.2.1 Patenting Output of the FGAS Network by Time Interval

-	Total patents by network principals	Overall distribution of patent activity
1990-1994	1	8%
1995-1999	6	46%
2000-2004	6	46%
Total Patents	13	

Patenting activity appears to grow over time with a significant jump in activity from time interval one to time interval two.

5.2.3. FGAS Network Capacity for Securing Funding

As previously noted, the ability to secure funding for research is an important skill for those participating in research projects or networks. In the case of the FGAS network, data was collected on grants and scholarships secured through: NSERC and CFI. A search of the CIHR database returned no results for FGAS network participants and, as in the case of FPMI, no funding was obtained through SSHRC.

According to the data, there appears to be no grants awarded jointly to FGAS network principals through either NSERC or CFI. As with the FPMI network, data collected on funding begins in 1990 and ends at point-of-award in 2001.

Table 5.2.3.1 outlines total grants and awards (including scholarship monies) by funding agency and time interval. Table 5.2.3.1 outlines funding by agency and time interval. Results are also normalized by time interval.

Table 5.2.3.1 FGAS Network Grants and Awards by Funding Agency and Time Interval

	CFI	NSERC	TOTAL $	% distribution	Funding $/principal
1990-1994	n/a	$2,711,052	$2,711,052	23%	$129,098
1995-1999	$1,054,000	$5,641,858	$6,695,858	55%	$318,850
2000-2001	$233,213	$2,430,383	$2,663,596	22%	$126,837
	$1,287,213	$10,783,293	$12,070,506		

According to the results, the FGAS network principals secured a total of $12,070,506 in funding between 1990 and 2001. A significant proportion of funding was secured in the 1995-1999 time interval (55%) which, in terms of cereals (namely wheat (GM)) and canola, seems consistent with industrial trends at that point in time (a GM canola crop was introduced to the market in 1995 while a significant amount of research for the development of GM wheat began around then and continued thereafter). Normalised results for each time interval are provided in the final column. Again, the condensed 2000-2001 time interval accounts for significantly lower amounts there.

Of particular interest to this case study is the divergence between research foci for this FGAS network considered to be 'imposed' and presumed to be more fragmented in terms of structure. Searches of the CFI and NSERC database, by research foci, are conducted with results broken out over the time intervals of interest. Table 5.2.3.2 outlines this break out.

Table 5.2.3.2 FGAS Network Grants and Awards by Research Foci and Time Interval

	Total Funding Allocations (CFI & NSERC)		CFI		NSERC	
	Brassica	Cereal	Brassica	Cereal	Brassica	Cereal
1990-1994	84%	16%	n/a	n/a	84%	16%
1995-1999	76%	24%	100%	0%	72%	28%
2000-2001	57%	43%	0%	100%	63%	37%

The results indicate a ratio of 84% of funding targeted towards activities in Brassica to a mere 16% towards research in cereals in the time interval of 1990-1994 (NSERC only). The ratio shifts to a 76% - 24% split in 1995-1999 and then onto a 57% to 43% split in 2000-2001.

This trend suggests a gradual shift in the federal strategy from supporting Brassica-based research to cereal-based knowledge generation and research. Over the entire pre-award period, agency strategies show that the CFI allocated 100% of its funding activities (in the context of FGAS network activities) to Brassica-related research from 1995-1999 and then shifted entirely (100%) to cereals related research in the following time interval. NSERC, on the other hand, allocated most funds (in all time intervals) to Brassica research (63%+).

5.2.4. Key Principals in FGAS Network Activities

Again, as previously established, individual and not collaborative effort appears to dominate the funding application process. Therefore, this part of the analysis examines individual output per interval. It includes not only each principals' capacity to secure funding, but also individual capacity to publish and to patent during the pre-award time period.

A review of funding sources (CFI and NSERC) obtained by FGAS network principals finds that Taylor, Moloney, Good, Sarhan and Hill (in that order) were the top five performers in terms of securing funding, obtaining in excess of $8.5 million. This represents over 70% of the total funds ($12.0 million) collected over the pre-award period. In total, Taylor and Moloney alone attracted over $5 million (42%) in funding during this period (see Table 5.2.4.1).

Table 5.2.4.1 Key Network Principals in Sourcing Funding (1990-2001)

	Funding Secured 1990-2001 (CFI & NSERC)	Per Cent Funding Secured by Principal
Taylor	$2,858,549	24%
Moloney	$2,230,196	18%
Good	$1,318,925	11%
Sarhan	$1,276,716	11%
Hill	$862,626	7%
Average funding $ per network actor	$561,904	
Total funding by network principals	$12,070,506	

In terms of publishing output, network principals generated a total of 697 articles over the course of the pre-award period (1985-2001). Sixty four percent (392) of the total publication activity took place during the time intervals covering 1990-1999. Over 50% (358) of the total publishing activity over the entire pre-award period was conducted by Abrams, Fowler, Gusta, Cutler and Laroche (in that order). These principals exchange leads in terms of publishing activity over the pre-award period. For instance, Fowler leads for 1985-1989 while Laroche leads for the 2000-2001 time interval. However, Abrams was the overall leader. Not only did she publish more than the other network principals (n=87), but she also led activity for both the 1990-1994 and 1995-1999 time intervals which, as previously mentioned, were the peak co-publication periods for the network during the pre-award period. See Table 5.2.4.2 for an outline of leaders in terms of publication activity. Time interval leads are highlighted.

Table 5.2.4.2 Key Network Principals in Publishing Activity by Time Interval

	1985-1989	1990-1994	1995-1999	2000-2001	Total
Abrams	13	**34**	**34**	6	87
Fowler	**20**	24	9	10	63
Gusta	14	20	20	2	56
Cutler	18	10	14	6	48
Laroche	5	7	19	**15**	46
Average output (publications) per network principal	6.5	9.6	9.1	3.6	28.8
Total publications by top five network principals	136	201	191	76	n=432

In terms of patent output, the window for this activity for the FGAS network was considerably smaller with a total of 13 patents awarded between 1990 and 2004[80]. The period for peak patenting activity occurred during the latter periods of 1995-1999 and 2000-2004 where each time interval accounted for 46% of the overall patenting activity. Of the 21 network principals, only 11 were involved in patenting activity (Abrams, Chibbar, Good, Gusta, Houde, Laliberte, Laroche, Moloney, Muench, Sarhan and Weselake).

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[80] The author extended the data to include the post-award time period of 2002-2004 to account for those patents filed prior to that period. Provisional patents or patent applications are used in post-award analysis for this activity.

The top five principals named as inventors on patents were: Moloney, Sarhan, Chibbar, Gusta and Abrams (in that order) and, often, these principals were named jointly on patents (See Table 5.2.4.3). In total, these principals were named as co-inventors in 11 of the 13 patents (85%) for the overall time period. Moloney and Sarhan accounted for 54% of all patents (n=7). Further exploration into the activities of these individuals shows that both Moloney and Sarhan are heavily involved in private sector activity. Maurice Moloney, currently holds joint interests in both public and private sectors. He is the Chief Scientific Officer (and founder) of SemBioSys, he holds the Natural Sciences and Engineering Research Council of Canada (NSERC) Industrial Research Chair in Plant Biotechnology and he is also a professor in the Department of Biological Sciences at the University of Calgary[81]. Prior to these positions, Moloney was head of the Cell Biology Group at Calgene Inc., where he developed the first transgenic oilseed plants using canola as the model crop[82]. Fathey Sarhan is currently a Professor in Biological Sciences at the University of Quebec in Montreal but also is the co-founder and CEO of ICE BIOTECH Inc. ICE BIOTECH Inc. is a Canadian company founded in 1997 and developed by a group of professors from various universities in Ontario and Quebec. The foundational technology of ICE BIOTECH evolves around cold tolerance in plants. Sarhan also is a consultant for Microstar Inc.

Table 5.2.4.3 outlines the top five principals in terms of patenting activity. Abrams and Gusta were named as collaborators on two patents, one in the 1990-1994 time interval (accounting for the lone patent in that time period) and one in the next time period. Between 1995 and 1999, Moloney, Sarhan and Chibbar were each named on separate patents, accounting for the five remaining patents for that time period (Moloney=2, Sarhan=1 and Chibbar=2). No other network principals were named on any of these patents. Other than one patent (Moloney; patent # 5,650,554; 1997), all patents across all time intervals listed two or more inventors.

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[81] Moloney serves on many federal and corporate advisory boards and is currently a member of NSERC Council and the Chairperson of NSERC's Committee on Research Partnerships. Dr. Moloney has received a number of prestigious awards, including the Alberta Science and Technology (ASTECH) Award for leadership in Alberta Technology.

[82] Moloney's efforts resulted in a landmark patent in plant biotechnology and eventually became the basis of Monsanto's Roundup Ready® and Liberty Link® canola products.

Table 5.2.4.3 Key Network Principals in Patenting Activity by Time Interval

	1990-1994	1995-1999	2000-2004	Total
Moloney	0	2	2	4
Sarhan	0	1	2	3
Chibbar	0	2	0	2
Gusta	1	1	0	2
Abrams	1	1	0	2
Average output per network actor	0.05	0.29	0.29	0.62
Total patents by network principals	1	6	6	13
Overall distribution of patent activity	8%	46%	46%	

See Appendix F for a listing of the patents, inventors, award dates, assignees and number of co-inventors.

5.3 Post-Award Analysis of FGAS Network

Descriptive analysis and output measures are used in post-award analysis. The time period of interest here is from the time of award onward (2002-2004). In interviews with select FGAS network principals, the following parameters were suggested to be good indicators of short-term post-award output: seminars, presentations, publications, provisional patents/patent applications, spin-offs, trained personnel and tools for discovery[83]. The FGAS network output is outlined in Table 5.3.1.

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[83] FGAS does not report awards and, therefore, this type of output is not listed in the FGAS case analysis. Similarly, while seminars were suggested as a good short-term output indicator, no records were available for this measure.

Table 5.3.1 Post-Award Output for the FGAS Network (2002-2004)

Short-term Indicator	Network Output
presentations	42
publications (total)	130
publications (network based)	13
trained personnel	24
tools for discovery	ESTs / Microarrays / BAC library
provisional patents / patent applications (total)	9
network-based provisional patents	4
spin offs	1
funding secured	$4,465,680

In total, post-award network output included 130 publications along with forty two presentations (including abstracts and poster presentations) given at various events such as conferences or related events.

Additionally, the FGAS network generated a total of 9 provisional patents in the post-award period. Appendix G provides a detailed listing of post-award provisional patents[84]. Of these 9 post-award provisional patents, 4 involved two or more FGAS network principals. In eight of patents, FGAS network agents or principal investigators were listed as lead inventors. On average, the provisional patents listed 3.8 inventors per application. Of the 9 provisional patents, only three listed assignees. In this case, the assignees were private sector actors (SemBioSys Genetics Inc. and Metabolix Inc.). Of note, Moloney collaborated with Gijs van Rooijen in three of four of the patents credited to him (USPTO patent documentation #s: 20030093832, 20030059910, 20030096320). This latter actor is also on the Genome Prairie radar. Van Rooijen was the Senior Research Scientist with SemBioSys Genetics Inc. but has since been appointed as Genome Prairie's first Chief Scientific Officer. Given his change in status before the project was funded, he was not included within the network boundaries of the FGAS project as defined in point-of-award analysis.

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[84] An exploration of co-patent applications (2002-2004) associated with post-award activity indicates that the FGAS network is not facilitating geographical cross-fertilization of co-patenting activity.

The FGAS project is also responsible for the establishment of one spin-off company. This spin-off is the Proteomics Division of United Bioinformatica Inc. (UBI) developed through the collaboration between Lindsay Moir (President of UBI) and Russel Trischuk[85], a former student of L. Gusta at the U of S. Trischuk utilised his combined experience as senior researcher in Gusta's laboratory and his work with A. Ross in Mass Spectrometry at NRC - PBI to fill a niche in solving proteomics problems[86]. Numerous requests from national and international researchers prompted the development of this spin-off.

Another important indicator of short-term output is the number of personnel trained over the course of the post-award period. This includes undergraduate and graduate students as well as post-docs. The FGAS project trained 24 individuals over the course of 2002-2004.

A very important and, according to Nanak[87], unforeseen output of the FGAS project has been the development of a number of key tools for discovery such as ESTs, microarrays, and BAC libraries (as outlined in Table 5.3.1). This unforeseen output reiterates the notion of innovation as a dynamic process wherein improvements or incremental innovations may be more important than downstream commercialisable products or processes.

Funding and capacity to attract funding is considered an important actor-level performance indicator. During the post-award period, FGAS network principals secured a total of 4.47 million dollars of funding, ninety five percent of which was sourced through NSERC (see Table 5.3.2). Normalised by network size, this represented in excess of $200,000 per principal during the post-award period. However, when combined with the previous time interval of $126,837 (2000-2001), the total of $339,488 represents an increase in funding sources of 6% from that of the previous time interval (1995-1999) ($318,850) (refer to table 5.2.3.1 in the

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[85] Trischuk completed his Master's degree under Gusta in 2002.

[86] Problems or challenges range from setting up proteomics labs to processing materials and data to training personnel.

[87] Ongoing personal communications 2004 to 2005.

previous section). According to these results, there appears to be a growing capacity to attract funding on the part of FGAS network principals.

Table 5.3.2 Post-Award Funding Secured by FGAS Network Principals (2002-2004)

	CFI	NSERC	TOTAL $		Funding $/principal
2002-2004	$225,000	$4,240,680	$4,465,680	28%	$212,651

5.4 Summary

The FGAS network was defined early in this dissertation as one that was 'imposed', with a strong government hand involved in its structure and development. Given this, one would expect that a history of collaborative activity or collective output might be considerably less than that of an organically structured or self-organising network. Although this notion can only be fully tested by comparing networks (this will be covered in the following chapter), a few observations can be made at this point about the FGAS network:

Network Structure: Point-of-award analysis suggests that the FGAS network consists of predominantly local actors (Saskatoon region). Also, there appears to be one dominant research activity or focus (cereal stresses). However, in terms of organisational affiliation, there is almost a 50/50 split between actors that represent the academic sector and those that represent the public sector. Little or no private sector representation exists in the FGAS network.

Knowledge Exchange Capacity: In terms of collaborative activity, there is evidence of network evolution in patenting activity over time in pre-award analysis. Although the evolution of the overall network is fragmented, there are clear sub-groups that do evolve and grow over time in terms of collaborative output. Principals in these sub-groups are characterized by first, a common research focus, and secondly by geographic location. Network evolution in terms of co-patenting activity is, again, at the sub-group level and proximity appears to play a larger role than in co-publishing activity.

Knowledge Creation Capacity: In point-of-award analysis, clear leaders are identified in terms of their centrality actors within the network: Nanak, Abrams, Gulick, Fowler, Gusta and Chibbar[88] (in that order). Comparing that list with the list of key actors identified in pre-award analysis, there are inconsistencies between those leaders defined through institutional analysis (the subjective process of point-of-award analysis) and those identified through more quantitative, objective methods (pre-award analysis using bibliometrics and technometrics). For instance, in terms of securing funding none of the central actors identified in pre-award analysis are identified in point-of-award analysis. Abrams, Fowler, Gusta and Chibbar are identified as central both in terms of patent and publication output. However, Moloney and Sarhan are clear leaders in terms of patenting and yet are not identified in point-of-award analysis as key actors.

Results from both case analyses are contrasted and compared in the following chapter. Conclusions regarding network structure and performance are drawn from these comparisons.

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[88] This list of key actors is limited to individuals and not organizations. Thus, the USDA is eliminated from this list and for comparative purposes.

Chapter 6

COMPARING PERFORMANCE OF FPMI AND FGAS NETWORKS

The purpose of this chapter is to contrast and compare the results generated through the case analyses for both the FPMI and FGAS networks. The results from each case analysis, on their own, offer little insight into the relationship between a history of social interaction or collaborations. However, by comparing these results, conclusions can be made about the role of network structure, the history of collaborative activity and other factors on network-based performance.

6.1 Point-of-Award Knowledge Management Capacity (FPMI vs FGAS)

The FPMI network is categorised as an 'organic' network, one which was awarded funding with nominal changes (little or no Genome Canada intervention) to network structure or principals. The FGAS network, on the other hand, is characterised as 'imposed' with its award contingent on substantive structural changes to its network of principals. The networks are categorised and compared in Table 6.1.1 along with density measures and other knowledge management capacity measures.

Centralisation measures, here, are conferred with slightly different labels that reflect their application to whole network level analyses and comparisons. Centralisation-betweenness is assumed to reflect 'Knowledge Flow Capacity' which in turn assesses the level of connectedness among actors within the network and the capacity of the network to facilitate flows of knowledge. In other words, higher levels of network level centrality betweenness would indicate a higher level of actors that connect or broker sub-groups within the network. Also, a higher level of 'brokering' activity is also an indicator of network capacity to bridge to other networks or individuals outside of the network of interest. Centralisation Eigenvector provides an indication of 'Network Cohesiveness' or how well connected actors are to one another within the network. Higher levels of network connectedness would point to the existence of a higher number of (central) actors that are connected to other central or well-connected actors. Total degree centralisation is an indicator for 'Intra-network Connectedness' and provides insight into the overall internal connectedness of the network. In combination, these measures provide an indication of point-of-award network capacity for knowledge management.

Centralisation measures are drawn from individual case analyses from Chapters 4 and 5 in the point-of-award analysis sections. Comparisons of measures are drawn and results are shown in Table 6.1.1 The + and – signs are used to compare the FPMI and FGAS networks. These symbols act as indicators of network-level centralisation measures (or measures of Knowledge Management Capacity) relative to: 1) ORA sample database means and; 2) the other network. For example, FPMI's measure of Knowledge Flow capacity is higher than both the ORA sample database mean (in terms of centralisation betweenness) and FGAS's level of Knowledge Flow Capacity. This is symbolised with a '+ / +'. The FGAS network's level of Knowledge Flow Capacity is also lower than the ORA database and this is indicated with a '– / –'.

Table 6.1.1 Point-of-Award Comparative Analysis: Assessing Knowledge Management Capacity (FPMI vs FGAS)

	FPMI	FGAS
Network Type	Organic	Imposed
Density	2.4%	9.1%
	Measures relative to: ORA Database Mean / FGAS Network	Measures relative to: ORA Database Mean / FPMI Network
Knowledge flow capacity (CB)	+ / +	– / –
Network Cohesiveness (CE)	+ / +	+ / –
Intra-network connectedness (TDC)	+ / +	+ / –

However, when exploring individual network Knowledge Management Capacity, there are differentiated results across the measures.

The FPMI network outperforms both the FGAS network and the ORA Sample Database mean across all measures of Knowledge Management Capacity. The FGAS network, however, does outperform the ORA Database mean in terms of Network Cohesiveness and Intra-network Connectedness. Based upon the comparison of FPMI and FGAS point-of-award analyses results, the density of the FGAS network, at time of award, is significantly higher than that of the FPMI network (9.1% vs. 2.4%). Yet, based upon the results of analysis of knowledge management capacity, a higher network density does not necessarily equate to higher levels of network centralisation.

Next, sub-group activities (across sub-projects, institutional affiliations and location factors) for the FPMI and FGAS networks are compared. In analysing sub-group activity, '+' and '–' are used to indicate measures relative to the averages generated in point-of-award analyses (FPMI – Table 4.1.2; FGAS – Table 5.1.2).

In examining sub-project activity, both the FPMI and FGAS networks focus more on one particular activity than others. In the case of the FPMI networks, the focus is on 'animal models' while the FGAS network focuses on 'cereal stresses' (see Table 6.1.2). However, FGAS activity is more significantly focused on 'cereal stresses' relative to other sub-projects ('Brassica stresses' and 'platform technology') when compared to the FPMI network. Both networks' appear to have more nationally based partners or affiliates relative to internationally or locally based ones. However, local activity on the part of the FPMI network is more concentrated than that of FGAS. In both cases, international partnering activity is significantly low. For both networks, academic affiliates dominate activity. However, in the case of the FPMI network, hybrid affiliates and activity plays an important secondary role. This is not surprising given VIDO's dominant role in the project and its affiliates' characterisation as a hybrid actor or agent. Public sector affiliates and activity plays an important secondary role for the FGAS network. Its well-anchored position within the NRC-PBI would seem to support this.

Table 6.1.2 Point-of-Award Comparative Analysis: Sub-Group Activity (FPMI vs FGAS)

Sub-Group of Interest	FPMI Degree Centralisation	FGAS Degree Centralisation
Sub-Project (FPMI / FGAS)		
Pathogenomics / Cereal Stresses	0.5000	**0.5714***
Animal Models / Brassica Stresses	**0.6667***	0.3929
Bioinformatics / Platform technology	**0.4444***	0.2857
Affiliation/Organisation Type		
Academic	**0.3889***	**0.4821***
Hybrid	0.3333	0.1429
Private	0.1667	0.0179
Public	0.1667	0.3750
Location		
International	0.0556	0.2500
Local	0.4444	0.2679
National	**0.6111***	**0.5000***

***** indicates highest centrality measure for that particular research focus, affiliation type or location.

Another important factor in this analysis is the nature of partnering activity between public and private sector actors. In the case of the FPMI network, 15% (3) of the 19 agents or nodes identified in Point-of-Award analysis are identified as private sector actors. On the other hand, the FGAS network shows that only 1 of the 57 agents is identified as being a private sector actor.

Further to this, a comparison of FGAS network centralization values with ORA generated results indicate that the private sector is significantly underrepresented within that network. The network-ORA database comparisons were illustrated in previous chapters (4, 5). Although the FGAS network appears to have a balance of representation across all sub-project indicated, the FPMI network has significantly less representation in the sub-project 'platform technology'. However, common to both networks are the significantly lower centralization measures of the location 'international'. Again, this would suggest that the international or 'global' attribute or connection is not particularly visible for either network.

6.2 Pre-Award Capacity for Knowledge Creation and Exchange (FPMI vs FGAS)

Pre-award analyses results are contrasted and compared to evaluate the evolution of the FPMI and FGAS networks' principals. Co-publishing, co-patenting as well as capacity to collaboratively secure funding are used to proxy knowledge exchange capacities over time.

Additionally, the capacity for knowledge exchange is supplemented by the level of knowledge creation. This is proxied through total output (publications, patents and funding awards) and compared across the two networks of interest. The latter results are normalised by network size for comparative purposes.

Table 6.2.1 compares FPMI and FGAS density measures of collaborative activity in terms of publishing amongst individual network actors for the selected time intervals (1985-1989; 1990-1994; 1995-1999 and; 2000 to point of award). Note that point-of-award for the FPMI network is 2002 and for the FGAS network is 2001. So, in order to obtain a picture of the continuing evolution of both networks beyond pre-award intervals, density measures are generated on both networks taking into account a full time interval of 5 years from 2000 to 2004 in terms of density of collaborative activity (Table 6.2.1). For this final adjusted interval, FPMI and FGAS density measures increase to 55.4% and 4.5% respectively. For the FGAS network, this provides a slightly improved picture on its evolution over time in terms of co-publishing activity.

Table 6.2.1 FPMI vs FGAS in Publishing Activity

	FPMI				*FGAS*			
	Density	% change	Output / principal	*% change*	Density	% change	Output / principal	*% change*
1985-1989	7.1%	--	17.12	--	1.9%	--	17.00	--
1990-1994	3.6%	-49.3%	18.62	*8.8%*	3.8%	100%	25.13	*47.8%*
1995-1999	14.3%	297%	29.75	*59.8%*	3.3%	-13.1%	23.87	*-5.0%*
2000-point of award	25.0%	78.6%	19.62	*-34.1%*	1.0%	-69.7%	3.62	*-84.8%*
2000-2004	*55.4%*	*287%*	*36.6*	23.0%	*4.5%*	*36.3%*	*9.8*	-58.9%

* Point of Award for FPMI = 2002; Point of Award for FGAS = 2001.

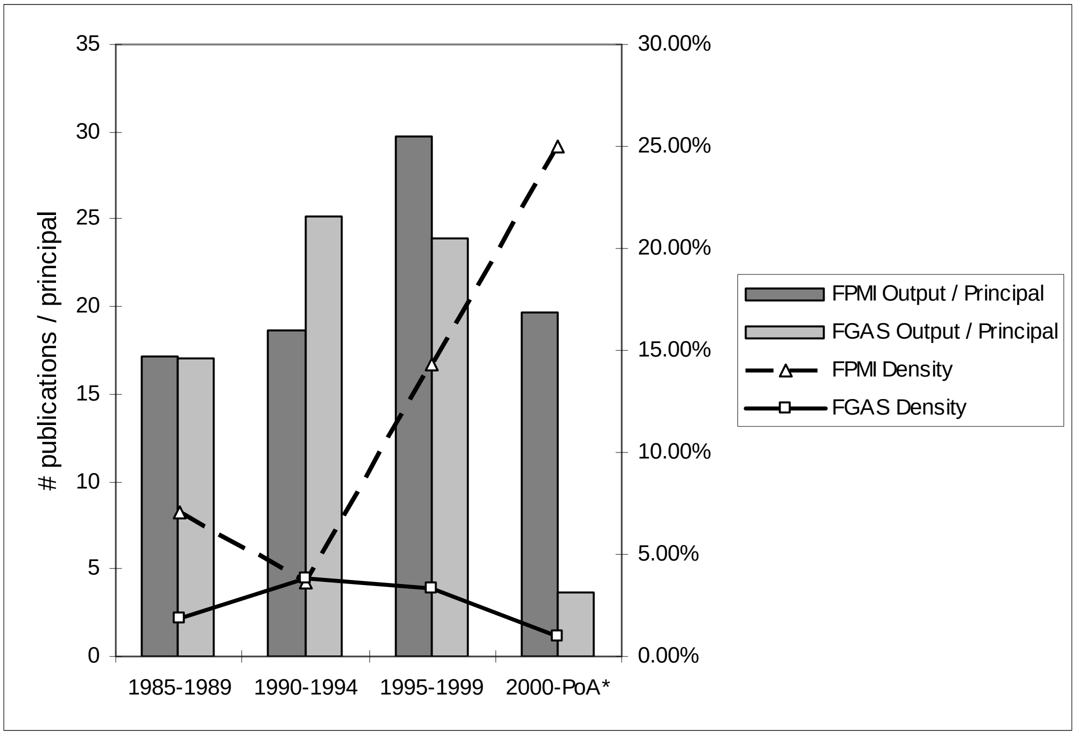
Overall, in comparing density measures, the FPMI network appears to outperform the FGAS network. Other than a negative net change in density between the first two intervals (1985-1989 and 1990-1994), the FPMI network demonstrates significantly higher density measures and higher net changes in those values as compared to the FGAS network. For instance, the net change in density for FPMI from the second time interval (1990-1994) to the third time interval (1995-1999) is almost 300%. On the other hand, the net change in density of co-publishing activity for the FGAS network is -13.1%. Net change between the final two intervals (including point-of-award to 2004 density measures) for FGAS is 36%. However, this value is surpassed by the sizeable net change of 287% as demonstrated by the FPMI network. Again, the only exception to this performance trend for both networks is in the net change between the first and second intervals. Here, FGAS experiences a net change in co-publishing activity of 100% while the FPMI collaborative activity decreases by 49.3%. As suggested in Chapter 4, the FPMI network appears to evolve more 'organically' over time when looking at the density measures of co-publishing activity over the time intervals of interest. Comparing these density measures and the net changes in those density measures with those of FGAS, as above, appears to support this assertion.

In terms of knowledge creation, other than in time interval 1990-1994, FPMI outperforms FGAS in total knowledge output (publications) over the entire period of interest (1990 to point-of-award) (see Table 6.2.1). For FPMI, the net change in output from time interval one to time interval two are 8.8%. However, output per principal for the FGAS network reveals a net change of 47.8% over the same period. There is a minor decrease in productivity for FGAS in the following time interval (5.0%) while the FPMI network demonstrates a 59.8% net change in output. Lower numbers in 2000 to point-of-award is attributed to the shorter time interval (one year for FGAS; two years for FPMI).

Taking into consideration the full time interval of 5 years (2000-2004), the FPMI network principals account for a total of 293 publications while FGAS principals account for 206. Normalised by network size, these numbers translate into 36.6 per principal (FPMI) and 9.8 per principal (FGAS) respectively. For the FPMI network, this represents a continued increase in output over the previous time interval (23.0%) while, in the case of FGAS, this represents a 58.9% drop in output from the previous time interval. These results may suggest reduced basic research capacity on the part of FGAS.

Knowledge creation or total knowledge output (over intervals of interest) in terms of publications normalised by network size (FPMI=8 principals; FGAS=21 principals) is outlined in Figure 6.2.1 with density measures (as outlined above) superimposed over results and illustrated through the y axis on the right hand side of the graph. Collaborative activity in co-publication output increases substantially for the FPMI over the latter three time periods. On the other hand, the FGAS network appears to decrease over the same time periods.

Figure 6.2.1 FPMI vs. FGAS Pre-Award Publishing Activity by Time Interval (normalised by network size)



** Point of Award for FPMI = 2002; Point of Award for FGAS = 2001.*

Co-patenting activity by network over time intervals (1990-1994, 1995-1999) is outlined in Table 6.2.2. Co-patenting activity for the full final interval of 2000-2004 is also included to accommodate for lag times between patent filing and award dates. In terms of pre-award collaborative activity in patenting, a search of the USPTO database returned no collaborative patents awarded jointly to FPMI network principals[89]. FGAS network principals, on the other hand, did participate in collaborative co-patenting activity. The density of activity, although

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[89] A review of the USPTO database, with results including those patents awarded for 2005, reveals one (1) patent awarded jointly to Babiuk and Griebel (patent **#6,946,448 (September 2005)).** In fact, Babiuk, who is identified as a leader (in terms of the FPMI project, VIDO activity, and as a community and local economic actor), co-patents with an entirely different set of actors (from the FPMI group of principals). For example, Babiuk co-patents most actively with the following individuals (# of co-patents)): S.K. Tikoo (5), S.K. Mittal (4), F.L. Graham (4), L. Prevec, T. Zamb (4), S. van Den Hunk (4) and D. Fitzpatrick (4) (amongst others).

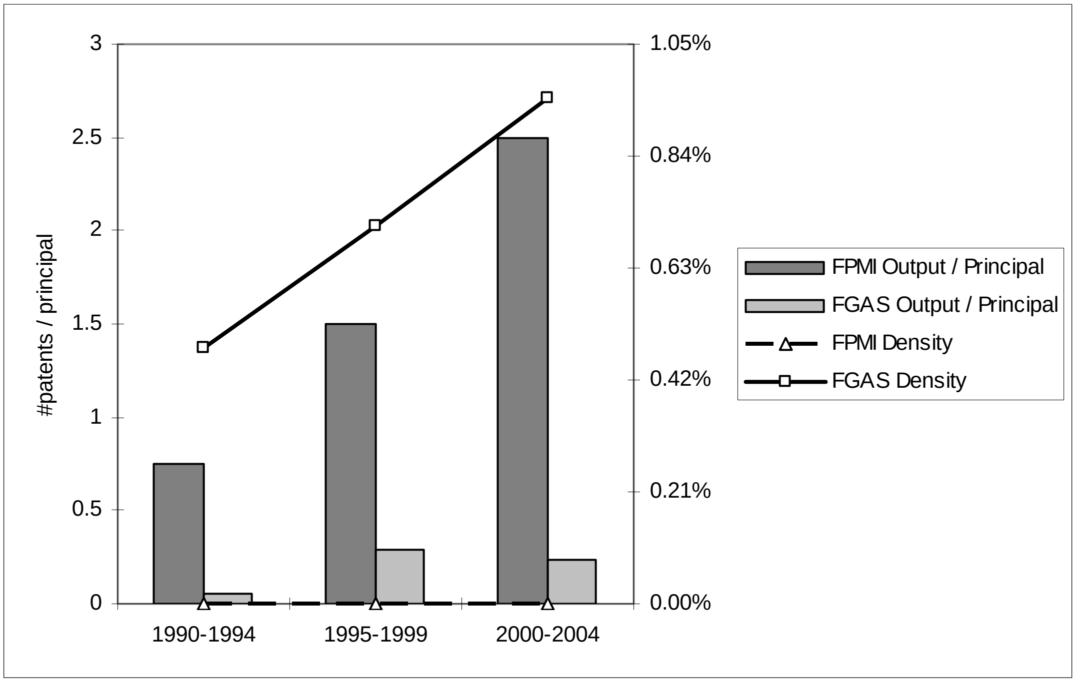
extremely low, does appear to grow steadily over time, increasing 47.9% from time interval one (1990-1994) to time interval two (1995-1999) and 33.8% over 2000-2004 (refer to Table 6.2.2).

Table 6.2.2 FPMI vs FGAS in Patenting: Density of Activity and Output by Principal

	FPMI		FGAS	
	Density	Output / principal	Density	Output / principal
1990-1994	0%	0.75	0.48%	0.05
1995-1999	0%	1.5	0.71%	0.29
2000-2004	0%	2.5	0.95%	0.24

Knowledge creation or total knowledge output (over intervals of interest) in terms of patents normalised by network size (FPMI=8; FGAS=21) is outlined in Figure 6.2.2. Density measures (outlined above) are superimposed over output by principal and illustrated along the right y axis. Although there was no network-based co-patenting activity for FPMI (0% density across all intervals), results indicate that the network substantially outperformed the FGAS over all three time intervals in terms of patent knowledge creation activity.

Figure 6.2.2 FPMI vs. FGAS Pre-Award Patenting Activity by Time Interval (normalised by network size)



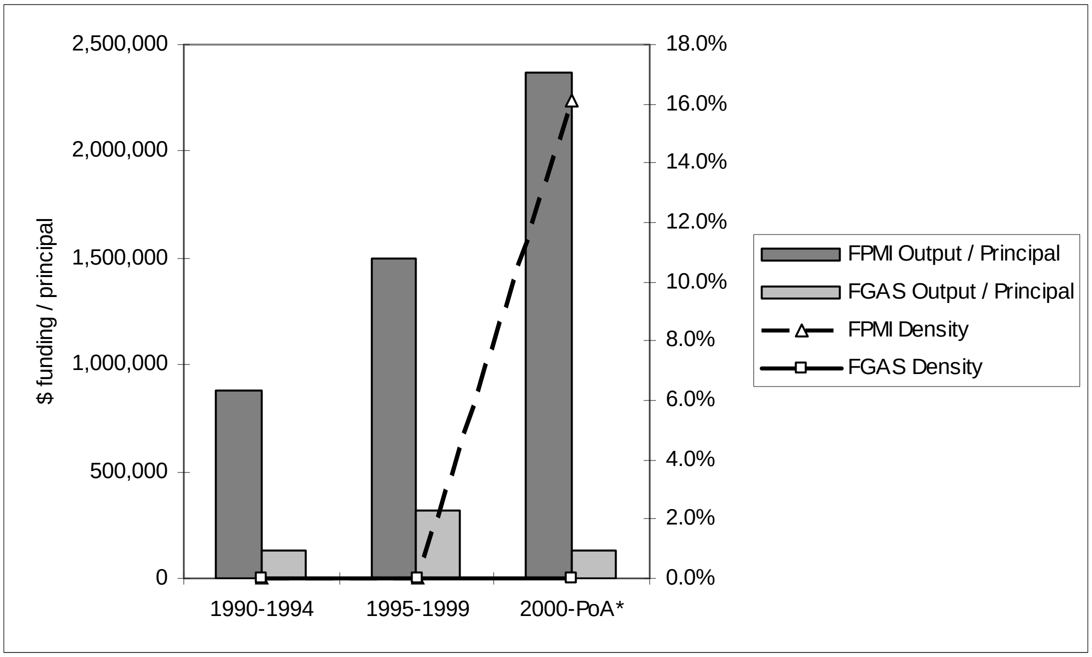
Another parameter for exploring knowledge creation and exchange is the network capacity for principals to attract funding. Table 6.2.3 compares and contrasts FPMI vs FGAS density measures for funding collaboratively awarded to network principals as well as aggregate, in terms of capacity to attract funding, dollars by principal. According to the results, there is little to no funding awarded jointly to network principals in the pre-award period (up to point-of-award) and no funding awarded jointly, in particular, to FGAS principals whatsoever, even up to and including 2004. On the other hand, FPMI network principals are awarded a significant amount of funding, which translates into 16.1% density level for collaborative activity in the final time interval (2000 – 2004).

Table 6.2.3 FPMI vs FGAS: Density of Collaborative Activity in Securing Funding and Output by Principal

	FPMI		FGAS	
	Density	Output / principal ($)	Density	Output / principal ($)
1990-1994	0%	877,255	0%	129,098
1995-1999	0%	1,499,816	0%	318,850
2000-point of award	16.1%	2,369,489	0%	126,837

Knowledge creation capacity, in terms of attracting funding, or total knowledge output (over intervals of interest), is normalised by network size (FPMI=8; FGAS=21), is illustrated in Figure 6.2.3 with density measures (outlined above) superimposed over results. Although density of collaborative activity is negligible in all but the last interval, the FPMI network still outperforms the FGAS network in terms of individual output over the time intervals of interest. Total funding attracted by FPMI principals grows significantly over time (from 877K in the first interval to over $2.3 M in the last time interval) while the FGAS capacity over the pre-award time period for attracting funding is sporadic and low (relative to FPMI).

Figure 6.2.3 FPMI vs. FGAS Pre-Award Funding Activity by Time Interval (normalised by network size)



** Point of Award for FPMI = 2002; Point of Award for FGAS = 2001.*

The comparative results of pre-award analysis (as outlined above) of the FPMI and FGAS networks are summarised in Table 6.2.4. The three knowledge sources or types (publications, patents and funding) are listed and density of collaborative activity for each serves as an indicator of capacity for knowledge exchange (KXΔ) while output normalised by network size is used as an indicator for knowledge creation (KC).

According to the results, the FPMI network appears to be higher performing overall in terms of capacity for knowledge exchange activity (collaborations) and in overall output across all knowledge types of interest. Overall, the FPMI network scored 'high' across all dimensions. The one exception to this is in terms of collaborative efforts with respect to patenting, where in the pre-award period, FPMI network principals did not collectively engage in such activity. The FGAS network, on the other hand, was inconsistent in terms of both knowledge creation and exchange activity over time. An interesting observation is the FGAS network's high density of knowledge exchange activity (particular with respect to patents) with an overall low level of knowledge creation activity. Evidently, what little patenting activity in the pre-award period that FGAS accounts for, appears to have been collaborative in nature.

Table 6.2.4 Summary of Pre-Award Performance in Knowledge Exchange and Knowledge Generation Activity (FPMI vs FGAS)

	Publications		Patents		Funding	
	KXΔ (density)	KC (output / normalised)	KXΔ (density)	KC (output / normalised)	KXΔ (density)	KC (output / normalised)
FPMI	High	High	0	High	High	High
FGAS	Moderate	Moderate-High	High	Low	0	Low

Prior to moving into comparisons of post-award performance, 'key principals' within the FPMI and FGAS networks with respect to knowledge creation activity are analysed with results outlined in the tables below. Table 6.2.5 outlines the total knowledge output (publications, patents, funding secured) by the key actors in the FPMI and the FGAS networks. Babiuk, Hancock, Potter and Finlay place consistently in the top three positions across all knowledge-based activities, in terms of output in the pre-award period. The results for the FGAS network are less consistent. For each activity, there appears to be a different set of key principals responsible for a larger percentage of knowledge creation output relative to other network actors. Interpreting these results further, the FPMI network appears to be significantly more cohesive than the FGAS in terms of historical collaborative activity.

Table 6.2.5 Synopsis of Key Principal Knowledge Creation Activity in the Pre-award Period (FPMI vs. FGAS)[90]

	FPMI		FGAS	
Knowledge-based Activity	Key Principal(s)	% of KC Activity	Key Principal(s)	% of KC Activity
Publishing	Babiuk Hancock Finlay	36% 28% 24% **88%**	Abrams Fowler Gusta	20% 15% 13% **48%**
Patenting	Babiuk Hancock Potter	45% 42% 11% **98%**	Maloney Sarhan Chibbar	30% 8% 15% **53%**
Funding	Hancock Babiuk Finlay	40% 37% 14% **92%**	Taylor Moloney Good	24% 18% 11% **53%**

Comparatively speaking, calculated values for each network appear to be much closer. Nevertheless, the top 50% of FPMI network principals are responsible for more knowledge creation activity (90%+) – in all areas – in the pre-award period than the top 50% of the FGAS network (as low as 68%). In particular, patenting and publishing activity appears to be distributed across a higher percentage of network actors in the FPMI network than that of the FGAS network.

6.3 Post-Award Performance (FPMI vs FGAS)

A higher incidence of historical collaborative activity (evolving social capital) is assumed to be positively linked with high network-based performance. In order to test this, post-award output (publications, patents, seminars, posters, presentations, # trained personnel, spin-offs

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[90] To compensate for the skewed results above ('top 3' represents a much larger portion of the FPMI network (over 30% of principals) than that of the FGAS network (at only 14% of all principals)), the total output by network is normalized and concentration ratios for the top 50% of principals in each of the networks are compared. The top 50% of FPMI principals account for 90% or greater across all activities whereas the top 50% of FGAS principals account for a broader range of activity from 68% for patenting, 78% for publishing and 93% for funding.

and total funding secured) for each network are normalised by network size (as outlined in Chapters 4 and 5; third section). The results are compared in Table 6.3.1.

Table 6.3.1 Comparison of post-award performance indicators normalised by network size (FPMI vs FGAS)

	FPMI (n=8) (2003-2004) (output per principal)	FGAS (n=21) (2002-2004) (output per principal)
abstracts/posters/seminars	2.87	n/a
presentations	5.50	2.00
publications (network-based)	2.13	1.24
publications (total)	19.00	6.19
patent applications	1.25	0.43
trained personnel	5.62	1.14
awards	3.63	n/a
Spin-off activity	0.25	0.05
Funding (CFI, NSERC, CIHR)	$3,701,405	$212,651

Across all indicators, the FPMI network appears to outperform the FGAS network, doubling and even more than tripling the normalized output of the FGAS network. In particular, FPMI substantially outperforms FGAS in securing funding in the post-award period. This result is particularly significant in light of the shorter timeline for post-award output on the part of FPMI.

6.4 Conclusions

A review of the comparative results from pre-award analysis indicates that FPMI is a good performer (relatively speaking) in terms of knowledge creation activity, ranking 'high' across all activities (publishing, patenting, securing funding). In terms of knowledge exchange, FPMI ranks high for both funding-related activities and in publishing. However, the exception here is in patenting where no collaborations are reported amongst network principals in the pre-award period for this activity. The FGAS network, on the other hand, performed less consistently than the FPMI network over time for both knowledge exchange and collaboration. In terms of the latter activity, FGAS ranked anywhere from no collaborative activity (in securing funding) to 'high' for collaborative activity in patenting. Performance in knowledge creation activities was also inconsistent with FGAS ranking from 'low' (patent and funding output) to 'moderately high' for publications. Overall, according to these results the FPMI network outperforms the FGAS network in terms of pre-award knowledge exchange and output capacities.

In post-award comparisons, FPMI significantly outperforms the FGAS network across those technical output indicators for performance.

Chapter 7

CONCLUSIONS, LIMITATIONS AND IMPLICATIONS

7.0 Conclusions

This dissertation introduces and applies a novel framework to assess performance in Genome Canada funded projects. In particular, it tests the overriding assumption that a history of social interactions or collaborations amongst network actors results in higher future output. Drawing on the case analyses and comparisons, the three hypotheses asserted in Chapter one are outlined below and conclusions are reviewed:

1. A history of collaborative activity amongst a set of actors does, in fact, result in self-organisation of those individuals into formalized research networks.

In testing this hypothesis (and the others), the FPMI network is assumed to be 'organic' in terms of structure while the FGAS network is 'imposed'. As a self-organised network, the FPMI network appears to evolve over the pre-award period (1985 to point-of-award), at least with respect to co-publishing activity. Although identified as an 'imposed' network, the FGAS network exhibited high levels of collaborative activity (co-patenting and co-publishing) amongst particular sub-sets of principals over time. As such, there is a certain level of self-organisation of actors within the network but these sub-groups appear to be eclipsed by the overall network structure.

Overall, as a collective unit, the FPMI network demonstrated higher levels of overall collaborative activity over the pre-award period than the FGAS network. Therefore, hypothesis #1 is not rejected by the evidence.

2. Self-organised research networks, as opposed to those that are imposed, may generate higher levels of knowledge creation and exchange over time.

Based upon the results (combination of pre- and post-award analyses), it appears that the wholly 'self-organised' FPMI network outperformed the FGAS network. Knowledge creation capacity was higher across all indicators (publications, patents and funding by principal) in the pre-award period. Similarly, FPMI output was significantly higher in the post-award period.

These results appear to conform with the second conditional hypothesis. Hypothesis #2 is not rejected.

3. How a network is structured – in terms of density, organisational affiliations, research focus and the geographic dispersion of actors – may affect output and network-based knowledge management capacity.

Network structure, in this case, is defined or characterized through density measures, organisational affiliations, research focus and the geographic dispersion of actors in this framework. As reported, the FPMI network outperformed the FGAS network in most, if not all, of the activities defined. FPMI is assumed to be the higher performing network in interpreting the data as it relates to this hypothesis.

Density: Overall density measures – as calculated at point-of-award analysis – find that the FGAS network exhibits a higher density measure than FPMI. Given that the FPMI network outperformed the FGS network in terms of post-award output, these results would suggest that higher network density does not necessarily equate with higher performance (according to the data FPMI outperforms the FGAS network). This would support Burt's theory of 'structural holes' and Granovetter's theory of the 'strength of weak ties'. Further supporting this notion is the fact that in terms of co-patenting activity, the FPMI network exhibited zero density. No patents were awarded to two or more FPMI network principals.

Examining the pre-award results further, activity density measures in the pre-award period are higher for FPMI than FGAS (with respect to co-publishing and co-funding). Again, as the FPMI network demonstrated higher post-award performance one might conclude – in this instance – that higher network density (e.g. the structure) with respect to these activities may be an indicator of higher future network-based performance.

Upon deeper examination, density by particular collaborative activity (co-patenting, co-publishing etc) returns differential results when looking solely at pre-award results. For example, publication output per principal (knowledge creation) appears to be comparable for both networks (with the exception of 2000-2004). Yet the complimentary density measures for those time intervals indicates that there are much higher co-publication densities for the FPMI network than for that of FGAS (see Table 6.2.1).

It would appear from these results that density affects performance differentially and is dependent upon the type of activity analysed. This relationship between density and network performance requires further investigation.

Affiliation: According to point-of-award analyses, for the most part, network agents are split between two primary affiliation types for both networks. FPMI network agents are primarily connected to academic or hybrid organizations. Again, VIDO was identified as a hybrid agent within the FPMI network and several network members are affiliated with this organization. VIDO grew out of the University of Saskatchewan and, therefore, has significant connections with it. Additionally, some FPMI network principals are located in and around the University of British Columbia. As well as strong links to academia, FGAS has a significant numbers of links with the public sector. Again, several network agents are either directly and indirectly (through the University of Saskatchewan) affiliated with the National Research Council's Plant Biotechnology Institute. In both networks, there is little visible private sector participation. As results for both networks are similar, it is very difficult to link affiliation-type (in terms of network structure) with higher performance.

Research Focus: Both the FPMI and FGAS networks appear to have a stronger emphasis on one particular research activity or focus in the point-of-award analysis. There is slightly more variability within the FGAS network. This latter variability may represent a more balanced approach to network research or it may, in fact, be yet another indicator of the overall divisive structure of the network. In pre-award analysis, it is apparent that for both networks research focus does play a role in the evolution of a collaborative activity. In both cases, and across the knowledge-based indicators, network actors tend to collaborate with those that have the same research interest. There is some evidence of cross-over but not until later intervals.

Geographic dispersion of principals: Structurally speaking, the FGAS network would appear to have a more balanced collection of actors geographically located across all location types (local, national, international) as there is higher variability in centralization measures according to point-of-award results. However, less variability on the part of the FPMI network and its configuration of location-based centralisation measures may, in this case, be more positive. Most FPMI network actors are either located in Saskatoon or in and around Vancouver, B.C., suggesting that the close proximity of principals is affiliated with higher network performance. FGAS, on the other, consists of agents that are widely dispersed. This may, in fact, negatively affect performance. Moving into pre-award analysis of both networks, it is apparent that proximity does play a role in the evolution of a network. In both cases, and across the knowledge-based indicators, network actors appear to collaborate with those that are geographically closer. While this appears to be the norm, there are some exceptions to this. In later intervals, there is evidence of collaborative between and amongst principals that are proximally based.

Based upon the results, a higher degree of density and centrality does not necessarily equate to better performance. Assuming that the FPMI network is the higher performing network and taking into account the summary of data results above, it would be fair to assume that, although conditional (again, indicator and context specific), network structure does affect performance. It appears that there is a correlation between network structure (in terms of proximity, research focus and density) and performance. According to the results, network structure in terms of affiliation-type appears to not affect performance either way. Again, these conclusions suggest that network structure and its effects on performance are both indicator and context-dependent.

Therefore, hypothesis #3 is challenged but not unambiguously rejected by the data.

Based upon the outcomes and the observations made from the analytical study of these two networks and the hypotheses proposed, it appears that – as assumed – a history of higher levels of collaborative activity amongst network principals or actors would, all other things equal, be positively correlated with enhanced performance.

7.1 Study Limitations

The three-part framework proposed and applied in this dissertation pulls together traditional measures (e.g. descriptive indicators) and the network analysis method into a novel approach to analyse (ex ante and ex poste) performance in and the economic and social impacts of collaborative research and research networks. The framework, novel in terms of structure and application, shows promise in addressing the complexities of evaluating network based performance. For example, using some form of pre-award evaluation would likely shed light on future capacities of candidate networks. In these analyses, the FPMI network consistently outperformed the FGAS network. If the efficacy of these two networks is tested by simply comparing aggregate output for a ten year period prior to the award date, similar results are confirmed. For example, aggregate output of publications for this pre-award interval is 397 for FGAS and 531 for FPMI. This translates into values normalized by network size of 18.9 and 66.4 respectively. Therefore, some form of pre-award evaluation of output may provide a partial indicator of future performance.

Despite this, the framework has some limitations in its capacity to completely predict or evaluate performance levels. Although the results of comparisons of output suggests that the proxies used for knowledge creation and exchange in pre-award analysis, may serve as good indicators for determining (future) performance in networks, point-of-award analysis may not offer much as a forecasting tool. This part of the analytical framework draws largely on secondary or tertiary, qualitative-based sources (primarily web-based sources).

At point-of-award, many secondary and tertiary actors were not included within the network boundaries. For example, Advanta, Aventis and Pioneer also play a role in the FGAS network. Unfortunately, at the point of gathering data, these agents or private sector organisations were not included as part of the team. The International Triticeae EST Cooperative (ITEC), the International Triticeae Mapping Initiative (ITMI) collaboration and NSF Wheat Project are other organisations or collaborative partners that were overlooked as well. In terms of individual actors (i.e. principals), van Rooijen was linked to patenting activity by the FGAS network. Although van Rooijen is not formally involved with the project as a signatory, it appears that his partnering activity with Moloney plays an important, yet indirect role in FGAS knowledge creation[91].

As a result of these omissions, the data gathered and analysed in this dissertation does not include a number of particular publication, patent or funding units[92]. This prevents the all-inclusive analysis of network-based activity in terms of these activities. As outlined earlier, errors in establishing network boundaries and in ascertaining all of the data is a significant limitation of social network analysis.

In addition to missing data, pre-award analysis also has other limitations. This part of the framework applies measures to select intervals over a period of time. The five year interval approach used for this dissertation here may, in fact, be too broad. Incorporating something like a three-year rolling average over the time period of interest might be more useful in future studies.

The post-award analytical process is problematic in that it represents such a short time span. Output is limited to those that can be accounted for within a 2 – 3 year window (from point-of-award). Using short-term technical output as a proxy for post-award network performance offers a short-term solution. Additionally, it is important to note that comparing and contrasting network output based upon tools for discovery or publications and patent applications, for that matter, are limited at best. It would be fair to assume that different research foci (animal vs plant genomics) may have different windows for discovery, processing and generating research results, even in the short term. Also, in the genomics R&D context, using a truncated window to determine technical output is dangerous, as most

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[91] Another example of limitations on the data is in the case of FPMI principal Fiona Brinkman. Fiona Brinkman was married in the 90s and published under her maiden name prior to that (a fact which was not uncovered until well past analysis and comparatives).

[92] Diehl et al (2006) examine the issue of name resolution in exploring organizational email communications. According to the authors, a shared context is the impetus for simplified communications which, when viewed from outside the context, may be difficult to interpret and understand. Thus, if one is not immersed within the context, it may be difficult to ascertain all of the information required to conduct a thorough investigation of data.

socially and economically valuable output is not realised for 10 or more years. There is a misalignment between expectation of output on the part of Genome Canada (eg. "…to develop [the] asset for social and economic benefit") and the realities of time constraints imposed by project parameters (funding window of three to four years). Additionally, the output measures do not take into account the nuances of funding lapses and preparation of new applications. For instance, in the third round of Competition (results announced in July 2005), principals from networks (FPMI and FGAS) re-organised their strategies to varying degrees in applying for this round of funding from Genome Canada. While the FPMI network was funded outright again with moderate changes to the original structure[93], principals of FGAS network re-organised into new networks and applied for funding under five different research proposals[94]. Of those original five, only two were funded (Wheat II and Brassica Seeds)[95]. Based upon these observations, it is important not to over-emphasise the results of these analyses and comparisons.

The density measure, incorporated as it is throughout this analytical framework, provides a quantitative indicator of network structure or capacity to a greater or lesser degree depending upon its application. It appears that results of applied density measures have differential effect on performance. In point-of-award analysis, results indicate that a higher density measure does not necessarily signal higher performance. Yet, as applied in pre-award analysis, the opposite is true. Based upon the observations made here, network density impacts performance or outcomes, but no unambiguous conclusions can be drawn as to whether enhanced performance is linked to high density or low density.

There are limitations in even using the discrete output measures. Measures such as peer review research grants, publications or patents are more "concerned with intent rather than success" and may be more a measure of "promise and not a guarantee of output" (Cooper et al 2005: 9). For example, patents are often used as a (short-term) output indicator of investment in R&D. In conducting interviews for this research, it was unanimously agreed by

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[93] More international actors were brought to the table including the Gates Foundation and the Sanger Institute.

[94] Wheat I = Sarhan; Wheat II = Fowler; Wheat III = Chibbar; Brassica Seeds = Weselake/Keller; Flax = Good.

[95] The other project principals are actively seeking other sources of funding.

project principles and managers that patents were, indeed, an important indicator for them in terms of monitoring output and performance. Although commonly used in such circumstances, employing patents as performance indicators has limitations. For one, just because something is patentable doesn't mean that it offer social value. Patent value is optimized in cases where they are cited or, in fact, used for new R&D activity. In fact, there are those that believe that patents serve more desirably as a measure of input of innovation or R&D. In this case, then, the patents employed would obviously have secondary or tertiary value in that they are either used or cited in the development of new or incremental innovations. Finally, as previously mentioned, patents or patentable inventions – even if successful – do not see their way to the market or end-user for several years.

On the subject of social capital, the issue of training graduate students in the pre-award period would present an alternative, yet valid, measure of knowledge output and even knowledge flow. Cooper et al (2005) identify 'skilled people' as key to developing knowledge pathways and facilitating exchange: "Highly qualified personnel are the principal product of universities, and play a major role in developing absorptive capacities in [organisations] (6)." And although volume of output is considered within this framework, the quality of output is not. Citation analysis may provide an indicator 'quality' of both patents and publications, further qualifying the nature of network-based activity.

Although these more quantitative approaches to evaluating and mapping knowledge have significant relevance in this type of analysis, the 'softer' more informal elements of knowledge are not effectively captured by such approaches. Tacit knowledge – that leads to the development of codified knowledge in research networks – is often a product of chance meetings, serendipitous conversations and exchanges facilitated through, for example, the conference setting. However, capturing such exchanges is significantly more challenging. One option may be, in fact, to explore more deeply into key principals' curricula vitae outlining conference papers/presentations and comparing those with the records of conference proceedings captured through the ISI Thomson database. Linkages between key individuals may then be illuminated and yet another source of knowledge incorporated into the analytical process. Evidently, a more holistic picture of knowledge – and all its aspects – needs to be illuminated.

No matter how knowledge is represented, the SNA tool itself appears to offer a unique – yet incomplete – approach to incorporating the role of social factors and evaluating performance in R&D networks. There are a large number of software options – some that perform better than others – and it is difficult to determine an appropriate candidate for use. The ORA software, primarily used in this dissertation, is limited in its capacity in that it cannot as yet incorporate attribute-based data or information into its nodes (although updated versions are being introduced on a monthly basis).

Particularly problematic is the ORA sample database used to contrast and compare the networks (FPMI and FGAS) results. As this type of analytical approach – using SNA to evaluate performance – is in its infancy, a more comprehensive and relevant database with which to compare results is not yet available. Rather, the ORA database consists of a small (20+) repertoire of unrelated (non R&D) a network (limited to terrorist, communication, email networks) that does not really provide an accurate or necessarily relevant database with which to compare results. Growing interest in social network analysis as a tool for evaluating performance will undoubtedly help to mitigate this gap in the resources as efforts to understand the role of relationships and capture the softer elements of knowledge and productivity increases. Further research is, undoubtedly, required.

7.2 Recommendations for Further Research

Although preliminary in nature, this framework offers a way in which to evaluate performance in public-private collaborative research networks. Different parts of the framework can serve different purposes. For example, pre-award analysis offer an ex-ante evaluative method to look at the structure of the network and how principal or agent based relationships have evolved over time. A history of successful collaborations amongst network principals can indicate high levels of output. On the other end of the framework continuum, post-award analysis (even in the short-term) can provide an indicator of project output.

These preliminary results suggest that the proxies used for knowledge creation and exchange may serve as merely partial indicators for determining future performance in networks. Other factors such as return on investment or more in-depth analysis of the agent-to-agent relationships may highlight other more useful proxies.

As suggested earlier, deeper analysis of the social factors that drive network development and structure may be helpful as well. To achieve this, in-depth, ego-network (at the principal or actor level) analyses would need to conducted on each principal which are then supported by data and information derived from one-on-one in-depth interviews. However, it is important to note that such a strategy would be time and research intensive, with variability in the legitimacy or validity of results once completed. Thus, the 'ego' approach may not really offer a practicable and time-sensitive option for the policy maker.

A more feasible strategy would be to apply the framework to other collaborative networks, gather those measures, and develop a database of R&D related measures which was identified earlier as a gap in the resources. Such a database would provide the foundation for more accurate comparisons of network results and, with a large enough database, would allow for regressions that might provide an even richer analysis of research networks.

Finally, the framework could be applied for ten or more years after the point-of-award to track outputs and outcomes of approved projects. This would account for the lag-time between point-of-award and output (commercialisable products or processes) associated with R&D and provide a more accurate picture of the innovation process.

7.3 Implications of Research

Like the concepts that are associated with innovation, current evaluative approaches utilised by the federal government to monitor projects and programs appear to be vague and ill-defined. Research and development activities generate new knowledge but where socially viable outcomes or downstream products or processes are not realised for several years. Private sector involvement also represents yet another complexity which also brings into question the appropriate role of the government in partnerships with the private sector. Differentiated evaluation strategies are required that are practicable yet rigorous.

Despite the limitations outlined herein, this framework shows promise in addressing the complexities of evaluating network based performance. For example, using some form of pre-award evaluation would likely shed light on future capacities of candidate networks. As stated earlier, by simply comparing aggregate output for a ten year period prior to the award date, similar results to that produced through the application of this model are confirmed.

This study and the application of this framework contribute to the advancement of knowledge in assessing performance in research networks. This study presents and tests not only a novel model, but it also achieves a number of other key goals. First, it critically assesses the associated literature and points out some important gaps and addresses these gaps. In particular, it points out the lack of effort for academics and practitioners to address the 'soft stuff' in evaluating performance. Human and social capital are recognized as a key components to innovation yet efficacious ways in which to quantitatively and qualitatively assess their impacts have not been developed nor adopted. Publications and patents are used in this study as proxies for performance, knowledge exchange capacity and output. However, optimal research capacity is sustained through ongoing relationships amongst key actors and/or institutions. Ensuring that there are proper mechanisms in place to cultivate and support such relationships is key to sustainable productivity within networks of public and private actors.

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Appendix A Genome Prairie Survey

Survey of IP Management in Genome Canada Projects

2003-2004

Part 1: Structuring the Project

The purpose of this section is to determine your past, current, and anticipated relationships related to research and commercialisation involving Genome Canada research projects.

1. What is the title and main purpose of your project?

2. What is the expected timeline for your project?

Formal announcement of start of project	
Announced Completion Date	

3. What is the architecture of your project in terms of human capital?
Please indicate the number of people involved in each category, whether they are directly or indirectly involved in the project, and whether they are located locally or non-locally. If they are located non-locally, where are they from?

	Number	Formally Involved	Informally Involved	Local	Non-local (specify location)
Principal Investigator(s)					
Investigator(s)					
Post Doc(s)					
Graduate Students					
Other Researchers/ Technicians					
Project Managers					
Support and Admin Staff/Other					
Contract Professionals (eg. Accountant, Lawyer)					

4. What is the total amount of funding that you will receive from Genome Canada?
$CDN ______________________________

4.1. What are the most important sources of matching or supplementary financial funding other than Genome Canada?

	Not Applicable	Most Important (> 50% of matching funding)	Very Important (25% to 50% of matching funding)	Important (5% to 25% of matching funding)	Somewhat Important (1% to 5% of matching funding)	Not Important (<1% of matching funding)
Funds from partners or collaborating firms						
Government Grants (please specify)						
Internally Generated Funds						
Angel Investors						
Venture Capitalists						
Equity Investment (Private)						
Equity Investment (Public Capital Markets, IPO's)						
Banks						
Government Loans and Subsidies						
Other						

4.2 What type of in-kind support do you receive from others?

	Lab Space	Equipment	Office Space	Services	Labour	Other (please specify)
University						
Public Lab						
Industrial Partners						
Government Facility						

4.3. How has financing changed from your approved project base?

4.4. Briefly describe challenges faced in obtaining matching finances.

5.0 Looking at your project, what *prior* relationships existed among principal investigators/investigators?

Type of Relationship	Did a prior relationship exist?		Date of earliest relationship	
	Yes	No	Month	Year
Same Department or University				
Previous joint grant holder				
Previous Student/Teacher Relationship				
Joint partnership in Network of Centers of Excellence (NCE)				
Other long term research project				
Other (Please Specify)				

6. Do any of the Principal Investigators or Investigators of the project have their own private companies?
Yes [ ]
If yes, please provide company name ___________________________.
No [ ]
Do not know [ ]

6.1 Do you or others working on your project have active collaborations with private companies and academic institutes?
Yes [ ]
No [ ]
Do not know [ ]

If you answered yes, please proceed to the next question.
If you answered No or do not know, please proceed to Part 2: Creating and Starting the Project. (see page 7)

6.2 If yes to the above question, please provide more information about these collaborations. (name of company, location, types of interaction, modes of interaction, frequency of interaction).

Part 2: Costs of creating, starting and managing the project

The purpose of the following questions is to examine the 3 stages of project development, namely:

a) search costs: These costs start at the date of the original project concept to the date that Genome Canada approved the project.
b) negotiation costs: These costs start at the date that Genome Canada approved the project to the date the formal research contract was signed with the genome centre.
c) ongoing costs: These costs include any on-going costs that may arise after the contract is signed with the genome centre.

7. What are the key dates for your project development effort?

	Month and Year
Concept Date	
Date of Award	
Date Interim Agreement signed (Letter of intent or Memorandum of Understanding)	
Date Contract Signed with GC	
Other key dates (specify)	

8. Who led the effort in the search for partners for your project, and who made the investment (time, expenses, etc) in the search? Please check all that apply.

Search Leader(s)		Investments made by:	
Scientist		Scientist	
University Advisory Committee		University Advisory Committee	
Partners		Partners	
Contract Lawyer		Contract Lawyer	
Contract Management		Contract Management	
Consultant		Consultant	
Project Manager		Project Manager	
Industry Associations		Industry Associations	

9. In your search to develop and draft the project proposal, please estimate how much time and out of pocket costs were required to locate partners.

Person Years Months	Days	Out of pocket costs to find partners (eg. travel, communications costs/meetings, advertisements, other)
		C$

9.2. What other costs do you attribute to your project development efforts?

9.3. Did project activity (eg. start to spend money on research) start before or after a formal contract was signed with the Genome Centre?

Before [ ]
After [ ]

9.4 If project activity started before a formal contract was signed, did the activity start before the award date?

Yes [ ]
No [ ]

10. Who was responsible for negotiating the genome project contract with the Genome Centre once you received formal approval for the project? How much effort and money was invested?

	Lead Negotiations	Participated	PY effort (months, days)	Out of pocket costs (C$)
Scientists				
University Administration				
Partners (commercial partnerships)				
Industry Associations				
Contracted Parties (Lawyer, Management Consultant, Project Leader)				
Other (please specify)				

11. Has the contract negotiating process delayed the progress of your project?

Yes [ ]
No [ ]

If so, by how many months? ___________________

What do you believe is the impact of these delays on your ability to generate world leading research results?

12. Please indicate the actual or expected one time or annual costs of your project for each category.

One-time or Annual Costs (Canadian dollars)	
Project Management Yearly Budget	
Project Business Manager's Salaries	
Office expenses	
Communications/Travel related to management of project	
Principal Investigator's/Investigators time spent on management	
Advisory Committees' honorarium and travel	
Other (please specify)	

12.1 Does your project pay overhead?
If so, what is your total yearly or one time overhead budget?
C$ _________________________

13. What plans do you have in place to manage the project or its outputs after your formal agreement has ended with Genome Canada? Please check off all that apply.

1.	Request extension from Genome Centre	
2.	Find other sources of funding (please specify sources)	
3.	New relationships will provide the base for other collaborations	
4.	Shut down project	
5.	Assign Rights to Manage IP with :	
	Principal Investigator/Investigator	
	Genome Centre	
	Other (please specify)	

Part 3- Intellectual Property Strategy

The following questions are used to determine your intellectual property strategy, and the costs incurred in the search, negotiation, and monitoring of intellectual property rights.

14. Do you have an intellectual property strategy?
Yes [ ]
No [ ]

14.1 Is it formal or informal?
Formal [ ]
Informal [ ]

15. What are the expected outputs of your project? Do you have an intellectual property strategy for these outputs?

Process	Expected Output	IP strategy		*Product*	Expected Output	IP strategy	
		Yes	No			Yes	No
Diagnostic techniques				Gene sequences			
Sequencing techniques				Isolated Genes			
Data simulation techniques				Data banks			
				Transgenic Products			
Other Process(es) *Please specify*				Other Product(s) specify:			

16. Which intellectual property mechanisms are you using?

Process	None	Patents (#)	Trade Secrets	Plant Breeder Rights	Copy-rights	Trade-marks	Other (specify)	Who will hold rights*	Who will exploit*
Diagnostic techniques									
Sequencing techniques									
Data simulation techniques									
Other Process(es) Please specify:									

Products	None	Patents (#)	Trade Secrets	Plant Breeder Rights	Copy-rights	Trade-marks	Other (specify)	Who will hold rights*	Who will exploit*
Gene sequences									
Isolated Genes									
Data banks									
Transgenic Products									
Other Product(s) Please specify:									

*For who will hold rights or exploit rights, please insert corresponding numbers:
1=Principal Investigator/Investigator; 2=Institution where inventor works; 3=Funding Partner; 4=Private Partner; 5=Sell/license rights to other party

16.2 What markets will you target these Intellectual Properties to?
[ ] Canada [ ] International (please indicate location(s))____________________________

17. Who directly involved with your project makes decisions regarding IP?

PI's/ Investigators	
Management Team	
External Contractors	
Advisory Board	
Other (please specify)	
Unsure	

18. Do you have a formal method for valuing your intellectual property?
[ ] Yes
[ ] No

18.1 If yes to the previous question, please briefly describe your method.

19. Can you please indicate your yearly budgeted costs associated with the following:

Canadian Dollars	Patent search	Patent Negotiation	Patent Monitoring
$0- $5000			
$5000- $10,000			
$10,000- $25,000			
$25, 000- $50, 000			
$50, 000 +			

19.1 What other costs do you incur for Intellectual Property Management?

Part 4- Commercialisation Strategy

The questions in this section are to determine your commercialisation strategy.

20. Have you commercialised any technologies yet?
Yes [ ]   No [ ]

If you answered no to this question, please skip ahead to Question 23 on page 16.

20.1 If you answered yes to the above question, what type of technologies have you commercialised?

Process		*Product*	
Diagnostic techniques		Gene sequences	
Sequencing techniques		Isolated Genes	
Data simulation techniques		Data banks	
		Transgenic Products	
Other Process(es) Please specify		Other Product(s) Please specify	

21. Have you experienced any of the following issues in relation to the transfer and commercialisation of technology? Please mark all that apply.

Lack of timely decision making [ ]
Understanding who is responsible for making decisions [ ]
Valuable IP that has not been identified [ ]

Valuable IP that has not been protected [ ]
Loss of potential IP as a result of failing to properly protect [ ]
IP ownership disputes or lack or clarity in relation to ownership,
that has caused problems for commercialisation opportunities [ ]

22. Who leads the commercialisation process?

	Location (please specify)
Scientist	
Management	
Accountant	
Attorney	
Consultant	
Other (please specify) _________________	

23. Do you have any other observations about the commercialisation process?

End of Survey
Thank you very much for your time.

Appendix B Listing of FPMI Principals, Affiliations and Partnering Organisations

Name	Affiliation or Affiliation Type	Location
Abrahamsen*	University of Minnesota	Minneapolis, MN
Babiuk*	VIDO	Saskatoon, SK
Brinkman*	SFU	Burnaby, B.C.
Finlay*	UBC	Vancouver, B.C.
Griebel*	VIDO	Saskatoon, SK
Hancock*	CMDR	Vancouver, B.C.
Hodgson	VIDO	Saskatoon, SK
Jones*	GSC	Vancouver, B.C.
Mah	FPMI	Vancouver, B.C.
North	Inimex Pharmaceuticals Inc.	Vancouver, B.C.
Potter*	VIDO	Saskatoon, SK
Centre for Microbial Diseases and Immunity Research (CMDR)	Public	Vancouver, B.C.
Genome Sciences Centre (GSC), BC Cancer Agency	Public	Vancouver, B.C.
Inimex Pharmaceuticals Inc.	Private	Vancouver, B.C.
Pyxis Genomics	Private	Chicago, Ill / Saskatoon, SK
Simon Fraser University	Academic	Burnaby, B.C.
University of British Columbia (UBC)	Academic	Vancouver, B.C.
University of Saskatchewan	Academic	Saskatoon, SK
Vaccine and Infectious Disease Organisation (VIDO)	Hybrid	Saskatoon, SK

* Principals of interest for network analysis (pre-award and post-award)

Appendix C Pre-Award Patents by FPMI Network Principal (n = 38)

Principal Name	Patent #	Date Awarded	Assignee	# of Co-Inventors	Lead?
Babiuk	5,124,145	23-Jun-92	Ciba-Geigy Corporation	1	
Babiuk	5,151,267	29-Sep-92	U of S	3	
Babiuk	5,234,684	10-Aug-93	Ciba-Geigy Corporation	1	
Potter	5,238,823	24-Aug-93	VIDO / Ciba Geigy	2	√
Potter	5,273,889	28-Dec-93	U of S / Ciba Geigy	2	√
Babiuk	5,369,026	29-Nov-94	VIDO	2	
Babiuk	5,585,264	17-Dec-96	U of S	3	
Hancock	5,593,866	14-Jan-97	UBC	2	√
Potter	5,594,107	14-Jan-97	U of S / Ciba Geigy	2	√
Babiuk	5,672,350	30-Sep-97	VIDO	2	
Hancock	5,688,767	18-Nov-97	UBC	3	√
Hancock	5,707,855	13-Jan-98	UBC	2	√
Hancock	5,789,377	4-Aug-98	UBC	3	√
Babiuk	5,820,868	13-Oct-98	VIDO	3	
Babiuk	5,858,989	12-Jan-99	U of S	3	√
Hancock	5,877,274	2-Mar-99	UBC	1	√
Babiuk	5,879,895	9-Mar-99	U of S	3	√
Babiuk	6,001,591	14-Dec-99	U of S	3	
Hancock	6,040,435	21-Mar-00	UBC	1	√
Hancock	6,057,291	2-May-00	UBC	1	√
Babiuk	6,086,890	11-Jul-00	U of S	3	
Babiuk	6,086,902	11-Jul-00	U of S	2	
Potter	6,096,320	1-Aug-00	U of S / Ciba Geigy	2	√
Hancock	6,172,185	9-Jan-01	UBC	2	√
Hancock	6,191,254	20-Feb-01	UBC	2	
Hancock	6,288,212	11-Sep-01	UBC	4	√
Hancock	6,297,215	2-Oct-01	UBC	1	√
Babiuk	6,319,716	20-Nov-01	U of S	5	
Hancock	6,337,317	8-Jan-02	UBC	1	√
Finlay	6,355,254	12-Mar-02	UBC	4	√
Hancock	6,358,921	19-Mar-02	Pence Inc (AB)	5	
Babiuk	6,379,944	30-Apr-02	U of S	3	
Babiuk	6,458,586	1-Oct-02	U of S	2	
Hancock	6,465,429	15-Oct-02	UBC	1	√
Babiuk	6,492,343	10-Dec-02	U of S	2	
Hancock	6,747,007	8-Jun-04	UBC	1	√
Babiuk	6,794,163	21-Sep-04	U of S	3	
Hancock	6,818,407	16-Nov-04	UBC	4	√

Appendix D Post-Award Patent Applications by FPMI Network Principal

Name	USPTO Patent Application Documentation #	Date Filed	Assignee	#Co-inventors	Lead?
Babiuk	20020034519	31-May-01	--	3	
Potter	20020025322	11-Jun-01	--	2	√
Potter	20020044928	11-Jun-01	--	2	√
Potter	20030082781	11-Jun-01	--	3	
Hancock	20030096949	17-Jul-01	UBC	4	√
Babiuk	20020110567	10-Aug-01	--	3	
Griebel	20020110567	10-Aug-01	--	3	
Babiuk	20020106639	20-Aug-01	U of S	3	
Potter	20020106639	20-Aug-01	U of S	3	
Potter	20020160020	3-Jan-02	--	1	
Finlay	20020160020	3-Jan-02	--	1	√
Hancock	20020156017	8-Jan-02	UBC	1	√
Babiuk	20020192185	14-Jan-02	--	3	
Potter	20030007981	13-Mar-02	U of S	2	√
Babiuk	20020177216	27-Mar-02	--	3	
Potter	20030072765	26-Apr-02	--	3	√
Potter	20030165524	26-Apr-02	U of S	3	
Babiuk	20030086905	23-May-02	--	3	
Griebel	20030086905	23-May-02	--	3	
Babiuk	20030008390	13-Aug-02	--	2	
Babiuk	20030130187	16-Sep-02	--	2	
Hancock	20030176337	15-Oct-02	UBC	1	√
Hancock	20040001803	2-Dec-02	--	5	√
Finlay	20040001803	2-Dec-02	--	5	
Babiuk	20030170616	31-Dec-02	--	13	
Potter	20030170616	31-Dec-02	--	13	
Hancock	20040019181	28-Mar-03	UBC	3	
Jones	20040048277	8-Sep-03	--	4	
Potter	20040062774	27-Aug-03	U of S	2	
Babiuk	20040132178	2-Sep-03	--	3	
Potter	20040132178	2-Sep-03	--	3	
Hancock	20040180038	12-Sep-03	--	4	√
Finlay	20040180038	12-Sep-03	--	4	
Hancock	20040186272	12-Apr-04	--	4	√
Potter	20040219639	8-Jun-04	U of S	3	√
Babiuk	20050032045	10-Jun-04	--	4	
Griebel	20050032045	10-Jun-04	--	4	
Potter	20050089529	6-Dec-04	U of S	3	
Jones	20050101773	8-Sep-03	--	5	

-- assignee not indicated

Appendix E Listing of FGAS Affiliations and Partnering Organisations

Name	Affiliation or Affiliation Type	Location
Abrams*	National Research Council / Plant Biotechnology Institute	Saskatoon
Chibbar*	National Research Council / Plant Biotechnology Institute	Saskatoon
Crosby	University of Saskatchewan	Saskatoon
Cutler*	National Research Council / Plant Biotechnology Institute	Saskatoon
Fowler*	University of Saskatchewan	Saskatoon
Good*	University of Alberta	Edmonton
Gray*	University of Saskatchewan	Saskatoon
Gulick*	University of Montreal	Montreal
Gusta*	University of Saskatchewan	Saskatoon
Haughn	University of British Columbia	Vancouver
Hill*	University of Montreal	Winnipeg
Houde*	University of Quebec	Montreal
Laliberte*	University of Quebec	Montreal
Laroche*	Agriculture and Agri-Food Canada	Lethbridge
Moloney*	University of Calgary / Sembiosys	Calgary
Muench*	University of Calgary	Calgary
Nanak	FGAS	Saskatoon
Parkin*	Agriculture and Agri-Food Canada	Saskatoon
Pelcher	University of British Columbia	Vancouver
Rivoal*	University of Montreal	Montreal
Ross	National Research Council / Plant Biotechnology Institute	Saskatoon
Sarhan*	University of Quebec	Montreal
Scoles*	University of Saskatchewan	Saskatoon
Taylor*	University of Alberta	Edmonton
Varin*	University of Quebec	Montreal
Weselake*	University of Lethbridge	Lethbridge
Australian Centre for Plant Functional Genomics Group	In conjunction with University of Adelaide	Adelaide, Australia
BASF	Private	North Carolina
Brewing and Malting Barley Research Institute	Public	Winnipeg, Manitoba
Canadian Forestry Service	Public	
Concordia University	Academic	Victoria, B.C.
Cornell University	Academic	Ithaca, N.Y.
Development Centre for Biotechnology	Public	Taiwan
Enhancing Canola Through Genomics	Genome Canada Project / hybrid	Saskatoon
Experimental Institute for Cereal Research	Public	Italy
FGG	Public	Bristol, U.K.

Hormone Research Institute	Public	U.K.
Hungarian Academy of Agricultural Sciences	Public	Martosavar, Hungary
Institut Armand-Frappier	Public	Laval, Quebec
National Agricultural Research Centre for Hokkaido Region	Public	Japan
National Research Centre / Plant Biotechnology Institute	Public	Saskatoon, SK
Plant Biotech Alberta Research Council	Public	Vegreville, Alberta
Research Institute of Crop Production	Public	Praha, Czech Republic
Simon Fraser University	Academic	Burnaby, B.C.
TILLING	Hybrid	Seattle, Washington
University of Alberta	Academic	Edmonton, AB
University of Calgary	Academic	Calgary, AB
University of Lethbridge	Academic	Lethbridge, AB
University of Manitoba	Academic	Winnipeg, MB
University of Montreal	Academic	Montreal, QU
University of Saskatchewan	Academic	Saskatoon, SK
University of Quebec	Academic	Montreal, QU
University of British Columbia	Academic	Vancouver, BC
University of California Riverside	Academic	Riverside, California
United States Department of Agriculture	Public	Pennsylvania
Waite Institute	Public	Adelaide, Australia

* Principals of interest (for pre-award and post-award analysis)

Appendix F FGAS Pre-Award Patents by Network Principal (n = 13)

Principal Name	Patent #	Date Awarded	Assignee	# of Co-Inventors	Lead?
Gusta	5,201,931	13-Apr-93	NRC	1	
Abrams	5,201,931	13-Apr-93	NRC	1	√
Gusta	5,518,995	21-May-96	NRC	3	
Abrams	5,518,995	21-May-96	NRC	3	√
Chibbar	5,589,617	31-Dec-96	NRC	2	
Moloney	5,650,554	22-Jul-97	Sembiosys Genetics Inc.	0	√ (sole)
Sarhan	5,731,419	24-Mar-98	U of Qu @ Montreal	2	√
Houde	5,731,419	24-Mar-98	U of Qu @ Montreal	2	
Laliberte	5,731,419	24-Mar-98	U of Qu @ Montreal	2	
Moloney	5,856,452	5-Jan-99	Sembiosys Genetics Inc.	2	√
Chibbar	5,866,793	2-Feb-99	NRC	2	
Muench	6,084,153	4-Jul-00	University of Alberta	2	
Good	6,084,153	4-Jul-00	University of Alberta	2	√
Moloney	6,509,453	21-Jan-03	SemBioSys Genetics Inc.	2	√
Weselake	6,552,250	22-Apr-03	U of L	2	
Laroche	6,552,250	22-Apr-03	U of L	2	
Moloney	6,586,658	1-Jul-03	Metabolix, Inc.	3	
Sarhan	6,627,793	30-Sep-03	U of Qu @ Montreal	1	√
Sarhan	6,787,147	7-Sep-04	Not listed	3	

Appendix G FGAS Post-Award Patent Applications by Network Principal (n=9)

Principal Name	USPTO Patent Application Documentation #	Date Filed	Assignee	# of Co-Inventors	Lead?
Moloney	20030093832	21-Jun-02	--	2	
Gusta	20030077566	9-Sep-02	--	4	
Moloney	20030059910	1-Oct-02	SemBioSys Genetics Inc.	2	√
Moloney	20030096320	1-Oct-02	SemBioSys Genetics Inc.	2	√
Good	20050015828	17-Dec-02	--	3	√
Muench	20050015828	17-Dec-02	--	3	
Moloney	20030233677	28-May-03	Metabolix, Inc.	3	
Houde	20040068769	20-Oct-03	--	3	
Sarhan	20040068769	20-Oct-03	--	3	
Abrams	20040103451	7-Nov-03	--	3	
Cutler	20040103451	7-Nov-03	--	3	
Good	20050044585	12-Jan-04	--	3	
Muench	20050044585	12-Jan-04	--	3	√

-- assignee not indicated