2009

Centreless governance for the management of a global R&D process: Public-Private Partnerships and Plant-Genetic Resource Management

Peter W.B. Phillips
University of Saskatchewan, peter.phillips@usask.ca

William P. Boland
University of Saskatchewan, billboland@shaw.ca

Camille D. Ryan
University of Saskatchewan, cami.ryan@ucalgary.ca

Centerless governance for the management of a global R&D process: Public-Private Partnerships and Plant-Genetic Resource Management

Peter W.B. Phillips, William P. Boland* and Camille D. Ryan

Department of Political Studies, University of Saskatchewan, Canada

*= Corresponding author

Abstract Public-private partnership is one new model of centreless or networked governance that has emerged in recent years. This article examines the development and use of partnerships in the management and funding of public pulse breeding programs. The paper evaluates the theory of innovation and knowledge management and uses case study and social network analysis to examine the nature and strength of the international public pulse breeding system and analyzes in detail the three major national public pulse breeding systems in Australia, the US and Canada. Australia appears to have the most developed system of public-private partnerships, centred on the Grains Research Development Corporation and, CLIMA. Canada lacks a centralized national body such as the GRDC, but possesses a regional system centred on a university research centre (the Crop Development Centre) and a hybrid organization (the Saskatchewan Pulse Growers). The US is remarkable for the lack of any significant public-private partnerships in public pulse breeding.

Key words:

Public private partnerships; research management; social network analysis; global knowledge management

1. Introduction

Margaret Thatcher's new Conservative government in 1979 in Britain launched an effort to change the role for the public sector in a wide array of policy and program areas. One can trace the roots of this to the 1970s and the rising dissatisfaction with the state-dominated model of development (Weiss 2000). While this effort (and the corresponding Reagan, Howard and Mulroney programs of privatization in the US, Australia and Canada) was initially targeted at selling, shutting down or spinning off public agencies that provided specific services to individuals or industry, it eventually morphed into a new model of 'governance.' The important change was that the determination of the objectives, laws and methods of governing largely moved away from "absolutism, authoritarianism and even the autarkic conception of the modern state" (Weiss 2000:9). British political scientist Rod Rhodes (1995:1) suggests that governance should not be viewed as simply a recasting of analysis, but actually "a new process of governing; or a changed order condition of ordered rule; or the new method by which society is governed." As such, it is not a synonym for government but rather involves a new system of "self-organizing networks or 'governing without government'." Others (Phillips 2007) suggest governance involves government, but goes beyond government to a variety of non-traditional actors. Rhodes suggests we are seeking the emergence of networks or systems of a distributed and 'centreless' socio-cybernetic system, involving subsidiarity, absence of a single sovereign authority, multiplicity of actors, interdependence and blurred boundaries.

One area where we are seeing the emergence of a less ordered sort of governance (especially centreless or networked) is in the national and international structures and substructures of research, development, commercialization and knowledge management that have emerged in the past generation in the global agri-food system. This paper examines four functioning networks/subnetworks of research, development and commercialisation related to pulse-breeding—the global network and three national subnetworks in Australia, Canada and the US—to discern the national and international trajectories in the development and use of public-private partnerships (PPPs) in the governance and management of pulse breeding.

This paper examines the theory of innovation and knowledge management and uses case study and social network analysis to analyze the nature and strength of the four key systems. The networks each involve a range of 11-56 network actors, a wide range of interconnective densities and an array of central actors. This paper has four further sections. Section 2 offers some context for the pulse research effort. Section 3 presents the methodology for this paper. Section 4 examines the pulse networks in question; reviewing the individual actors, partnerships and the formal networks they have constructed to undertake pulse research, development and commercialization. Section 5 examines the role that three central actors play in maintaining the vitality and interconnectedness of the international pulse system. Section 6 offers some concluding observations.

2. The global pulse industry

Pulses are the edible seeds of legumes. Pulse crops include pea, bean, lentil, chickpea and faba bean. They comprise a small, but very important part of the 1800 species in the legume family. The use of pulses dates back more than 20,000 years ago and spans the globe. Lentils originated from the wild lentils that still grow in Turkey and other Middle Eastern countries while pea, faba bean and chickpea originated in western Asia. Dry beans originated in South and Central America. Pulses are now grown on all continents of the world.

Pulses are an important source of protein, providing about 10% of the total dietary protein in the world (Sask. Pulse Growers' Website). Pulses have twice the protein content of most cereal grains. Bean, pea and chickpea, respectively, are the three most important pulse crops in terms area and production. Pea is produced mainly in developed countries such as France and Canada, and chickpea is produced and consumed mainly in India. Lentil is produced mainly in India, Turkey and Canada. Beans of various types are produced in many countries around the world.

In 2002-6, Australia, Canada and the US accounted for 12% global pulse production and 41% of global exports. Pulse production has risen significantly in those three markets in recent years (table 1).

Table 1: Production and exports of pulses, 2002-06, million tonnes				
	Production		**Exports**	
	Volume	**% total**	**Volume**	**% total**
Australia	1,641	3%	750	8%
Canada	3,524	6%	2,444	26%
United States of America	1,791	3%	689	7%
World Total	59,217	100%	9,248	100%
Source: FAOStat.org and Authors' Calculations				

One hypothesized reason for the absolute and relative rise in market share in each of the three countries is that their governments, universities and producers invested relatively heavily in research, development and commercialization. The performance is uneven, with Canada developing and introducing both the absolutely and relatively largest number of new varieties. The US is second and Australia is third (table 2).

Table 2: Registered varieties of pulses by country, selected categories, 2007

Varieties	Canada	Australia	US
Field Peas	101	14	4
Lentils	31	2	4
Field Beans	131	6	38
Area harvested (HA)	2,132,000	1,571,972	1,026,456
Number of varieties per 100,000 HA	12.3	1.4	4.5

Source: Author's calculations; cultivated hectares from FAOSTAT (http://faostat.fao.org/site/567/default.aspx#ancor); registered varieties from CFIA (http://www.inspection.gc.ca/english/plaveg/variet/lovric.pdf); IP Australia (http://pbr.ipaustralia.plantbreeders.gov.au/) and USDA/ARS (http://apps.ams.usda.gov/PVPO/CertificateDatabase/pvplist2.asp)

This paper examines the organization and management of the global pulse research system and the nationally-based sub-networks in the three key countries under review.

3. The theoretical and methodological approach

Governing systems are difficult to analyze and understand at the best of times. While some systems exhibit formal, acknowledged leaders in industry, government and the civil sector, knowledge-based systems are inherently diffuse and complex. This section examines the theory of innovation, examines the emergence of new knowledge generation systems and discusses the theoretical underpinnings of a triad of institutional approaches and then discusses the role so social network analysis in characterizing the resulting governing systems.

3.1 Theory

Three points jump out from the innovation literature (Phillips 2007). First, we can definitively say that innovation is clearly different than invention. While a prototype is an invention; the introduction and widespread use of a product or service is an innovation. Second, there is general agreement that innovation most frequently occurs within cultures, communities and organizations whose aim is to transform information into knowledge, to invent new applications for that knowledge and to convert those creations into socially-valued goods, services, processes or organizations. Third, success is marked by the ease in which creations are introduced, absorbed into and persist in the economy and society.

Phillips (2007) offers one approach to a general model of innovation, involving four stocks of knowledge input/output and four social processes. The obvious place to start in the context of the contemporary innovation challenge is with the profusion of information. Information is explicitly separated from knowledge, in that the latter requires context and increasingly is governed by the complex knowledge 'industry'. At its root, new information, or newly mobilized information, is often the starting point of an innovation process. Formal and informal structures, incentives and processes identify, assemble, transmit and store an array of bits of information in multiple forms. Knowledge is generated within cultural and community social processes. While much of the work on innovation has focused on patentable, know-what type knowledge, there is actually a wide range of tacit and codified knowledge that are critical to the generation of an innovation (i.e., codified know-why basic science, tacit know-how and know-who contextual knowledge). The creative activity of generating an invention (something that is novel, useful and non-obvious) takes place within a social context and has organizational and social consequences. These three aspects of innovation tend to concentrate activity in business, organizations and the economy in regional, sectoral or functional clusters in which new knowledge and skills complement imaginative industry leadership, all of which are supported by active partners, including communities and governments. This pattern is frequently seen in innovation centres or corridors, such as found in Silicon Valley in the lower San Francisco Bay area, Boston Route 128, Austin's T3, the Research Triangle Park in North Carolina, Cambridge Research Park and the BioValley spanning the borders of Germany, France and Switzerland. Translating an invention into a socially embedded innovation then involves a complex web of principals, agents, promoters and regulators on the supply side and middlemen, marketers and consumers on the demand side. Constructing new markets for new products or services is seldom straightforward or simple. Multiple governing systems come to the fore at this stage.

Research, development and commercialization of new technologies are fundamentally about identifying, creating, conserving, applying and using knowledge. Knowledge displays mercury-like properties—we can often see it but frequently it is hard to grab on to. Professor Michael Gibbons and a group of colleagues from SPRU offer one interpretation of the problem (Gibbons et al 1994). They posit that two modes of knowledge generation now exist: Mode 1, which they call traditional knowledge, is generated within disciplinary, primarily cognitive, contexts; and Mode 2 knowledge is created in broader, "transdisciplinary" social and economic contexts. They argue that Mode 2 knowledge tends to lead to a more socially distributed knowledge production system and, hence, is both socially accountable and reflexive. Mode 2 knowledge thus presents a profound challenge to the traditional governing system because communications tends increasingly to take place across institutional boundaries and not within established hierarchies.

Fundamentally, Mode 2 knowledge generation present a complex systems problem. There is no single approach to understanding the dimensions of the challenge of governing it. Economist Kenneth Boulding (1970) offers one approach that captures the economic, social and political aspects—he argues that human relationships can be classified as the compulsory, the contractual and the familistic. This yields three different methods of integration: coercive hierarchical relations that distribute rights and obligations, led by the state; quid pro quo exchanges in the market governed by the Marshallian scissors of supply and demand; and voluntary dealings, where cooperation, reciprocity and solidarity engage community and society (Paquet 2001). Boulding (1970) argues that society can be viewed as a triangle (his 'social triangle'), where all organizations—including the state, the market and civil authorities—are built on one or a balance of the three relationship systems.

The nature of the activity being governed provides a foundation for the analysis. The transactional approach to governing offers some insights into a useful way of categorizing economic and many social activities. That approach suggests most traded goods or services exhibit three main characteristics—rivalry, excludability and voice—which can be used to identify three categories of pure goods—public, private and collective (Picciotti 1995). Rivalry is simply a measure of how many people can use a property at the same time. If a property can only be used by one person at a time (e.g. a hammer), then the product has a high level of rivalry; if it can be used simultaneously by more then one user at a time (e.g. a computer program), it is non-rival. The more disembodied the property (such as some forms of know-how knowledge and various know-what style 'recipes'), the less rivalrous it is likely to be. Excludability is a measure of whether people can be kept from using the good or service. The degree of excludability depends on the physical structure of the property (e.g. a physical property can be fenced but ideas are much harder to control), the cost of duplicating and using the property and the legal and social impediments to use. Voice measures the amount of input required from others to generate value from a good or service. The more production or consumption depends on information provided by others, the more it is said the product has high voice. If we can get beyond the economic slant of the terminology, we can see that these three concepts can offer insights into of the activities inherent in research systems.

These three factors can be used to categorize three relatively discrete types of pure goods and a multiplicity of hybrid goods with mixed properties. Public goods can be defined as those activities that are characterized by low excludability, low rivalry and limited voice. Although some democratic debate may be involved in the decision processes, public goods are inherently designed for the entire population and not simply those mobilized in any consultation. Private goods (e.g. machinery and equipment, most consumer products and proprietary seeds) usually exhibit high excludability, high rivalry and limited voice. Common pool goods (e.g. conservation, standards, marketing services and know-how, among others) involve high voice and may involve a range of degrees of excludability or rivalry.

Different institutional structures are more effective at producing particular types of goods (Picciotti 1995, drawing on Coase 1936 and Boulding 1970). The government sector is best at producing public goods—the low excludability makes privatization infeasible while the low voice component makes it difficult for the collective sector to organize. The private sector tends to dominate whenever property rights can be assigned to make goods excludable. The property of exclusion allows private firms to sell at or above the marginal cost of production. The participatory sector (alternatively called the collective sector or civil authorities) is best at governing common pool goods (e.g., marketing services)—the collective group will usually have more information that will enable them to more effectively manage the resource and capture the benefits.

The challenge in examining public private partnerships is to understand both the intra-institutional structure and function and the inter-institutional relationships.

3.2 Methodology

This paper uses social network analysis to investigate the interconnections among and between different actors (i.e. the state, the market and various collective entities, such as PPPs). In the knowledge-based world it is necessary to integrate a variety of different types of knowledge that derived from different epistemic roots and a triad of governing institutions (and an infinite array of hybrid organizations), all in the context of a social system of innovation. Mode 2 knowledge generation implies that no institution can be or is self-contained in its technological activities (Metcalfe 1995). All firms, large or small, have to rely on knowledge from other sources. Systems that support a firm's ability to access, absorb and use external knowledge can be critical to the growth of firms, sectors and regions, especially during the early stages of the development of a technology or whenever a technology has a rapidly changing knowledge base, as is typical with transformative technologies.

It is possible to identify the relative position and functions of individuals and organizations using social network analysis (SNA). Ryan (2008) suggests that social network analysis can track "…how knowledge intensive work is done and is used to assess the complex communication channels within a network" (41-42). The tool also can make invisible work visible. [1] SNA views actors and actions as interdependent units; it acknowledges that the 'relational ties' between actors are channels flow of resources which can provide opportunities for or constraints on individual action. Social network analysis identifies boundary spanners, gatekeepers, knowledge bottlenecks and as well as under- and over-utilized individuals or organizations within a given network. The guiding principle behind social network analysis is concerned with the relationship between agents, nodes and actors and in how such units affect one another.[2] The method enables a researcher to better identify subgroups in a given network such as clusters or cliques or to pinpoint isolates or those agents or nodes that appear to be disconnected from the larger network. Such analyses also enable the characterization of such networks into categories such as core-peripheries or emergent groups.

[1] Mead 2001.
[2] See Ryan and Phillips, forthcoming.

A number of measures related to density and centrality in social networks are used to examine communities.

The concept of density—the proportion of bilateral ties among actors in a system relative to the number of all possible ties—is often used to measure that degree of untraded interconnections in a community (Knoke and Kuklinski 1982). The density of the entire network, is a ratio calculated as the number of all ties occurring in the matrix divided by the number of all possible ties (ibid). N is the number of actors within the region in the same or related industry, while L is the number of links that the particular actor acknowledges. The number of links (L) is multiplied by 2 in the equation because relationships are assumed to be bilateral, and the denominator (N*[N-1]) already accounts for all possible permutations and combinations. Equation 1 expresses the density formula.

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

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: 169). Centrality, applied at the node level, is a family of measures each answering a different theoretical question. Three somewhat different measures of centrality are used in this paper.

'High degree centrality' refers to the capacity of a node for informal leadership according to the number of ties that the node has—high degree central actors are "in the know" or as Ryan (2008: 61) suggests "…is an indicator intra-network connectedness." 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. Equation 2 expresses total degree centrality.

$$TotalDegreeCentrality = \frac{\mathrm{td}(\mathrm{x_i})}{2*(\mathrm{N}-1)} \qquad \text{Equation 2}$$

'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.

According to Ryan (2008), it is an indicator for over knowledge flow capacity within the network. 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. This is one measure of potential influence. According to Valente (1995), betweenness centrality is a measure of how often an individual lies between the shortest path linking two other individuals or actors. Freeman (1979) outlines the concept as in equation 3.

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

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 (1972) 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, 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. Ryan (2008) suggests that nodes with high Eigenvector centrality are powerful connectors within the network.

Although one might think that the theory and analytical methods should lead to a deductive set of experiments that ultimately should explain evolution over time, it is far from clear whether there is one, or even a range, of stable, optimal configurations of innovation systems. Some density is required but more is not always better. One hypothesis is that while uniform density may assist product, supply chain or geographic agglomerations to bring forward incremental inventions, such a configuration could stifle potential transformative changes. Transformative changes may require what has come to be called ‘structural holes,’ that is areas where there is a gap in the governance system that allow truly revolutionary ideas and approaches to germinate and emerge (Burt 2005).[3] Similarly, although some central actors are needed, it is far from clear who they should be and what types of roles they should play.

The remainder of this paper applies the social network analysis to the four networks. The data was acquired from two methods. First, an internet search was conducted using known public pulse breeders to search for pulse oriented PPPs and their respective network(s). Second, a keyword search of the ISI Web of Knowledge was utilized to identify research and financial links between various pulse breeders and funding agencies. The search was limited to research/funding alliances active in 2008; therefore, some institutions may have been omitted, as is the case with Washington State University. The keywords utilized are pulse crops, legumes, dry peas, chickpeas, lentils, faba beans, dry beans and lupins. The Grain Legume Technology Transfer Platform from the EU was not included as it was difficult to determine what, if any, financial or research relations existed between this program and producer public-private partnerships. The North American Pulse Improvement Association was omitted because it does not appear to be a direct funder of pulse research.

3.3 The data and analysis

In summer the of 2007, a research assistant developed a case study of public-private partnerships in Australia, Canada, the US, the EU and a variety of other countries. In each case, the relationships identified were formal, contractual or financially based. This data reflects research collaborations and financial connections. The Australian data search started with the GRDC and worked through the related breeding networks to identify the full array of interconnections. The information for CSIRO is likely incomplete due to data limitations and some state-level financing may be missing. The Canadian networks and nodes represent financial relationships throughout Canada, beginning the search form the federal government and then expanding the search outwards; all information was derived from the internet and supplemented with interviews; the data may overlook some inter and intra-provincial financing of projects. All of this data was coded as university, government or partnership by the researchers using the heuristics above.

---

[3] Rosenberg 1994, using different terminology, has argued that the first industrial revolution was only possible because the ‘institutional negative feedback’ of the earlier period was removed.

The social network maps were derived from Organizational Risk Analyzer (ORA), a SNA software program developed by the Centre for Computational Analysis of Social and Organizational Systems (CASOS) at the Institute for Software Research at Carnegie Mellon University. The empirical results were imported into Microsoft Excel 2003 and analysed using the statistical functions.

Individual organizations were evaluated as candidates for central actor functions by comparing their individual centrality scores against the average centrality score for each measure in each of the national sub-systems and in the global network. Only those institutions that had a centrality measure greater than one standard deviation higher than the mean of the source population were considered central actors. Thus, in each of tables 3, 4, 5 and 6, the number of stars in the context column indicates the number of standard deviations the individual measure of central tendency is above the mean for the entire population. Any institutions recording a centrality measure below this threshold are considered to not be undertaking those central functions.

4. Comparative Analysis

The data offers insights into four interconnected pulse-breeding innovation networks: Australia, Canada, the US and the global system. Each of these networks has different size (range from 11 to 56); density (ranges from 0.123 to .404) and distribution of central actors by type (table 3).

Table 3: The Four Pulse Innovation Networks

			Number of central actors based on centrality measures one standard deviation or more above the mean		
Network	N	Density	Degree	Betweenness	Eigenvector
Australia	19	.404	7	2	1
Canada	21	.281	2	4	1
US	11	.182	1	1	4
Global	56	.123	15	7	2

Depending on the framing (national or international), different actors occupy different absolute and relative roles. A few actors such as the GRDC, CDC and USDA-ARS Pullman, play important roles both nationally and internationally, but some actors are influential only in an international context (such as ICARDA) while others are only relevant nationally.

The balance between types of central actors varies by country. The Australian system has a large number of total degree central actors, but only two with gatekeeper or power leaders. Canada, in contrast, has four gatekeeper organizations (with high betweenness centrality measures) while the US has many powerful actors but few well connected or gatekeeper leaders. When the three national systems are put together, with the addition of a few international organizations, the more actors exhibit centrality, gatekeeper roles and power positions.

It is worth noting that the Australian and Canadian systems are relatively well rounded and that they have some degree of redundancy, which reduces their vulnerability to change in roles, while the US system is highly vulnerable to change. The global system is actually more than the sum of its parts. While it exhibits lower density, the number of central actor rises. Nevertheless, the global system is highly dependent on two power leaders (both from Australia), which makes it vulnerable to change and instability.

4.1 Australia

Australia has vast and expansive areas of nutrient deficient soils, which, because of technological innovations and economic pressures, make them suitable for rotational crops such as legumes. The industry has expanded from very limited production to having more than 1.1 million hectares planted annually in the last 20 years. CLIMA has set a goal of expanding national production to 2.3 million hectares (CLIMA, 2006).

The Australian pulse network involves 19 actors (table 4 and figure 1). The Grains Research and Development Corporation (GRDC) is the most centrally placed actor on all three primary measures of centrality. It has a perfect eigenvector measure of 1.0 and a near perfect total degree centrality of .94. All are statistically significantly higher than the mean of the Australian subnetwork. The GRDC is connected to all the influential actors and with the highest betweenness measure also occupies a role as a primary gate keeper, controlling both the flow of information and funds throughout the Australian pulse-breeding network. The Centre for Legumes in a Mediterranean Area (CLIMA) is the only other Australian institution with a dominant position, posting a statistically significant role as gate keeper (measured via the betweenness centrality measure). The Commonwealth Scientific and Industrial Organization (CSIRO), the federally funded Future Farm Industries Cooperative Research Centre (FFI-CRC) and three state governments (WA, Victoria and Queensland) recorded a statistically significant above average number of links (measured via total degree centrality) but their relative role was relatively weak. The Australian system has the highest network density measure, indicative of the high number of well-placed and connected actors.

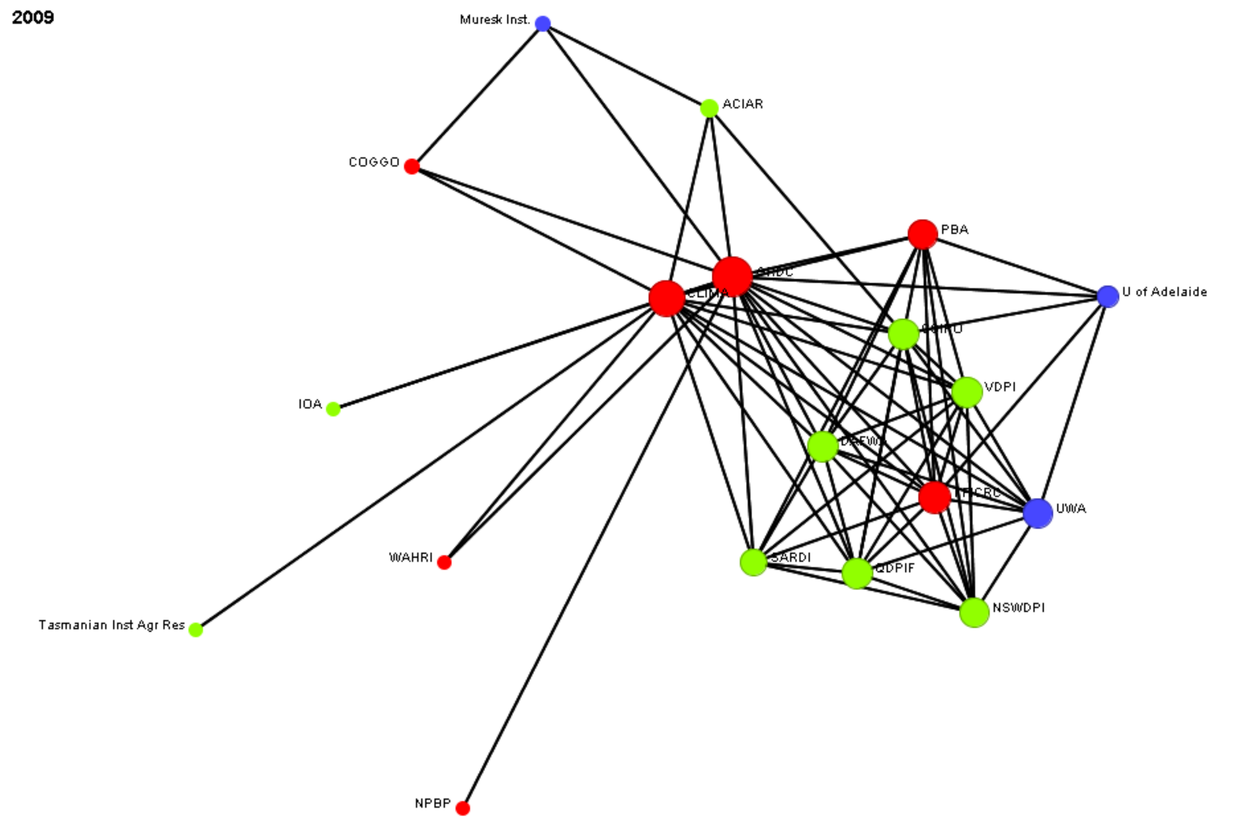
Table 4: Central Actors in Australia (N=19)						
	Total Degree Centrality		Eigenvector Centrality		Betweenness Centrality	
Agent	**Value**	**Context***	**Value**	**Context***	**Value**	**Context***
GRDC	0.944	****	1.000	*	0.366	*********
CLIMA	0.778	***			0.229	*****
FFI-CRC	0.611	*				
CSIRO	0.556	*				
DAFWA	0.556	*				
QDPIF	0.556	*				
VDPI	0.556	*				

* number of standard deviations greater than the mean
Source: Authors' calculations

Institutionally, government laboratories and hybrid organizations are the primary pulse actors in Australia. Three of the top four institutions are hybrid: the GRDC, CLIMA and the FFI CRC, indicating the critical role of voice for the producers that the hybrid organization provides in the management of plant breeding.

The Grains Research and Development Corporation (GRDC), the centre of the system, was formed by the Australian Federal Government in 1990 by the Primary Industries and Energy Research and Development Act of 1989 (PIERD). The primary purpose of the GRDC is to provide strategic direction to the Australian grains industry (GRDC, 2006). The GRDC represents a national consolidation of various publicly funded state-level and university plant breeding programs. The GRDC works jointly with industry, government and private and public researchers to develop research strategies that meet the needs of local, regional, national, and commodity interests (GRDC, 2006). The core objective of the GRDC is a national-based private-public partnership to provide stewardship to the Australian grains industry.

Figure 1: The Australia Pulse Network



Essentially, the GRDC is a management organization that uses funding to develop and enhance the competitive position of the Australian grains industry. It provides both upstream and downstream technology to producers and breeders through its funding initiatives. The GRDC's funding is designed to capture and retain both the monetary and technological gains developed by the Australian breeders and producers for the benefit of the Australian grains industry. To do so, the GRDC uses equity positions in a variety of public and private entities and acts as a commodity facilitator by developing and organizing national commodity-breeding groups to consolidate regional breeders into a nationally oriented program.

GRDC funding for varietal development led to its partners releasing 10 new pulse varieties (1 bean, 2 chickpea, 3 lupin, 3 peanut and 1 lentil) in 2005-06 and 7 new releases in 2007-08. A$10 million was directed to pulse breeding in 2005-06 and A$5 million in 2007-08.

The GRDC is structured to be a pluralistic organization, representing the needs of its two major stakeholders: the federal government of Australia and the producers through the Grain Council of Australia (GCA). The board of directors of GRDC has 9 members, 6 recommended by the GCA and 3 selected by the federal government. The board is responsible for selecting the managing director. The disparate geographic regions of Australia are represented by 3 regional panels, formed around local growers, marketers, and industry experts. This structure incorporates the needs of local producers without compromising national perspective of the GRDC.

In March of 2007, the GRDC, Pulse Australia, the University of Adelaide and five state-level agricultural/industry[4] departments, teamed together to launch Pulse Breeding Australia (PBA). The objective of PBA is to consolidate Australia's state-level pulse breeding programs into one nationally based organization. PBA is managed by an advisory board and Consultancy Group (CG), staffed by representatives of its 8 partner organizations. This single structure reduces any duplication of effort in breeding and germplasm-uptake programs in Australia. PBA is designed to share germplasm, breeding technologies and IP across all public pulse breeding programs. PBA released four varieties in 2007-08 and has a multitude of varieties in various stages of development. GRDC and PBA are currently negotiating the initiation of a national molecular-marker research program for pulse crops. PBA is also negotiating with both Genome Canada and the Crop Development Centre at the University of Saskatchewan regarding international collaborative genomic pulse research.

The GRDC/PBA also has exchange relationships with both the Crop Development Centre in Saskatoon and the USDA/ARS pulse-breeding program, located in Washington State. Germplasm is exchanged annually between the three agencies. The GRDC and PBA also procure germplasm from ICARDA (International Centre for Agriculture in Dry Areas) in Syria and from ICRISAT (International Crop Research Institute for the Semi Arid Tropics) in India as part of its pulse variety development program.

PB Seeds Pty Ltd. has been awarded an exclusive, five-year, first right-of-refusal contract to commercialize lentil varieties developed by PBA. AWB Seeds has the commercialization rights for the field pea and desi chickpea programs, with the same five-year, right-of-first-refusal exclusive contract. Release Advisory Groups consisting of industry representative from all sectors (breeding, production, and investment) manage the timing of new releases of pulse varieties to maximize producer and sector benefits.

---

[4] The 5 state-level breeders are, South Australia Research and Development Institute (SARDI), the Victorian Department of Primary Industries (VDPI), the New South Wales Dept. of Primary Industries, the Queensland Dept. of Primary Industries (QDPI) and Fisheries and the Dept. of Agriculture and Food Western Australia (DAFWA).

The Cooperative Research Centres (CRC) Program, developed by the Australian government to facilitate cooperative research in Australia, has become a core part of the system. Formally launched in 1991, the CRC program was a response to declining research and development investment in Australia. A report in the late 1980s noted that research and development spending in Australia, as a percentage of GDP, had been falling relative to the rest of the OECD (Buller & Taylor, 1999). The report indicated that research and development, as a percentage of GDP was, on average, 50% higher in other OECD countries, when compared to Australia (ibid, 1999).

The CRC program has three formal objectives: to create and maintain permanent research and development links between government, academia, and industry; to provide for continuous market-oriented research and development through the use public-private partnerships; and to acquire economies of scale by merging government funding and R&D tax credits with public research capital assets and private sector downstream assets. The core purpose of the CRC program is to increase the national wealth of Australia through private-public research and development collaborations.

The Department of Innovation, Industry, Science and Technology of the Australian Government manages the CRC program. A committee of 14 members oversees the program and is accountable to the Minister. The Minister and committee administer a large-scale science and technology business incubator. The CRC program provides a complete turn-key operation that has developed over 160 operational CRCs spanning all sectors of the Australian economy. Participants gain access to 15 years of funding, technical expertise, linkages to other critical actors, operational templates including cost structures, and governance, accountability, and outcome standards (CRC, 2009). The CRC program is responsible for establishing monitoring and evaluation standards and schedules for the individual CRC partnerships.

An operational CRC is governed by a chairperson, independent of the participants, and a board of directors, the majority of which are independent of the key participants. CRC participants receive cash credit for non-cash intangibles from the government facilitating inter-sector collaboration. Each partnership is a unique and highly individualized operation that nonetheless uses a common governance and accountability structure. The ultimate objective of the program is to transform each CRC into a viable research or business operation independent of federal support.

The Centre for Legumes in a Mediterranean Area (CLIMA) was originally established as a CRC in 1992 and operated with Australian federal funding until 1999. This CRC was restructured as a research alliance in 2000 by DAFWA, University of Western Australia (UWA), Murdoch University and the Commonwealth Scientific and Industrial Research Organization (CSIRO).[5] This operating structure existed until 1 July 2007, when the Memorandum of Understanding expired. CLIMA is currently a specialized research centre at the UWA, where it has been located since its inception. CLIMA's primary funders are the GRDC, ARC, ACIAR (Australian Centre for International Agricultural Research), COGGO and the Australian government. CLIMA's primary objective is the expansion of the grain and pasture legume sector in Australia, including clover, vetch, faba beans, chickpeas, and field peas.

CLIMA has two major programs, one each for grain legumes and pasture legumes. Each commodity program has four sub-programs dedicated to germplasm acquisition and development, disease and pest management through genetic development, abiotic stress enhancement through molecular and genetic screening, and improving the quality and health value of the final product (CLIMA, 2006). CLIMA contracts with the DAWFA to commercialize its new varieties. CLIMA is actively working with ICRISAT and ICARDA as partners to search central Asia, a source of genetic diversity for pulse varieties, for new germplasm with traits suited to the Australian environment. CLIMA has multiple research projects with the Crop Development Centre at the University of Saskatchewan for field and chickpea development, with the GRDC funding CLIMA's Canadian collaboration. CLIMA also has a germplasm exchange program with USDA Pullman Washington pulse program.

Although created as a regional breeding operation supporting Western Australian producers, CLIMA has recently developed a national approach to pulse breeding. The management structure consists of a governing board of five, and an industrial advisory group (IAG) of 17 research, producer, and industry representatives. GRDC, CSIRO, COGGO, DAFWA, UWA and multiple producer groups serve on the IAG. As of early 2009, the director of CLIMA was a former official of ICARDA. Presently, CLIMA is undergoing a strategic review of its operations.

[5] The CSIRO plant science centre consists of 800 researchers and staff at nine facilities in Australia with an annual budget of over $80 million. CSIRO is as a world leader in all aspects of plant genetic resources. The CSIRO has active research and funding partnerships with a wide array of Australian state-level pulse breeders and the GRDC.

The Future Farm Industries (FFI CRC) is the 2nd phase of the original CRC for Plant-based Management of Dry Salinity. FFI CRC seeks to develop economic and sustainability capacity through a technology and science public-private partnership. The 23 key partners, including the GRDC, and 72,000 small and medium sized farmer stakeholders, are utilizing "profitable [legume] perennials" to mitigate the effects of long-term drought on 60 million hectares of land, while concurrently enhancing the lands economic value. The objective is to leverage the A$114 million in initial funding into a NPV of A$1.36 billion of economic activity.

In 2003, the Grain Foods CRC was established with the Southern Cross University, the GRDC, George Westin Foods, COGGO, the Export Grains Centre, and three other private sector partners. Grain Foods CRC has been allocated A$24 million over seven years from the Australian government, and has secured another A$70 million in cash and in-kind contributions from its research and private sector partners (GFCRC, 2007). The GF CRC objectives, from a plant genetics perspective, are upstream breeding technologies and downstream germplasm enhancements for pulse and grain related products. The GFCRC has an ongoing partnership with ICARDA for pulse research and germplasm exchange.

4.2 Canada

Pulse crop production in Canada is concentrated in Saskatchewan. Pulse production grew from 30,000 acres in 1980 to over 5 million acres by 2001. Although there is a small internal market for pulse crops, the majority of the production is exported: 90% of lentils and 75% of pea production are sold to other countries. Saskatchewan is the largest exporter in the world of dry peas and a dominant exporter of lentils, accounting, in 2004, for 51% of global pea exports and 33% of global lentil exports. The exports go to over 140 countries.

The social network analysis of the Canadian pulse research system reveals that Saskatchewan Pulse Growers' is the dominant and most highly connected pulse institution in Canada (based on the three centrality measures) (table 5 and figure 2). The SPG has a perfect 1.0 eigenvector measure indicating connections to all the critical pulse agents in Canada. Moreover the SPG is the mostly highly connected actor (based on the total degree centrality) and is the key gatekeeper in the system (with the highest betweenness centrality). The other actor with influence as indicated by the centrality measures is the Crop Development Centre (CDC). While the Agri-Food Canada (AAFC) research centre in Lacombe and the APGC have statistically significant betweenness centrality measures, the CDC and SPG are the dominate actors. Their high betweenness measures indicate they occupy roles of national gatekeepers of knowledge and research funding. This is similar to the Australian system.

Of the 21 pulse actors in Canada, 11 are government laboratories, five are university research centres and five are hybrid organizations including the SPG and CDC. The locally managed SPG makes an unusual candidate for the most influential pulse-breeding actor in Canada considering the existence of the nationally focused Agriculture and Agri-Food Canada (AAFC).

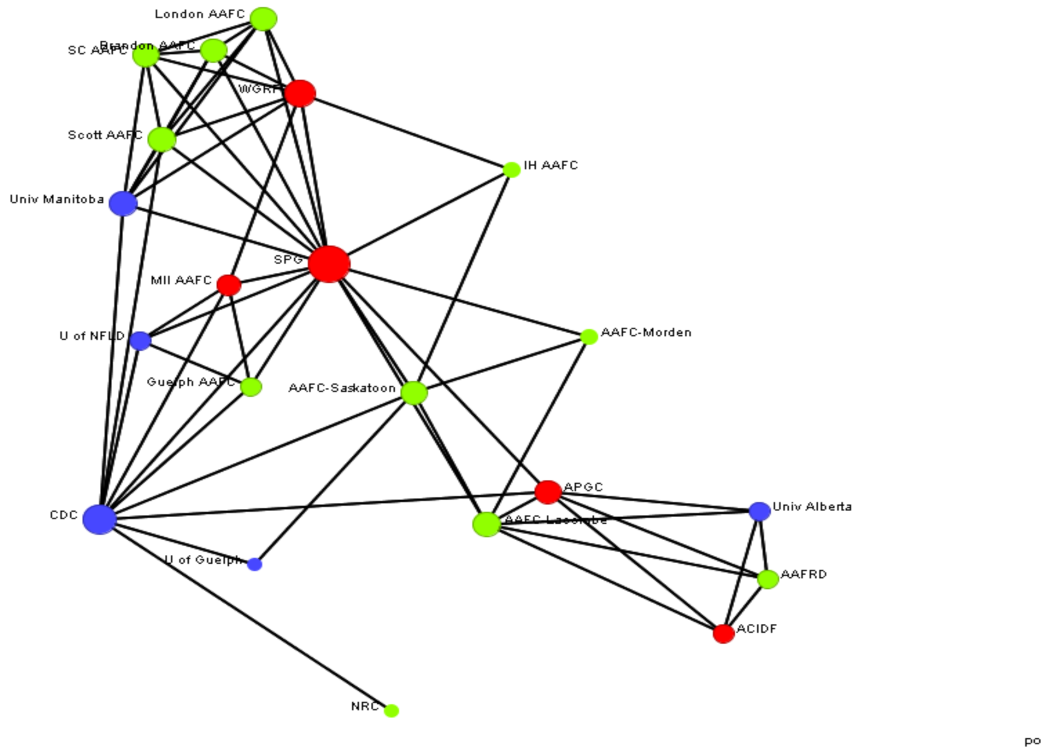
Table 5: Central Actors in Canada (N=21)

	Total Degree Centrality		**Eigenvector Centrality**		**Betweenness Centrality**	
Agent	**Value**	**Context***	**Value**	**Context***	**Value**	**Context***
SPG	0.750	****	1.000	*	0.424	************
CDC	0.500	**			0.226	*****
AAFC-Lacombe					0.121	**
APGC					0.144	**

* number of standard deviations greater than the mean
Source: Authors' calculations.

The most interesting aspect of the Canadian system is the roles that the SPG and CDC play, both as separate institutions and in the context of an exclusive research-oriented public-private partnership that they formed.

Figure 2: The Canadian Pulse Network



The Crop Development Centre (CDC), a division of the College of Agriculture and Bioresources at the University of Saskatchewan, is a producer and industry led public private partnership involving academia, industry and government. The CDC was established in 1971 when the National Research Council of Canada and the Saskatchewan Department of Agriculture provided funds to the university to create the Centre. The mandate of the CDC is to facilitate the diversification of crops grown by Saskatchewan producers. The CDC has released over 220 varieties in 22 crops, including 92 pulse varieties. Of the pulse varieties, 32 are lentil, 20 pea, 22 bean, 13 chickpea and 5 fababean. The CDC receives funding for pulse research and breeding from a variety of sources: AAFC, WGRF, National Science and Engineering Research Council (NSERC), the Government of Saskatchewan and the Saskatchewan Pulse Growers. The CDC has four primary functions: research, teaching, extension, and technology transfer.

The Saskatchewan Pulse Growers Association (SPG) was formed in 1976 to educate farmers about the benefits of pulse crop production. Price pressures on traditional crops such as wheat and barley created an opportunity for Saskatchewan producers to diversify. Saskatchewan's soil composition, cool summers, and cold winters are conducive to the production of pulse crops. The success of the pea and lentil check-off programs in the states of Washington and Idaho provided the impetus for the SPG to initiate a producer-supported levy program. A successful plebiscite in 1983, along with favourable provincial legislation, launched the SPG producer check-off fund, which was used to develop varieties at the CDC on a project-by-project basis.

The SPG has a mandate derived from the Agri-Food Act of Saskatchewan to improve the profitability of pulse production by the use of innovation from research and development. There are 20,000 members in the SPG, governed by an elected board of seven directors. The Board of Directors has the right to establish any other board within the SPG to fulfill their legislated mandate. Any registered member of the SPG can run for election to the board, and a recent outside service review indicated a high level of member satisfaction with the performance of the SPG (SPG, 2009).

A Research and Development Committee consisting of producers, researchers and industry representatives directs SPG research and development. This committee facilitates a compact feedback mechanism between producers and researchers at the CDC. The R&D and technology transfer philosophy of the SPG is referred to as “crop-ortunity”, which infers a comprehensive approach to research that begins with the yield needs and profitability requirements of the member/producers. The SPG/CDC research partnership maintains pre-competitive genomic collaborative research agreements with major breeders in the US, Australia, and the Grain Legume Technology Transfer Platform in the European Union.

Government fiscal austerity programs in the 1990s left the CDC without secure funding for its breeding programs. Concurrent with this development was strong growth in Saskatchewan’s pulse sector, leading to enlarged check-off funds. The growth in revenues permitted the SPG to enter into negotiations with the CDC for long-term variety development program. The producer-run SPG also sought access to new varieties without paying royalties or technology user fees (Scott, 2004). The result of these developments was the Variety Release Agreement (VRA) between the SPG and the CDC in 1997.

The SPG, under the VRA, receives, in a timely manner and on a cost-effective basis, new and improved pulse varieties without royalty payments. The CDC has a long-term agreement with the SPG to support pulse breeding and use of 320 acres of land to support its breeding program. The VRA was renewed in 2000 and again in 2005, with the program being extended for 15 years with C$21 million to be supplied by the SPG to support the CDC pulse program.

Of the 41 varieties released under the VRA between 1997and 2004, the average development cost to the SPG was C$466,000 per variety (Scott, 2004). Over 70% of the varieties released generated a grower surplus. The VRA averages 1.25 releases per year, for the four major pulses (lentils, peas, dry bean and chickpea). The Internal Rate of Return (IRR) has been estimated to be over 35%, and the benefit to cost ratio is 15.8 to 1 (Gray et al, 2008).

The SPG has developed into the largest funding organization of public pulse research in Canada (Gray, et al, 2008). Of the C$4 million in SPG pulse R&D expenditures in 2008, C$2.3 million went to varietal breeding and genetics research. The SPG manages its own genetic improvement programs centred on the CDC, but it also manages AAFC's multi-million dollar pulse research network (SPG, 2008). Acting as a national breeding coordinator, the SPG can leverage its producer levy with private and public funding to maximize the research impact of its investments. In 2002, the SPG raised C$1.5 million, which attracted the same amount in matching funds, to finance an expansion of the pulse research facilities at the CDC.

The export and production growth of the SPG suggests that the partnership between the SPG and the CDC is a successful, if not unique, collaborative model, possibly worthy of emulation. The research-driven philosophy of the SPG, with the royalty-free VRA with the CDC, appears to have provided the SPG with a long-term competitive advantage.

The Alberta Pulse Growers Commission (APGC), a producer owned and managed nonprofit organization with 4700 members, uses a crop levy to finance pulse-breeding and genetics research. Approximately 50% of the revenues from the producer levy are allocated to variety development and genetics research. As measured by member size, cultivated hectares and revenues, the APGC is about one-fifth the size of the SPG. The APGC uses the CDC for pea, lentil and chickpea research and development and AAFC for bean and pea breeding. Historically, the APGC has been a financial partner with the SPG in the Variety Release Agreement with the CDC. Although, this is currently not the situation, as no formal agreement is presently in place, the APGC continues to enjoy royalty free access to pulse varieties developed under the SPG/CDC partnership.

4.3 The United States

Compared to Canada and Australia, the US does not possess a well-organized and producer-funded pulse research network. Furthermore, in the US there does not appear to be any producer organized, funded, and managed research and development PPPs such as the GRDC or SPG. In many respects, the American system is anachronistically organized: centred upon a public breeder supported primarily by public funds and conducting general variety releases without the use of plant-variety or intellectual property rights protection. The graphical social network analysis confirms this perspective as the US pulse-breeding system is centred on the Pullman USDA-Agricultural Research Service (ARS) facility in Washington State (table 6 and figure 3). The US network resembles a hub and spoke configuration with a high number of loosely linked actors all connected only to Pullman. Interestingly, a network of three university research centres in the US was not connected to Pullman in any observable manner during the period of research, but was connected to number of Canadian institutions including several AAFC research centres and the WGRF. A small number of universities in the Mid-west and in the Pacific Northwest have pulse research facilities also supported by public-funds.

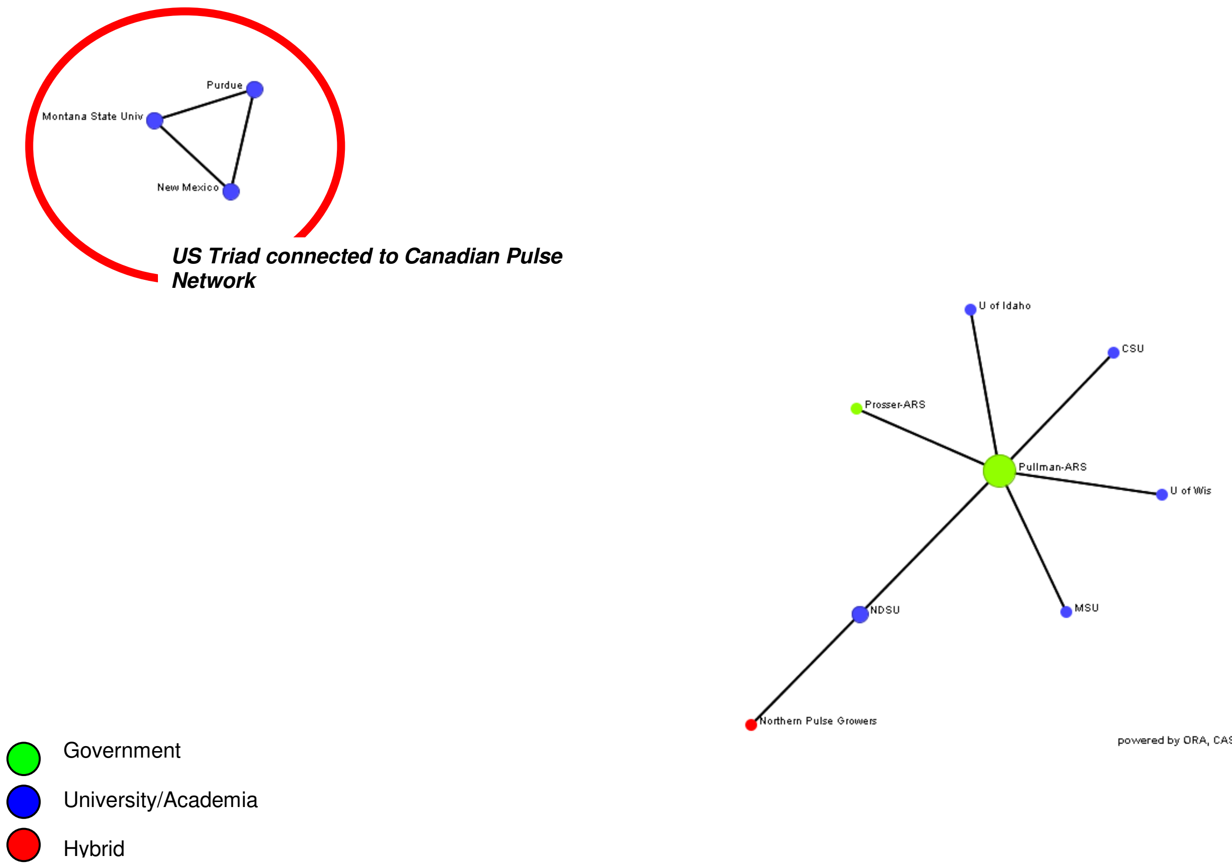
Table 6: Central Actors in the US (N=11)

	Total Degree Centrality		**Eigenvector Centrality**		**Betweenness Centrality**	
Agent	**Value**	**Context***	**Value**	**Context***	**Value**	**Context***
Pullman-ARS	0.600	***	1.000	*	0.444	***
Montana State U.			1.000	*		
U. of New Mexico			1.000	*		
Purdue U.			1.000	*		

* number of standard deviations greater than the mean
Source: Authors' calculations.

There are at least six producer groups in the US with levy programs. The USA Dry Pea & Lentil Council, a national organization, has five state-level member producer groups which have crop or association levies that support pulse research, generally at state universities. Despite this, many producers in the US, especially in the West and Northwest rely upon the SPG/CDC for pulse varieties.

Figure 3: The US Pulse Network



The US pulse research system has some of the attributes noted by Theodorakopoulou and Kalaitzandonakes (1999) in a social network study of the biotechnology-based research system. While the pulse system reflects the US model of a parsimonious set of functional networks, it does not obviously have any private sector central actors that Theodorakopoulou and Kalaitzandonakes conclude are necessary for the US to dominate in the biotechnology industry.

4.4 The International Pulse Research Network

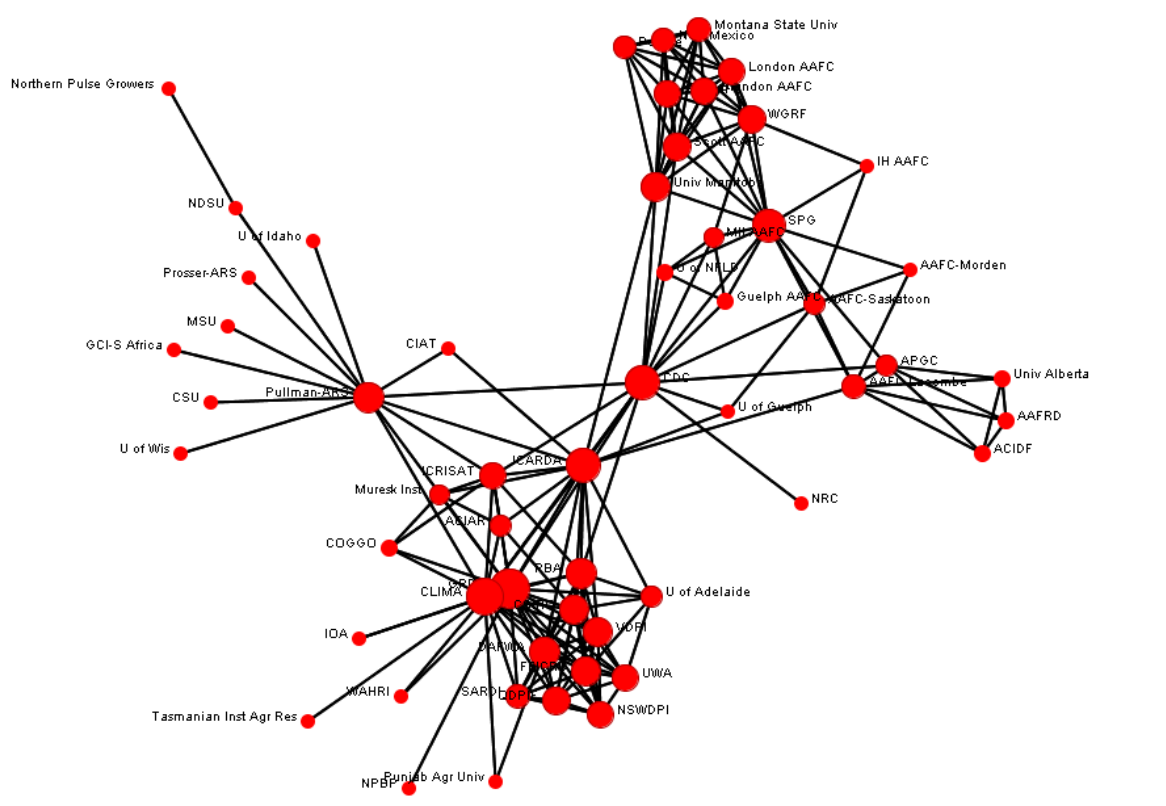
The international pulse-breeding network consists of 56 institutions from Australia, the US and Canada along with three research institutes with the Consultative Group on International Agricultural Research (CGIAR) stations and two research centres in India. The CGIAR itself is a public-private partnership of 52 public and private sector institutions that supports 15 international agricultural research centres around the globe. The CGIAR was established in 1971 for the purpose of utilizing agricultural research and development as a capacity-building tool to alleviate poverty and hunger in the developing world. As earlier noted, ICARDA and ICRISAT have germplasm exchange programs with the GRDC, Pullman ARS and the CDC.

Based upon the total degree and betweenness centrality measures there are five primary global pulse institutions. These are the GRDC and CLIMA from Australia, USDA-ARS at Pullman in the US, the CDC from Canada and ICARDA. As the social network analysis indicates these five institutions are the most connected and act as gatekeepers controlling the flow of information from the international system to the national networks. ICARDA acts as a centralized, non-aligned facilitator governing the flow of information through the international system, as well as distributing significant germplasm to the different national networks. The Australian institutions dominate the eigenvector measures, most likely a result of their highly integrated domestic network. This does not imply other actors do not possess influence or power within the international system, just that the entire Australian pulse network is both internally organized and inter-woven into the global network.

Of the 56 global institutions, 22 are government research centres, 17 are universities and 17 are hybrid organizations (table 7 and figure 4).Sixteen of those institutions occupy some position as central actors in the global system. Hybrids occupy a unique position within the international network. The four primary global institutions are hybrid—GRDC, CDC, CLIMA and ICARDA—and, overall, half of the central actor are hybrids. Government labs or organizations account for seven of the central actors while only one university occupies a central place in the network. Hybrids record the only statistically significant eigenvector centrality scores and four of the seven institutions occupying gatekeeper roles.

Table 7: Global Pulse Research Central Actors (N=56)						
	Total Degree Centrality		**Eigenvector Centrality**		**Betweenness Centrality**	
Agent	**Value**	**Context***	**Value**	**Context***	**Value**	**Context***
GRDC	0.382	*****	1.000	*	0.164	******
CLIMA	0.345	*****	0.904	*	0.157	******
CDC	0.291	***			0.342	************
ICARDA	0.291	***			0.223	*******
SPG	0.273	***				
Pullman-ARS	0.236	**			0.278	**********
DAFWA	0.218	**				
PBA	0.218	**				
CSIRO	0.200	*				
FFI CRC	0.200	*				
U. of Manitoba	0.200	*			0.119	****
VDPI	0.200	*				
QDPIF	0.182	*				
AAFC-Scott	0.182	*				
WGRF	0.182	*				
AAFC-Lacombe					0.078	**
* number of standard deviations greater than the mean Source: Authors' calculations.						

Figure 4: The Global Pulse Network – Node Sized According to Centrality Measure



To test the role of hybrid or partnerships, the 56 organizations were coded and analysed (table 8). Universities were given a code of 1, representing the least directive and focused effort. Government labs and agencies were given a code of 2, reflecting their higher degree of coercion but limited role for involving other actors in their programs. Hybrid partnerships were given a code of 3, representing the highest level of interconnectivity and control.

Table 8: The institutional structure of central actors in pulse research

Network	Institution	Coded type of organization	Rank of statistically significant central actor role		
			Total Degree Centrality	Eigenvector Centrality	Betweenness Centrality
Australia	GRDC	Partnership	1	1	1
	CLIMA	Partnership	2		2
	FFI CRC	Partnership	3		
	CSIRO	Government	4		
	DAFWA	Government	4		
	QDPIF	Government	4		
	VDPI	Government	4		
Canada	SPG	Partnership	1	1	1
	CDC	Partnership	2		2
	AAFC-Lacombe	Government			3
	APGC	Partnership			3
USA	Pullman-ARS	Government	1	1	1
	Montana State U.	University		2	
	U of New Mexico	University		2	
	Perdue U.	University		2	
Global	GRDC	Partnership	1	1	4
	CLIMA	Partnership	2	2	4
	CDC	Partnership	3		1
	Pullman-ARS	Government			2
	ICARDA	Partnership			3
	SPG	Partnership	4		
	DAFWA	Government	5		
	PBA	Partnership	5		
	CSIRO	Government	6		
	FFI CRC	Partnership	6		
	VDPI	Government	6		
	U of Manitoba	University	6		
	QDPIF	Government	7		
	AAFC-Scott	Government	7		
	WGRF	Partnership	7		

Source: Author's coding and calculations.

The correlation between the institutional measures of each of the three measures of centrality in each of the four systems was then calculated (only those that were statistically significant are shown in table 9). The global and Australian networks exhibited statistically significant positive correlation between the degrees of centrality and the nature of the institution. In effect, hybrid institutions were statistically more likely in those two networks to occupy central positions (as measured by the three measures of centrality)   The strongest correlations between centrality and hybrid partnership structure were for betweenness centrality. In other words, gatekeepers are much more likely to be hybrid actors than university or government actors. Meanwhile, Australia's network is more structurally biased to hybrid systems than either the US or Canada, which exhibited no statistically significant correlations.

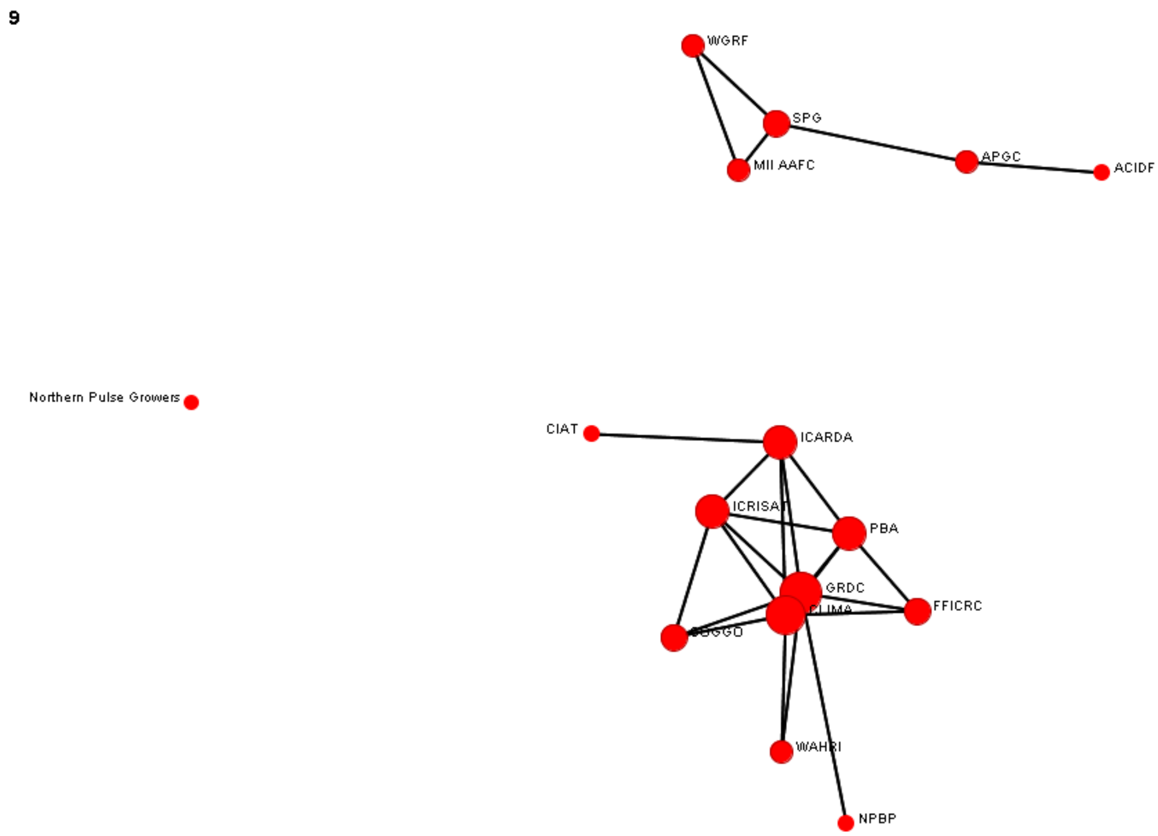
Table 9: Correlation between centrality and coded structure

	Global	**Australia**	**Canada**	**USA**
Size	56	19	21	11
Total Degree Centrality	0.371 (99%)	0.272 (75%)	-	-
Eigenvector Centrality	0.315 (95%)	0.197 (50%)	-	-
Betweenness Centrality	0.331 (95%)	0.474 (95%)	-	-

(%) represents level of statistical significanced
Source: Authors' calculation.

One aspect worth exploring is whether like organizations are more or less likely to partner with each other, or whether they are more likely to partner with others of diverse structure. Figure 5 shows the relationships between the 17 hybrid organizations. The relatively dense structure in Australia compared with Canada (which is more of a chain model) and the US, which is a disconnected system, adds support to the notion that the domestic structure in Australia and international position of Australian organizations is at least partly due to the large number of interconnected and engaged hybrid partnerships.

Figure 5: The Global Pulse Network – Hybrid Organizations



5. The Vulnerable International System

While one might be interested in determining whether these differently constructed networks deliver different results, it is difficult to arbitrarily separate the systems. While the data in table 2 suggests the Canadian system is most effective, followed by either the US or Australian systems (depending on what measure one looks at), there is not enough data yet to determine the efficiency of the system. Each system costs a different absolute and relative amount, so the respective outcomes in terms of new cultivars need to be scaled by effort (which cannot be done with the data gathered to date).

While we may not be able yet to evaluate the relative efficacy and efficiency of the three national sub-systems and the global system, we can say quite a bit about the stability and resilience of the system. The Crop Development Centre, USDA-ARS Pullman and ICARDA occupy the three most important gatekeeping functions. One might reasonably ask what might happen if their role in the system ended. Each depends on funds from public treasuries, so it is plausible to speculate that they might be constrained or forced to modifiy their mandates and functions.

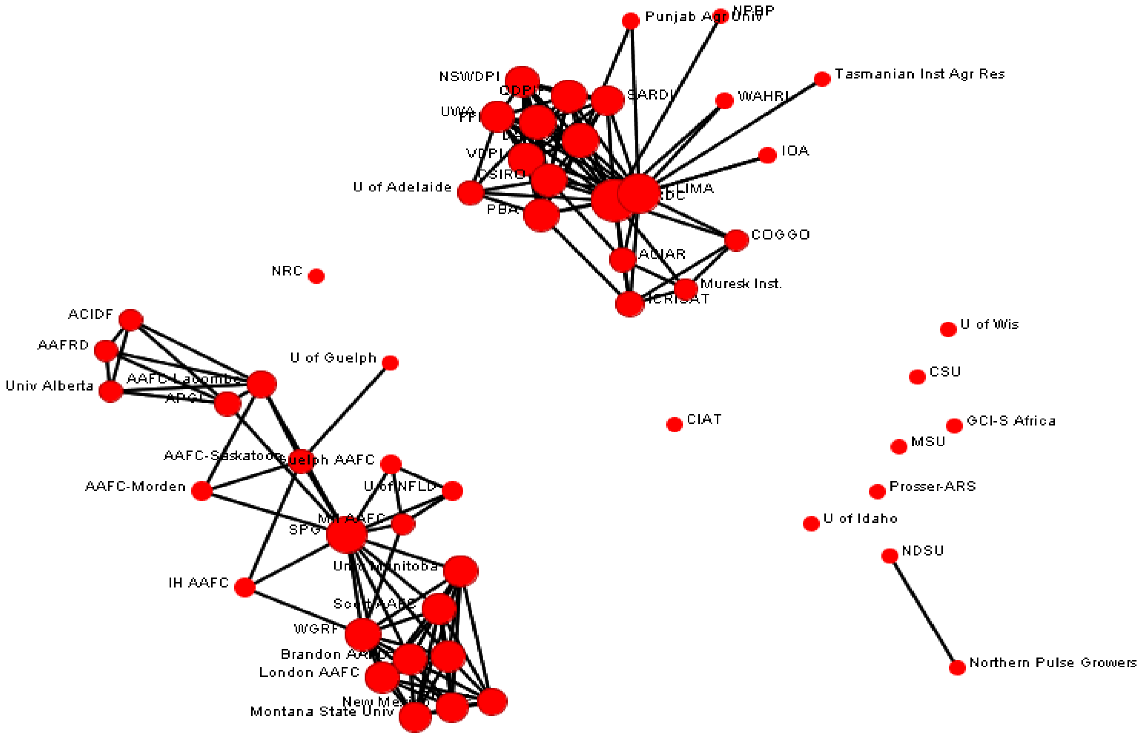
Table 10 reports the effect of losing those three actors. While the loss of the three would represent only about 5% of the network population, that would multiply into losses of 7.4% to 98.5% of network coherence. Ultimately the interconnected network of 56 organizations would develop into a disconnected world of 11 fragmented components. Australia would remain largely intact but disconnected from the rest of the system, Canada would remain coherent and linked to the US and the US would cease to have a nationally-based system.

Table 10: An estimate of the vulnerability of the global pulse network

	With CDC, Pullman-ARS and ICARDA	**Without CDC, Pullman-ARS and ICARDA**	**% effect of loss of 3 central actors**
# nodes	56	53	-5.4%
# links	378	294	-22.2%
Density	0.123	0.107	-13.0%
Network centralization	0.269	0.249	-7.4%
Betweenness centralization	0.317	0.090	-71.5%
Closeness centralization	0.392	0.006	-98.5%
Fragmentation (# components)	1	11	+1000.0%
Characteristic path length	2.643	1.880	-28.9%

Source: Authors' calculations.

Figure 5: The Global Pulse Network (less key organizations: CDC, Pullman ARS and ICARDA)



6. Concluding Analysis

The use of public-private partnerships (PPPs) is an emerging and expanding trend, internationally and nationally, in the management and financing of research, especially for pulse breeding. This is evident in three out of the four systems analyzed. In Australia, PPPs have become the structure of choice by policy makers for the management of public pulse-breeding operations. In a top-down process, through the GRDC and the CRC Program, Australia has reorganized its pulse-breeding facilities around nationally organized PPPs designed to link the producer-financier to the research-dependent output of pulse varieties. The result is a relatively dense and highly interconnected national system. Conversely, Canada has developed a bottom-up process of using PPPs as a policy tool for managing pulse breeding. The Canadian system is centred on a partnership between two regional/provincial actors, the SPG and the CDC, which has grown into a national pulse breeding system coordinated by the SPG. Governments have helped, by working with the SPG assuming responsibility for managing the AAFC pulse network of approximately a dozen research centres. In the US there do not appear to be any PPPs of significance in operation. Internationally, PPPs appear to have become the governance structure most closely identified with power and influence. With exception of the USDA-ARS facility at Pullman, PPPs are the national and international knowledge gatekeepers of choice (i.e. GRDC, CLIMA, CDC/SPG and ICARDA).

Clearly, there is more work that can and should be done to understand the role and impact of alternate research management systems. Social network mapping, in conjunction with case studies of economic and performance management, offer one way to understand and better manage the increasingly important research effort that drives the knowledge-based economy.

References

Boulding, K. (1970) 'Organizers of social evolution', chapter 2 in K. Boulding (ed), A primer on social dynamics: history as dialectics and development, London, Collier MacMillan Ltd,.19-36.

Bonacich, P. (1972)'Factoring and weighting approaches to status scores and clique identification." *Journal of Mathematical Sociology*. 2: 113-120.

Buller, Chris and Taylor, William. (1999) "Partnerships between Public and Private: The Experience of the Cooperative Research Centre for Plant Science in Australia. AgBioForum. Available online at http://www.agbioforum.org/v2n1/v2n1a04-buller.pdf

Burt, R. (2005) Brokerage and closure: an introduction to social capital, Oxford University Press. Available online at http://gsbwww.uchicago.edu/fac/ronald.burt /research/

Centre for Legumes in Mediterranean Agriculture. (CLIMA) (2006) Strategic Plan 2006.

Cooperative Research Centres. (2007) Innovation in Australia: a guide to the CRC Programme.

Freeman, C. (1982) *The Economics of Industrial Innovation*. Pinter: London.

Freeman, C. (1987) Technology policy and economic performance; lessons from Japan. London, Pinter.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., and Trow, M. (1994) The new production of knowledge: The dynamics of science and research in contemporary societies, London: Sage.

Grains Council of Australia. (GCA) (2007) About us.

Grain Foods Cooperative Research Centre. (GFCRC) (2007) Investments in Grain Foods CRC.

GRDC (2007) "Media Release: Pulse Breeding Australia".

GRDC. (2007) Annual Report 2005-06. Available online at http://www.grdc.com.au/director/about/corporategovernance/Annual%20Report.

GRDC. (2007) Annual Report 2007-08. Available online at http://www.grdc.com.au/director/about/corporategovernance/Annual%20Report.

Gray, Richard and T.G. Scott. (2003) "Returns on Producer Investments in Pulse Crop Research" No. GEN 0320. Available at http://www.saskpulse.com/media/pdfs/research-returns-report.pdf.

Gray, Richard, C. Nagy, V. Galushko and S. Weseen. (2008) Returns to Pulse Crop Research & Development and the Management of Intellectual Property Rights, accessed on March 3, 2009 at http://www.saskpulse.com/news/latest_pulse_news.php?detail=229.

Knoke, D. and Kuklinski, J. (1982) 'Network Analysis', Series: Quantitative Applications in the Social Sciences, Sage University Papers 28.

Mead, S. (2001) 'Using social network analysis to visualize project teams', Project Management Journal, 32(4), 32-38.

Metcalfe, S. (1995) 'Technology systems and technology policy in an evolutionary framework', Cambridge Journal of Economics, 19:25-46.

Meristem Land & Science.(2006) Building Canada's New Strategy. 2006 PRRCG Report. Available online at http://www.meristem.com/prrcg06/index.html.

Paquet, G. (2001) 'The new governance, subsidiarity and the strategic state', in OECD, Governance in the 21st Century, Paris: OECD. Available online at http://www.oecd.org/dataoecd/15/0/17394484.pdf.

Picciotto, R. (1995) 'Putting institutional economics to work: from participation to governance', World Bank Discussion Paper 304, accessed on March 3, 2009 at http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/1995/09/01/000009265_3961219115337/Rendered/PDF/multi_page.pdf.

Phillips, P. (2007) Governing Transformative Technological Innovation: Who's in charge? Oxford: Edward Elgar.

Rhodes, R. (1995) The new governance: governing without government, The State of Britain Seminar II of a joint ESRC/RSA seminar series, January 24.

Rosenberg, N. (1994) Exploring the black box: technology, economics and history, Cambridge University Press.

Ryan, Camille (2008) *Evaluating Performance of Collaborative Research Networks: a socio-economic framework for assessing funded research projects*. VDM Verlag: Germany.

Saskatchewan Pulse Growers. (2009) Overview of Research Program, Available online at http://www.saskpulse.com/research/index.php.

Scott, T.G. (2004) Saskatchewan Pulse Growers Variety Release Review.

Theodorakopoulou, I. and Kalaitzandonakes, N.. 1999. Returns and Structure of Public-Private Knowledge Networks in Plant Biotechnology: An EU-US comparison. Paper presented to the *International Conference* organized by the *International Consortium on Agricultural Biotechnology Research (ICABR) at the University of Rome Tor Vergata*, June 17-19.

Valente, T. (1995) *Network Models of the Diffusion of Innovations.* Cresskel, New Jersey: Hampton Press Inc.

Weiss, T. (2000) 'Governance, good governance and global governance: conceptual and actual challenges', Third World Quarterly, 21(5), 795-814.