National Innovation Systems, Social Capital, and Country Image: A Multi-
Country Study of International Scientific Collaborations

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ABSTRACT

The research examines the relationships among previously separate constructs from theories and literature regarding strategic alliances, country image, and social capital and their effects on international scientific collaborations (ISCs). Previous research on ISCs has primarily focused on specific aspects such as measurements of ISCs and the study of dyadic relationships within ISCs. This research examines the phenomena of ISCs in a more holistic fashion. The research examined the effects of key elements of these three streams of literature on the desired attributes of international partners for scientific collaborations, the perceived effectiveness of the ISCs, and the nature and extent of value creation outcomes of the ISCs. Building on the work of Nahapiet and Ghoshal (1998) on social capital, an integrative framework – the Integrated Framework of Interorganizational Social Capital in ISCs, was developed and operationalized at the individual-level country and at the collective ISC, and tested.

A two-phase, mixed-methods research project composed of twenty-one qualitative in-depth interviews and a quantitative international survey was conducted. Results of 177 surveys from Canadian and foreign senior scientists actively involved in large-scale ISCs indicate support for all hypothesized relationships of both individual-level country and the collective ISC research frameworks. The results confirmed the crucial role of S&T infrastructure as a key driver in the ISC process. S&T infrastructure is found to be a key predictor of partner attractiveness and a significant predictor of collaboration effectiveness. Country and scientists characteristics along with shared goals among

collaborators were significant predictors of trusting relationships in ISCs, which in turn is one of the significant predictors of partner attractiveness and collaboration effectiveness. Finally, collaboration effectiveness and to a lesser degree, partner attractiveness are significant predictors of value creation from ISCs – intellectual capital, industrial and political spillovers. The research contributes to the understanding of ISCs that will benefit Canada and other nations in ensuring successful involvement in ISCs.

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1 INTRODUCTION

Collaboration is one of the characteristic features of modern science (Meyer and Bhattacharya 2004) and often a critical aspect of scientific research (Hara, Solomon *et al.* 2003). The scientific collaborative enterprise has accelerated over the past few decades (Finholt 2003). The 20th century brought about a radical change in the way scientific research is conducted. While formerly research laboratories were composed of individuals or small teams working in isolated settings, major science has become mostly a collective enterprise, often conducted across several nations (Laudel 2001). These major collaborative science projects often have a high capital cost and a lifetime of several decades, but they generally reap a wide array of major benefits.

International scientific collaboration (ISC) is by no means an entirely new phenomenon. Astronomy has a long history of international collaboration dating back to the 16th century (Ratchford and Colombo 1996, McCray 2000). However, the increasing complexity of global issues and the interdisciplinary nature of scientific advances have led to an even stronger need to collaborate. For instance, the global AIDS epidemic is a research issue requiring unprecedented levels of international cooperation from disparate communities (e.g., scientists, policy makers, clinicians) that worked independently in the past (Finholt 2003). Furthermore, multi-disciplinary and international collaborations are actively promoted by government bodies as a means to leverage others' knowledge and resources to generate cost-savings and higher impact research (Katz and Hicks 1997).

The advent of the digital world has increased the interconnectedness of scientists and has facilitated collaborations and multi-sector networking of researchers from multiple disciplines. Thus, the organization of science appears to be moving away from an “invisible college” (Price and Beaver 1966), which is a form involving a small number of researchers well known to each other and collaborating frequently, towards a distributed, networked approach of major groups (Zare 1997).

The multi-faceted benefits of international scientific collaborations (ISCs) have been widely signalled (Katz and Hicks 1997; Katz and Martin 1997). In this knowledge-based economy, the competitiveness of countries is increasingly dependent on the creation and application of scientific knowledge. Despite the large number of studies examining the relationships among science, technological progress, and economic growth, only a handful of empirical studies have attempted to understand the mechanisms around the diffusion of knowledge, such as publication and patents, that might generate this linkage (Sorenson and Fleming 2004).

To achieve the goals of ISCs, government and scientists need to find suitable partners. Literature on strategic alliances points to relevant factors for the search and selection of scientific collaborators. Nevertheless, no research appears to have specifically addressed the factors affecting the choice of country partners for ISCs. However, the global scientific arena is fierce with strong emergent players such as China, India and Brazil. China, for example, has become the fifth leading nation in terms of its share of the world’s scientific publications (Zhou and Leydesdorff 2006). Consequently, science

policy makers may need to be concerned with how Canada's international partners, both current and desired, see Canada as a scientific partner.

More recent literature stresses the crucial importance of human and behavioural aspects of ISCs. Factors such as inter-cultural differences, trust, and collaborative propensity impact the effectiveness and outcomes of collaborations. The literature on trust related to collaboration is especially extensive (Doney, Cannon *et al.* 1998; McKnight, Cummings *et al.* 1998; Shrum, Chompalov *et al.* 2001; Madhok 2005). A particularly relevant stream of literature for the purpose of the study is social capital, which involves a set of resources rooted in relationships. A relatively recent concept, social capital lacked an accepted theory-based framework until Nahapiet and Ghoshal (1998), building on previous work, developed a framework that incorporates a multi-dimensional perspective of social capital and its interrelationships with the creation of intellectual capital. Several other researchers (Tsai and Ghoshal 1998; Yli-Renko, Autio *et al.* 2001; Adler and Kwon 2002; Autio, Hameri *et al.* 2004; Dakhli and de Clercq 2004; Inkpen and Tsang 2005) have built on this framework, legitimizing, expanding and applying it to a variety of contexts.

1.1 Purpose of Research

This research addresses some of the conceptual gaps in the current literature on large-scale ISCs. Specifically, the purpose of the research is to integrate the three theoretical perspectives most relevant to the field of ISCs, namely underlying theories of strategic alliances, country image, and social capital, to develop and test an empirical framework,

termed the Integrated Framework of Interorganizational Social Capital in ISCs. This framework enhances the understanding of the relationships among key constructs of each perspective, specifically for the attractiveness of international scientific collaborators, the perceived effectiveness of the collaborations, and the outcomes realized from large-scale ISCs. The overall goal is to contribute to the understanding of ISC formation and operation that would benefit a medium-sized country like Canada in positioning itself for successful involvement in ISCs.

In the context of this research, ISC is defined as *geographically dispersed scientists offering complementary expertise and resources to jointly contribute to a common scientific research endeavour*. This definition is derived from the various streams of literature and draws from the OECD's definition of Big Science (OECD 1993). The focus of the study is on large-scale, publicly-funded international scientific collaborations, in scientific fields of strong interest to Canada, that involve Canadian and foreign government laboratories from selected developed and emerging economies.

The research was conducted in two phases with a mixed-methods approach. Because of the unexplored nature of this topic, Phase I was an exploration and generation of themes from the literature and from in-depth interviews conducted with selected Canadian scientists and policy makers within Canadian federal government research laboratories. These respondents were extensively involved in scientific collaboration with foreign scientists, hence their relevance to the study. The interviews along with the concepts from the streams of research led to the development of an empirical framework used as

the base for Phase II, a quantitative study where the framework was tested. Phase II was conducted through a survey of Canadian and foreign scientists involved in large-scale, formal ISCs.

1.2 Organization of the Thesis

The thesis is composed of eight chapters. The current introduction chapter presents the overall purpose of the research. Chapter 2 presents an extensive review of the various streams of literature relevant to ISCs. Chapter 3 then covers the theoretical approaches, research questions and objectives, and research frameworks. Chapter 4 describes the Phase I research, a qualitative study using in-depth interviews of Canadian scientists and policy makers and the results of the interviews. Chapter 5 describes the quantitative study, an international survey of scientists involved in large-scale ISCs. Chapter 6 provides the results of the survey. Chapter 7 discusses implications from the results while chapter 8 concludes this research study.

2 LITERATURE REVIEW

The study of collaborations draws from a broad range of theoretical perspectives. International scientific collaboration is a form of collaboration. In order to adequately cover the literature related to ISCs, several areas will be reviewed:

- typology of ISCs,
- growth and measurements of ISCs,
- motives for ISCs,
- benefits of scientific collaboration,
- partner selection from the literature streams of strategic alliances, country image, and social capital,
- intellectual capital, political and industrial spillovers.

2.1 Setting the Context

This section will define the broad notion of collaboration, then narrow in to the concept of international scientific collaborations, the various forms scientific collaborations can take, and the specific focus of the research.

2.1.1 Definitions

Collaboration has been defined as the working together of individuals to achieve a common goal (Katz and Martin 1997). The literature is rather limited on a more precise definition of collaboration, with the term used intuitively and other terminology, such as “cooperation” and “coordination”, sometimes used interchangeably with it (Hara, Solomon *et al.* 2003). Integrating the bodies of literature involves dealing with differences in how such terms as collaboration and cooperation have been used in the

context of ISCs. Part of the challenge resides in the variety of institutions, actors, and contexts of collaboration, as well as different perspectives on collaborations e.g., collaboration as relationships, as organizational and interorganizational structures, or as a process. Collaborations can take a variety of forms including alliances, partnerships, joint ventures, networks, and a host of other forms of cooperative relationships. Interfirm collaborative arrangements for sharing of critical and strategic technological capabilities among partner firms are generally referred to as strategic alliances (Kuada 2002).

Collaborations can be formal or informal, short or long term in duration, and can involve a wide spectrum of participants. They can range from an informal bi-partite collaboration between two colleagues all the way to a large-scale, multi-disciplinary, multi-institution, multi-country effort. Collaborative activities vary from offering general advice and insights among members to active participation in a specific piece of research, hence from almost negligible to very substantial collaborative contributions, with these contributions likely to change during the course of the collaboration (Katz and Martin 1997). In higher education, the term collaboration typically covers a range of functions, including teaching, research commercialization, intellectual property technology transfer, and consultancy, as well as research (Smith and Katz 2000). Smith and Katz (2000) acknowledged that the concept of collaboration is a complex phenomenon, not well understood and with multiple meanings in practice.

A research collaboration can be defined as the working together of researchers to achieve the common goal of producing new scientific knowledge (Katz and Martin 1997). The

context of this dissertation is on scientific collaborations, although the terminology research collaboration is often used in the literature to mean the same thing. Some researchers refer to research collaborations in the context of corporate partnerships (Mowery 1998), others (Smith and Katz 2000) in the context of university research, and others simply as a catch-all label. A tentative distinction between scientific and research collaboration is that the latter generally refers to interfirm collaborative arrangements. R&D collaboration is yet another term generally associated with different firms or business organizations collaborating in industry-led consortia or with national laboratories or universities (Mowery 1998). Heimeriks, Horlesberger *et al.* (2003) distinguish between five categories of organizational entities typically involved in scientific collaboration: international and national governmental organizations; consultant firms and industry; non-commercial organizations; contract research organizations; and universities.

In spite of the variety of definitions of scientific collaboration offered over the years, a contextual definition with a clear boundary is lacking. The term almost seems taken for granted. Consequently, it is challenging to establish what scientific collaboration means and how to distinguish between the various levels of collaboration (Smith and Katz 2000). It has been noted that a large body of research defines scientific collaboration by one of its most visible outputs: co-authored papers. However, scientific collaborations may lead to a range of outputs, and a co-authored article is only one such output. In addition, several collaborations may not lead to any publications, co-authored or otherwise.

It is widely acknowledged that most ISCs are informal. In fact, the blurred boundary between an informal collaboration and the beginning of a more formal one helps explain the challenge in defining the concept. Moreover, perceptions of the boundary of the collaboration may vary considerably across institutions, fields, and countries as well as over time (Katz and Martin 1997). It has become apparent from the preceding discussion that several facets have to be considered in the definition of a scientific collaboration such as: the purpose, the duration, the levels (e.g., individuals, groups, departments, institutions, sectors and countries), the formality, the structure, the nature of the collaborators, the functions or activities, and the benefits. Regardless of these definitional challenges, there is broad agreement that collaboration between organizations is an important area of organizational study and a significant challenge for management practice (Huxham and Hibbert 2005).

2.1.2 Evolution of ISCs

Beaver and Rosen (1978) developed a comprehensive theory of scientific collaboration from an historical and sociological perspective, proposing that collaboration is a response to the professionalization of science. In their account of the evolution of ISCs, they claim that the first collaborative scientific paper was published in 1665, with collaborative linkages across national borders as early as the nineteenth century. Scientific collaboration was almost exclusively conducted by French chemists in the period 1800-1830. This was the result of the professionalization of science during the revolutionary and Napoleonic eras that helped achieve general social acceptance and support from the larger French society. This was unlike German and English science, which had little or no state support at the time. Beaver and Rosen (1978) established that when France was

the only country with a professional scientific community, its scientists produced the bulk of all co-authored research since virtually all joint research in the early 19th century was performed by French scientists. Beaver and Rosen (1979) demonstrated that co-authorship results in above-average productivity, defined by the number of publications and greater visibility of the research and researchers compared to individual scientific work.

Data from Chemical Abstracts, the largest database of publicly disclosed chemistry-related bibliographic information and abstracts by the American Chemical Abstracts Service, show that in 1900 more than 80 percent of all papers had a single author, with the remaining 20% mostly pairs, typically involving a professor with a graduate student (Price 1986). Scientific collaborations started growing at a much faster pace following WWII. Although the dominant model is still a dyadic approach, that is two individual collaborators, the trend is moving from little science collaboration to big science teamwork. The OECD (1993) describes Big Science as “a project that addresses a set of scientific problems of such significance, scope and complexity as to require an unusually large-scale collaborative effort, along with the facilities, instruments, human resources and logistic support to carry it out.”

Big science in high energy physics (HEP) and astronomy started multiplying after WWII. However, even in the 16th century Tycho Brahe’s astronomical observatory was a scientific megaproject of its day. The work of Brahe’s assistant, Johannes Kepler, underpinned the development of the Newtonian worldview, which was to dominate

science for over 300 years (Ratchford and Colombo 1996). In Canada, the research nuclear reactor 'NRX', at the time the most expensive science facility and the world's most powerful nuclear research reactor, began operation in 1947. A cooperative effort between the UK, the U.S. and Canada, the nuclear reactor operated for 45 years. In 1994, Canadian physicist, Dr. Bertram Brockhouse, shared the Nobel price in Physics for his work in the 1950s at NRX. A second facility, the National Research Universal (NRU) reactor, was built in 1957 and is still in operation today.

Science, the means of conducting science, and the organization of science have undoubtedly evolved over the years (Beaver 2001). Today, big science has spread to the life sciences, notably molecular biology and biomedical research. Large *distributed* projects – projects spread across several research locations – are emerging to rival the large-scale facility projects in scale, scope and complexity, not to mention costs. A case in point is the Human Genome Project, a 13-year international effort to identify the approximately 20,000-25,000 genes in human DNA (Human Genome Project 2006). Completed in 2003, it was a massive scientific undertaking involving several countries, with a huge budget and was fraught with ethical, legal, and societal issues. Other significant trends in ISCs include the globalization of scientific collaborations and an increase in cross-sectoral cooperation, a phenomena dubbed GUI (Government-University-Industry) research collaboration by Carayannis and Laget (2004). Accordingly, research about ISCs has grown considerably in the last few decades with a vast amount of literature focusing on motives, purpose, configuration, benefits, as well as

issues and challenges of collaboration. This certainly points to a recognition of the importance of ISCs.

2.1.3 Typology of ISCs

Science is typically a cooperative endeavour with the flow of knowledge among scientists from government research institutions in open economies largely unrestricted. Science collaborations take many forms. One of the dominant forms of organization has become known as the invisible college, a notion attributed to Robert Boyle in 1947 and popularized by Price (1963, 1986). Invisible colleges refer to scientists participating actively in international conferences and exchanges of communication, creating their own informal communities of interest in their field, an “in-group”, without regard to the political or institutional allegiances of participants. In other words, they are informal collectives of closely interacting scientists, generally limited to a size “that can be handled by interpersonal relationships,” certainly similar to the more recent phenomena dubbed communities of interest (Price and Beaver 1966). However, the increasing complexity of issues requires different forms of scientific collaboration.

The types and structures of ISCs are often predicated upon the purpose of the collaboration. Wagner (2005a) highlighted two very different dynamics – collaborative research involving simply sharing of information and collaborative research involving sharing of tasks and resources. The latter incurs more transaction costs, and has more obstacles to success than simply sharing information. Collaborative research involving sharing of tasks and resources is the focus of this research.

A synthesis of the literature on forms and types of scientific collaboration reveals the following forms:

- inter-personal collaborations involving 2 or 3 persons or laboratories, usually “peers”.
Direct cooperation between two or more researchers is the fundamental unit of collaboration (Katz and Martin 1997). The typical group structure consists of a principal investigator (PI), together with postdoctoral fellows and graduate students. This type of structure is often found in universities and government laboratories. Activities include informal partnerships, workshops, database development, sabbatical leaves, exchanges, and fellowships. These activities are initiated by the investigators where each partner contributes to the funding (financial or in-kind). The joint research projects are generally of short duration and involve problem-solving and sharing of complementary capabilities to address a specific research question (Wagner 2005a). The majority of ISCs fall into this category and are sometimes referred to as small science;
- inter-group collaboration, such as inter-departmental collaboration between departments within the same institution;
- inter-institution or interorganizational collaboration, usually involving some formal agreement such as a Memorandum of Understanding (MOU) between the collaborating organizations. Some examples of Canadian inter-institution collaborations include research on fuel cells and the hydrogen economy, and nanotechnology. One example is the National Research Council of Canada (NRC) and the University of Petroleum in Beijing working on an Athabaska oil sands project;

- teamwork, large-scale collaboration, Megascience or Big Science, which Ratchford and Colombo (1996) and Beaver (2001) consider the new paradigm for the organizational structure of research. Such large-scale collaborations encompass very large, predominantly basic scientific research projects or programmes and are capital-intensive (Ratchford and Colombo 1996). Large-scale collaborations are characterized by complex problems to address rapidly changing technology, dynamic growth of knowledge, and highly specialized expertise (Katz and Martin 1997). Teamwork implies a structure with extensive collegiality but also with substantial division of labour and some hierarchy (Walsh and Bayma 1996). The International Space Station (ISS) is an example of what has been termed a Big Science ISC. In the Canadian context, Big Science or major science projects and facilities are those of sufficient magnitude that they require resources beyond the capacity of any single institution, funding agency or department to build and operate. Big Science projects inherently necessitate ISCs. The “International Polar Year 2007-2008,” a Polar Regions research initiative, is another example of a big science collaboration. It involves over 60 countries, including China and India, with Canada taking the lead, the International Council for Science (ICSU), and the World Meteorological Organization (WMO – a UN organization). The focus of the research is on physical, geophysical, and social sciences.

The framework proposed by Smith and Katz (2000) is often referenced to understand the structure of collaborative teaming in scientific research. Three types are identified:

- type A, corporate partnerships, (in the sense of formal partnership) are collaborations corporately owned and initiated towards a specific goal, such as projects like the ISS or the European Organization for Nuclear Research (CERN), the world's largest particle physics laboratory. Located in Geneva and in operation since 1954, the facility has 20 member states. Canada participates as a non-member state in specific projects. These projects are quite costly and represent a small percentage of all ISCs. CERN is the object of a considerable amount of research studying collaboration, as is the scientific field of high energy physics (HEP) in general;
- type B, team collaboration, are formalized projects detailed in joint proposals or involving collective use of resources. The need for multi-disciplinary skills is usually the main driver;
- type C, inter-personal collaboration, are intellectually driven and dependent on personal relationships.

There is overlap between this taxonomy and the forms and types of ISCs drawn from the literature earlier. Overall, there is a dearth of literature on the taxonomy of ISCs and especially on scientific collaboration among government laboratories. This is perhaps because "Research collaboration is largely a matter of social convention among scientists" as noted by Katz and Martin (1997, p.16). Another challenge is what exactly constitutes a "collaborator." Katz and Martin (1997) offer some criteria: "those who work together on the research project through its duration or for a large part of it, or who make frequent or substantial contribution, who are responsible for one or more of the main elements of the research. It may also include those responsible for a key step"

(Katz and Martin 1997, p. 25). They assert that a research collaboration has a very “fuzzy” or ill-defined border and that the perception of this border may vary considerably across institutions, fields, and countries.

Over the past decades, a convergence has been witnessed along with a crossing-over of three worlds of university, industry and government that were once very much separate. This convergence has been represented and explained by Etzkowitz and Leydesdorff (1995) through the Triple Helix model. This model refers to a spiral versus traditional linear model of innovation that captures multiple reciprocal relationships among institutional settings at different stages in the capitalization of knowledge. In this configuration of institutional forces, knowledge is co-developed rather than transferred (Etzkowitz and Leydesdorff 1998). This transformation in university-industry-government research relations has, in turn, resulted in increased collaboration among the three groups.

Nearly two decades of technology evolution has led to a rich variety of capabilities to link people with people, people with information, and people with facilities. As a consequence of this Information and Communication Technology (ICT) revolution, new patterns of collaboration have emerged, such as virtual teams and the scientific collaboratory, a hybrid of collaborate and laboratory. The scientific collaboratory is a network-based facility and organizational entity that spans distance, supports recurring human interaction oriented to a common research area, fosters contact among researchers who may be known or unknown to each other, and provides access to data sources,

artifacts and tools required to accomplish research tasks. It was first proposed by visionary scientists and computer scientists in the late eighties, with the term coined by William Wulf in 1989 (Gallié and Guichard 2002). The primary goal of a typical collaboratory is to provide remote access to data sources, artifacts, tools and experts to facilitate scientists' individual research or a scientific community's initiatives (Finholt 2003; Sonnenwald 2003).

The discussion so far has not differentiated between scientific collaboration performed by government laboratories and university-based collaboration. However, some authors have drawn such distinctions. In particular, Bozeman (2000) has studied the comparative advantages of universities over government laboratories in the context of technology transfer. He believes that the major comparative advantage of federal laboratories over universities is their ability to perform interdisciplinary team research, considered difficult at universities due to their organization along disciplinary lines. On the other hand, the most obvious advantage of universities over federal laboratories are students. Students are a reservoir of "cheap labour" supporting university research, are a means of technology transfer, and often provide enduring links as the social glue holding together many faculty scientists and the organizations they work with. Bozeman (2000) also raised the advantage of expensive and often unique scientific equipment and facilities located in federal laboratories. This is, however, a U.S. based study. In Canada, the Canadian Foundation for Innovation (CFI) has been injecting substantial funds into university research infrastructure since its inception in 1997.

Traditionally, researchers have categorized collaboration by scientific fields. In particular, the classification is along the traditional fields of science: life sciences, natural sciences, engineering and materials science (Katz and Martin 1997). Luukkonen, Persson *et al.* (1992) found that the three fields that showed the most collaboration in the 1970s and 1980s were earth and space science, mathematics, and physics. As expected, a sizeable amount of research has investigated scientific collaboration in these fields. However, with the increasing complexity and interdisciplinary nature of scientific endeavours, this classification is not the most helpful for the study. David (2004) has used a taxonomy related to collaboratories and cyberinfrastructure needs, namely community-centric (aimed to bring researchers together), data-centric (access to data captured or extracted from remote sources, creating new information from the data), computation-centric (high-performance computing capabilities, and peer-to-peer sharing of distributed computation capacity), and interaction-centric (real-time interactions among participants). Although of interest, this taxonomy is too ICT-focused for the purpose of the study.

An interesting categorization of ISCs is that of Wagner, Staheli *et al.* (2002) who conceptualized the organization of collaborative research around two axes. One axis runs from spontaneous (“bottom-up”) to highly organized (“top-down”) research, while the other axis runs from centralized to distributed research location. The combination of the style of research and location produces four distinct quadrants of collaborative research shown in Figure 1.

Figure 1. Organization of collaborative research (Wagner, Staheli *et al.* 2002)¹

Looking at specific quadrants, collaborations in the “megascience” quadrant are generally well-known and highly visible. Megascience collaboration, such as centralized large-scale physics labs and astrophysics centers, are planned by a group of interested parties, usually including governments, and “sunk” into a location that becomes very difficult to change later due to expensive and specialized equipment. The location of research is greatly influenced by the question of who funds the research as well as the scale and scope of its attendant activities. However, these collaborations with stronger formality of government control represent the “tip of the iceberg” only. Most international collaborations fall within a diverse category of interpersonal and informal collaborations initiated by the investigators themselves and funded by each partner separately without reference to a specific proposal or project. Collaborations in the “resource-dependent” quadrant are also fairly well known as they tend to require sharing of a resource at a specific place. For example, the government of Japan has created a one-of-a-kind “shake table” that can be used to simulate earthquakes.

¹ HSFP : Human Frontiers Science Program; HGP : Human Genome Project; AR : Arctic Research; IMC : Intelligent Manufacturing Systems; IPCC : Intergovernmental Panel on Climate Change; CERN : European Organization for Nuclear Research; ITER : fusion research; ISS : International Space Station; ODP : Ocean Drilling Program; CRDF : Cooperative Research and Development Fund.

Conversely, “scientist-initiated research”, that is spontaneous and distributed collaboration, is usually initiated and decided by researchers and not dependent upon a centralized piece of equipment or the location of a resource. These projects are sometimes of short duration and involve problem-solving and sharing of complementary capabilities to address a specific research question (Wagner 2005a). These activities are diffuse, and it is difficult to say where they exist. These interpersonal collaborations are defined as type C collaborations under the framework of Smith and Katz (2000) described earlier. Distributed collaborations are more difficult to identify and therefore more difficult to manage even in the “dynamic cooperation” quadrant where the activities are centrally planned, such as the Human Genome Project (Wagner 2005a). A Canadian example of a dynamic cooperation is the major geoscience project NEPTUNE, the world’s largest cable-linked seafloor observatory, which is a U.S.-Canada geosciences collaboration. Distributed projects tend to have dynamics that are similar to networks, while centralized ones have dynamics more similar to a corporate structure. Research into ISCs suggests that distributed collaboration is growing much more quickly than centralized collaboration (Wagner and Leydesdorff 2005b).

Certainly, it can be concluded from the literature that ISCs can take a variety of forms. As summarized by Heimeriks, Horlesberger *et al.* (2003); “the knowledge production system is increasingly becoming a hybrid network, characterized by heterogeneous collaborations between different actors, and by heterogeneous communications using an increasing number of different media” (Heimeriks, Horlesberger *et al.* 2003, p. 2).

2.1.4 Growth and Measurements of ISCs

There is ample evidence of the growth of scientific collaborations (Luukkonen, Persson *et al.* 1992; Katz and Martin 1997; Wagner and Leydesdorff 2005a, 2005b). Ground-breaking advances in research domains are generally the result of collaboration (Carayannis and Laget 2004). Several explanations have been offered for the growth of ISCs:

- financial and economic as well as professional dependence of one researcher upon another (Price and Beaver 1966),
- professionalization of science and increased specialization within fields of science (Beaver and Rosen 1978; Beaver and Rosen 1979),
- structural factors, such as the expansion of the global scientific enterprise, the impact of ICT, the increased research capacity of the public and private sectors, economic growth, expansion of industrial R&D, and the impact of government science and technology policies,
- miscellaneous other factors such as cheaper and faster modes of transportation (Katz and Martin 1997; Ganz-Brown 2000), conferences, and increases in foreign students receiving advanced training with the U.S. and other major science producing countries leading to student-mentor collaboration afterwards (Ganz-Brown 2000).

The growth of scientific collaboration is a recurrent theme in the scientific collaboration literature and the subject of numerous empirical studies. Bibliometrics, or scientometrics, is the quantitative analysis of science and scientific development. The first known example of bibliometric research dates back to Cole and Eales in 1917 (Narin 1991). The

pioneering work of Price, considered the father of scientometrics, with *Little Science, Big Science* (Price 1963) and his subsequent book, *Little Science, Big Science...And Beyond*, (Price 1986) has acquired worldwide fame. Bibliometric indicators are based on a count of scientific papers and the citations they receive as a proxy for the overall output of scientific research. Together with patent indicators, they are one of the most frequently used indicators of R&D output (UNESCO Institute for Statistics 2005). Applications of scientometrics include studies of the state-of-the-art of specific countries, the shape of continental networks, the international openness of specific zones, North-South relations in scientific collaboration, stratification of sub-continental networks, level of resemblance and characteristics of the collaboration patterns among various countries in different fields of science (Zitt, Bassecoulard *et al.* 2000).

The extensive literature on measurements of ISCs can be regrouped under several approaches. By far the most important area of measurement studies is international co-authorship, a well-established tool in bibliometric analysis (Meyer and Bhattacharya 2004). An international co-authorship is defined as a collaboration between authors from different countries resulting in a co-authored paper. Co-authorship analysis can be used to trace collaborative links between individuals, organisations, or countries (Meyer and Bhattacharya 2004), to study creative processes and rewards in collaborative research (Laudel 2001), to analyse how impact varies with various types of collaboration (Katz and Hicks 1997), to explain country-to-country differences, to compare national versus international co-authorships, and international collaboration by scientific field (Luukkonen, Persson *et al.* 1992). For example, Zitt, Bassecoulard *et al.* (2000)

characterized the cooperation behaviour among five large scientific countries (France, Germany, Japan, UK, and U.S.) from 1986 to 1996 and found that international co-authorship had doubled over that period.

Other bibliometric studies have correlated the Gross National Product (GNP) with the number of scientific papers per capita (Pavitt 1998) and with patents (Narin 1991), have generated case studies in specific scientific disciplines (Wagner 2005b), and have studied differences among scientific disciplines (Moed, De Bruin *et al.* 1991; Hagedoorn and Narula 1996).

Bibliometric studies of collaboration mostly use quantitative data on internationally co-authored research articles provided by the Science Citation Index (SCI), the most prominent U.S. database of scientific publications, and the Social Science Citation Index (SSCI) of the Institute for Scientific Information (ISI – Thomson Scientific, Philadelphia, PA, U.S.). These sources of data provide a complete list of authors and their corporate addresses (Luukkonen, Tijssen *et al.* 1993). The key advantages of using co-authorship to study collaborations are that it is reproducible, is relatively inexpensive and is practical. The sample size can be very large and consequently be statistically significant, and it is a unintrusive method (Katz and Martin 1997). However, concerns have been raised about the adequacy of using co-authorship to measure scientific collaborations. Some of the shortcomings include:

- bibliometric measurements cover only published papers, and not all journals have comprehensive coverage in the SCI (Luukkonen, Persson *et al.* 1992). Further, papers

do not provide a complete description of the dynamics and activities of the collaborative relationships,

- bibliometric measures do not capture the breadth of research activity in the arts, humanities and social sciences (Moed, De Bruin *et al.* 1991; Smith and Katz 2000),
- co-authorship does not necessarily mean a collaboration, since researchers who have not worked together may decide to pool their findings and write them up jointly (Katz and Martin 1997), and some authors are listed for social reasons or as “honorary co-authors” (Bozeman and Lee 2003),
- paper attribution to the participating countries can also represent a problem, even using the fractional contribution approach whereby the number of publications is divided by the number of authors (Bozeman 2000; Bozeman and Lee 2003),
- with the increased international mobility of scientists, home institution can also present a reliability challenge since many scientists are affiliated with several institutions, nationally or internationally. This, in turn, can lead to over or underestimation of research activities of the countries. This situation is reflected in the discrepancies and multiple affiliations listed in the Scientific Citations Index database (Luukkonen, Tijssen *et al.* 1993; Carayannis and Laget 2004; Newman 2004; Persson, Glänzel *et al.* 2004; Kim 2006),
- there is a linguistic bias in SCI toward publications from Anglo-Saxon countries, especially the U.S. For instance, articles written in French are not processed for the SCI (Moed, De Bruin *et al.* 1991). This bias results in an underrepresentation of other regions and particularly the Third World.

In spite of these shortcomings, bibliometric indicators are still believed to provide the best available measures of scientific output by the world's countries (UNESCO Institute for Statistics 2005). The interest and limits of co-authorships for science policy studies have recurrently been described in the literature (Melin 2000; Zitt, Bassecoulard *et al.* 2000), and the limits of co-authorship data as a partial indicator of the complete scale and scope of ISCs are believed to be reasonably well understood (Katz and Martin 1997).

Finally, some have questioned whether the traditional methods of measurement of ISCs are still appropriate given the evolving infrastructure for global science today through the Internet. For example, in Internet-driven genomics, sequenced data is posted on public and freely accessible databases. Ganz-Brown (2000) notes that this creates co-authorship tensions between researchers devoting themselves to sequencing genomes and those who interpret their results and publish, as the former do not generally receive co-authorship in these articles. These issues, in turn, are creating a demand for new approaches to co-authorship in the digital world. It also raises the importance of studying a broader set of outputs than just publication from ISCs.

More recently, the spatial configuration of networks of collaboration (Newman 2004; Wagner and Leydesdorff 2004; Wagner 2005; Wagner and Leydesdorff 2005a) has become a popular approach to mapping relationships among scientific collaborators, still using co-authorships. A plethora of mapping approaches has been explored. A visualization of the networks provide insights into the dynamics, the breadth of collaborators and collaborating countries, the strength of collaborative ties, and their

connections. Time-based maps can help determine whether specific factors, such as science policies, have had an impact on the extent and growth of ISCs.

Several studies using network analysis have unequivocally demonstrated the growth of global research networks. For instance, Wagner and Leydesdorff (2005a) have demonstrated both the growth of the number of players involved and the links between players, between 1990 and 2000. The cluster created by scientifically advanced countries has expanded, and new entrants have joined regional networks. Even the smallest countries are now players in global science. Some nations (e.g., the Arab countries in the Middle East) are, however, grouped into disconnected networks from the main grouping of more advanced countries. Wagner and Leydesdorff's analysis further suggests that the global network is becoming more decentralized, with regional "hubs" emerging, a conclusion also reached by (Ganz-Brown 2000).

Even though maps of ISCs are well suited for descriptive and exploratory purposes, (Luukkonen, Tijssen *et al.* 1993), a variety of challenges has been raised. In particular, statistical analysis and resulting graphical representations or maps of collaborative networks are influenced by the set of countries included.

Wagner and Leydesdorff (2005b) applied network analysis tools to look from a different perspective at the growth of ISCs. They argue that "international collaboration in science at the sub-field level can be shown to self-organize based on rules of preferential attachment with social constraints. This suggests that the spectacular growth in

international collaborations may be due more to the dynamics created by the self-interests of individual scientists rather than to other structural, institutional or policy-related factors that have been suggested by others” (Wagner and Leydesdorff 2005b, p. 1616). Although their work is based on six case studies only and needs further testing, this perspective has policy implications for dissemination of knowledge, and organization of science.

2.1.5 Insights from Bibliometric Studies of ISCs

It is apparent from the preceding discussions that bibliometric studies are contributing to the enhancement of our understanding of ISCs. Some of the insights gained from such studies include:

- collaboration is the rule not the exception, the majority of scientific research is collaborative (Smith and Katz 2000). One of the major characteristics of modern science is the increasing amount of scientific cooperation, and the parallel increase in the amount of that cooperation which is international. This trend is also apparent in institutional co-authorship. Further, the scientific and technological communities are quantitatively linked by the dependence of modern technology upon modern science (Narin 1991);
- measurements of ISCs over the past 20 years demonstrate an intensifying collaboration for all fields and at all level of aggregation (Persson, Glänzel *et al.* 2004), and for most countries of the world, the exception being countries in the Middle East (Wagner and Leydesdorff 2005a);

- ISCs are highly concentrated in a few science-producing countries – the U.S., European countries, Canada, Japan, Australia and Israel. Some, however, believe that we might be drifting toward three separate scientific zones: U.S., European, and an Asian bloc centered around China (Ganz-Brown 2000), leaving out single mid-range countries e.g., Canada, Australia and Israel;
- multiple institution papers and papers co-authored at the international level are more highly cited than other papers (Narin 1991; Luukkonen, Persson *et al.* 1992; Katz and Martin 1997; Katz and Hicks 1997). Sole author papers appear to be in the minority and have less impact (Katz and Hicks 1997), yet Beaver (2001) believes that there is a persistence of prestige of single-author publications;
- experimentalists tend to collaborate more than theoreticians. Collaboration is particularly common in experimental research involving the use of large or complex instrumentation, such as telescopes, particle accelerators or CT scanners (Smith and Katz 2000).

Of particular relevance to this research are the following insights:

- Zitt, Bassecoulard *et al.* (2000) found strong geographic linkages in science. For instance, being a dominant country in the international scientific arena, the U.S. interacts actively with a substantial number of countries – Canada, the UK, Germany, France and Japan. The comparison of profiles over ten years (1986-1996) reveals a remarkably stable landscape even though the total number of partners has increased for each country and the amount of ISCs has roughly doubled for these countries. The stability of country-profiles over the period suggests a permanence of factors,

such as the influence of “proximity” between countries, either physical proximity or proximity stemming from cultural affinity and socio-economic factors, determining international collaborative behaviours. They conclude that the area of political and cultural influence is probably still the most accurate predictor of scientific networking in these five countries;

- the extent of ISCs is strongly country and field specific and collaborations take different forms based on the field of the collaborators. Big science tends to dominate international co-authorship, particularly the fields of physics, earth and space sciences, mathematics, and biomedical research (Moed, De Bruin *et al.* 1991; Ganz-Brown 2000; Melin 2000);
- social factors e.g., geopolitical aspects, history, language, and even cultural tradition, seem to be important influences on the collaborative patterns of individual countries at the macro level (Luukkonen, Persson *et al.* 1992; Zitt, Bassecoulard *et al.* 2000). These findings suggest that social factors are affecting the selection of partners.

In summary, bibliometric studies have shown that ISCs are increasing, the scientific network is growing, and the global science system is becoming more integrated (Wagner 2005b). Further, how a country is perceived and the impact of its positioning in the global scientific network on participation in ISCs are important questions.

For science policy makers, bibliometric studies are important for policy decisions and measurement of impacts. History has shown that no one nation or civilization remains the center of creativity and activity for long, but rather that there is a transition of

leadership of S&T over time (Beaver 2001). Although some believe that there is a global spread of international research, others cite data that point to the fact that this spread is far from uniform. The expansion of ISCs may be country-specific and the scientific world might be fragmenting rather than globalizing. Data also suggest that new centers of activity and patterns are evolving in the increased international collaboration (Ganz-Brown 2000). This is therefore an important area of research since who is 'in' may depend on how countries are viewed. Clearly, there are gaps in our understanding of the dynamics of such collaborations at the global level. Our knowledge and insight into the effective and successful management of large-scale ISCs is still limited and evolving.

2.1.6 Importance of ISCs to Canada

Scientific advances lead to innovation. A theoretical link between innovation and economic growth has been contemplated at an intuitive level since at least 1776 when Adam Smith articulated the productivity gains from specialization, followed by Robert Solow's neoclassical model in 1957. It is now well accepted that innovation and R&D are positively associated with productivity growth (OECD 2003b).

Knowledge is considered by many the most valuable resource in the modern economy, with learning the most important social process. The capacity of individuals, firms, regions and nations to tap into a rapidly expanding knowledge frontier and to learn and adapt to rapidly changing economic circumstances determines their future economic success in the global economy (Lundvall and Borrás 1998 in Wolfe and Creutzberg 2003).

Advancement of knowledge, economic development, and policy and program development are considered three key drivers of international S&T (Hickling Arthurs Low 2003). As Canada produces less than five percent of the world's scientific output (Unesco 1999), it is imperative to tap into the knowledge of others globally, and ISCs are one of several ways to do so. Therefore, "the Canadian Way" (Government of Canada 2006) of pursuing scientific research is founded on partnerships, networks and excellence. Out of the more than 27,000 scientific papers published by Canadians in 2003, approximately 42% were produced in partnerships with scientists in other countries, up from 28% in 1993. The majority of these papers were published with U.S. researchers (Government of Canada 2006).

As scientific collaborations are growing in scope, scale, and geographic areas, Canada and Canadian scientists have to compete with other scientifically advanced and emerging countries to attract attention. Recently, the Government of Canada (2007) undertook an extensive review of its strengths and challenges in order to develop its new S&T strategy. This new S&T strategy, *Mobilizing Science and Technology to Canada's Advantage*, states "The Government of Canada will support S&T collaborations involving the business, academic, and public sectors, at home and abroad. Partnerships are essential to lever Canadian efforts into world class successes and to accelerate the pace of discovery and commercialization in Canada. Through partnerships, the unique capabilities, interests, and resources of various and varied stakeholders can be brought together to deliver better outcomes" (Government of Canada 2007, p. 11). In its strategy, the Canadian government also recognizes the need to mobilize science and technology for

long-term economic and social advantages: “Scientific discoveries and new technologies are providing solutions to many of the issues most important to Canadians. They are giving us the knowledge and the means to improve the quality of our environment, protect endangered species, improve our health, enhance public safety and security, and manage our natural resources. S&T comes into play in virtually all aspects of our lives, helping us to solve problems and create opportunities” (Government of Canada 2007, p. 21). It therefore highlights the link between scientific and technological innovations and competitiveness and productivity for a higher standard of living and better quality of life.

The crucial importance of ISCs is emphasized: “As the approach to science becomes more multidisciplinary and S&T capacity more widely distributed, the government is increasingly drawing on research expertise in universities and business across Canada and internationally. Science-based departments and agencies are already engaged in and actively pursuing new collaborative opportunities. The Government of Canada plays an important role facilitating domestic and international partnerships among researchers, industries, and others to improve the speed with which advanced knowledge can be generated, tapped, and applied to solve problems and create opportunities. Strategic international and inter-sectoral collaboration among governments, researchers, industry, and investors is pointing the way toward new approaches to positioning Canada as a global R&D and innovation leader” (Government of Canada 2007, p. 41).

2.1.7 Canada's Mechanisms to Participate in ISCs

Canada maintains active S&T agreements with foreign countries through a variety of mechanisms. At the highest level are treaties between countries, which are legally binding agreements by international law between two countries. Canada currently has six Science & Technology (S&T) treaties; with Japan, France, Germany, Europe, India and with China. The Canada-Japan agreement celebrated its twentieth anniversary in 2007, while the Canada-India and the Canada-China agreements were only recently signed, in 2005 and 2007 respectively.

The term agreement is generally used by other countries rather than treaty, e.g., the International Science and Technology Agreement (ISTA) used in the U.S. Interestingly, the U.S. and Canada, the tightest and most complex bond in international science, do not have a formal ISTA, indicative of the fact that ISTAs may actually be an indicator of divergence in scientific culture between the signatories rather than of convergence (Wagner 2002). An S&T treaty is an umbrella agreement that shapes the overall S&T relationships between two countries. Some agreements are never fully implemented because of a lack of funds from one or both signatories. Two countries can also set up an international arrangement, also called a Memorandum of Understanding (MOU), a less-onerous and non-legally binding document. Canada has such an arrangement with Korea.

At the institution level, government departments can sign MOUs with foreign research institutions. There are currently more than 500 bilateral or multilateral S&T arrangements in place between Canadian federal and provincial government departments and counterparts in other countries. For example, the National Research Council of Canada

(NRC) has more than 100 formal MOUs for international research collaborations (National Research Council 2005).

Laboratories can sign less formal documents, such as a Memorandum of Collaboration, with foreign institutions. At the scientist level, there are many formal and informal collaborations and exchanges (post-doctoral fellows, sabbaticals) that may develop into larger, multi-partner international collaborations. These collaborations can be stand-alone or fall under specific formal umbrella agreements between Canadian and foreign research institutions or between countries.

The scientific field and the type of research can also dictate the mechanism for collaboration. For instance, the field of metrology (the scientific study of measurement) operates under an international treaty (The Meter Convention, since 1875). Therefore in this field, National Metrology Institutes (NMIs) collaborate among themselves to demonstrate equivalence to international measurement standards among trading economies, and traceability to national standards. There are also bilateral or trilateral collaborations for specific measurement projects.

Drawing up documentation related to the governance of the ISC – the statutes, rules and procedures by which the collaboration will be established, operated and terminated – including a sound managerial framework and decision-making processes, can be a prolonged process involving detailed consultation between partners and advice from external experts (OECD 2003a). The challenge to governments and scientists is to craft

a resilient, credible, international framework for the support of megascience (Ratchford and Colombo 1996).

2.2 Motives for and Desired Benefits from ISCs

The general context of ISCs was discussed in section 2.1. From this discussion, it becomes apparent that a significant stream of research has been conducted to describe and analyse overall issues of ISCs. There is, however, considerably less research concerning the reasons for collaboration and the processes at work. In this section, motives and desired benefits driving the formation of ISCs are explored.

2.2.1 Motives for ISCs

The motivations for ISCs are varied, complex and often inter-related (Carayannis and Laget 2004). The various theories underpinning the strategic alliance literature, although generally related to interfirm alliances, is of particular interest for the study of ISCs as they each bring a different perspective on the motivation of parties to enter into collaboration.

According to Varadarajan and Cunningham (1995) who synthesized the conceptual foundations of strategic alliances, the various theoretical frameworks underpinning strategic alliances are:

- the transaction cost theory (Williamson 1975). Transaction cost analysis (TCA) (Williamson, 1975, 1979, 1981, 1985) provides a market failure and efficiency approach to organizations in which the unit of analysis is the exchange

transaction between organizations. It is based on the single economic factor of transaction cost minimization and hence, not particularly relevant to the context of ISCs;

- The resource-dependency theory (Pfeffer and Salancik 1978). This theory is based on the premise that few organizations are self-sufficient with respect to critical resources, that firms are heterogeneous with asymmetric abilities to develop or acquire resources, and that this lack of self-sufficiency leads to dependence on other firms and introduces uncertainty into the firm's decision-making environment. A major implication of the resource dependency theory is the identification of dependence and uncertainty as the key antecedent variables underlying the formation of interfirm relationships;
- institutional economies (Oliver 1990). Oliver lists six factors or motives for relationship formation. The first one, the necessity factor, which refers to the legal or regulatory requirements governing business, is the only one used to explain why firms are mandated into relationship formation. The second is asymmetry, which refers to the fact that firms have different resources and abilities that are not shared equally among them. The third one, reciprocity, explains the motivation of firms to seek control over resources through cooperation and collaboration rather than through domination. The fourth one, efficiency, reflects the desire to reduce costs. The fifth one, stability, come into play when firms seek to adapt to uncertain environments. Finally, legitimacy aims to enhance an organization's stability to comply with prevailing norms or improves its reputation and image;

- The resource-based view of the firms (RBV) argues that firms possess resources that enable them to achieve competitive advantage and superior long-term performance. According to Barney (1991), a resource must have four attributes to have the potential of providing sustained competitive advantages: valuable, rarity, imperfectly imitable, and without strategically equivalent substitutes. Resources that are valuable and rare can lead to the creation of competitive advantage. That advantage can be sustained over longer time periods to the extent that the firm is able to protect against resource imitation or substitution. Understanding sources of sustained competitive advantage is a major area of strategic management research. An extension of the resource-based view, the relational view, maintains that competitive advantage derives not solely from firm-level resources but also from difficult-to-imitate capabilities embedded in dyadic and network relationships (Dyer and Singh 1998).

Varadarajan and Cunningham (1995) conclude that given their overlapping nature, it may be more appropriate to view the various theoretical explanations of strategic alliances as complementing explanations rather than as competing explanations of the strategic alliance phenomenon and their value. Taken together, these theoretical frameworks suggest that market uncertainty, the drive for increased efficiency, resource dependency, skill and resource heterogeneity, and imperfect factor markets drive firms to form alliances in their quest for competitive advantage.

It is useful to categorize the motives for forming ISCs, as highlighted in the strategic alliance literature, as having one of two ends:

1) to overcome obstacles:

- cost sharing – to share large, expensive and sophisticated facilities such as in astrophysics; to access equipment, resources, and unique materials; to improve access to funds (Melin 2000; Beaver 2001),
- risk-sharing – to make progress more rapidly and to find flaws more efficiently (Beaver 2001),
- efficiencies – division of labour and to make progress more rapidly (Beaver 2001),
- scientific isolation – to surmount intellectual isolation, especially for scientists who come from scientifically peripheral countries; for shared interest and personal chemistry (Melin 2000); to get to know people and to create a network; for fun, amusement and pleasure (Beaver 2001).

2) to improve results:

- knowledge sharing – to share ideas and to convey tacit knowledge and knowledge of technique; to gain experience or to train apprentice researchers (Price 1963; Beaver and Rosen 1978; Luukkonen, Persson *et al.* 1992; Beaver 2001); to advance knowledge and learning (Smith and Katz 2000); to improve productivity and avoid competition (Beaver 2001),
- complementarity of expertise given the growth of interdisciplinary research (Smith and Katz 2000),

- broader research context – to tackle more challenging problems,
- emergence of new scientific fields – to address complex issues requiring highly specialized expertise and the convergence of fields, for example biotechnologies with information technologies (Beaver and Rosen 1978; Price 1986),
- national prestige – to increase visibility and recognition, and to associate with the scientific elite (Luukkonen, Persson *et al.* 1992).

Furthermore, political agendas and government programs aimed at promoting ISCs influence ISCs in ways that should not be underestimated. An example is the U.S. funding of cooperation with Russia for foreign policy driven missions, such as retraining former Russian weapons scientists to other types of scientific research (Wagner 2002). Another influence raised in the literature is the scientists' reward system. Even though collaboration plays an important role in research work, it has not as yet changed the reward mechanisms of the scientific communities, which remain purely individual-oriented. In the world of science, rewards are primarily in terms of recognition (e.g., citations, prizes) and resources (e.g., research grants, endowed chairs, human resources). Other scientists may freely use knowledge generated by their predecessors as long as they give tribute to the original discoverer (Sorenson and Fleming 2004). Wagner and Leydesdorff (2004) noted that the influence of the rewards system on collaboration at the international level has not received a great deal of attention.

In summary, motives for the formation of ISCs are similar to those found by Varadarajan and Cunningham (1995) in their synthesis of strategic alliances. In particular, motives related to resource use efficiency, resource extension, risk reduction, and skills enhancement are as important for interfirm alliances as they are for ISCs.

2.2.2 Desired Benefits from ISCs

It is generally assumed that scientific collaborations produce benefits and spillover effects and that collaboration should be encouraged (Katz and Hicks 1997). Most agree that scientific collaborations make important contributions to the technological and economic well-being of nations (Mowery 1998; Wagner and Leydesdorff 2005). The value of collaboration in addressing important scientific questions is further evident in efforts by funding agencies to encourage collaboration via large initiatives and programs. Scientific collaborators are also generally positive about collaborative ventures in spite of the potentially greater transaction costs (Niks 2004). In a survey of university researchers involved in collaboration, Niks found that “Although participants acknowledged challenges, such as how much time collaborating requires, tensions arising from differing agendas and funding requirements, they recognized the many benefits” (Niks 2004, p.123).

2.2.2.1 Scientific benefits

The scientific collaboration literature extensively covers scientific benefits of ISCs, likely due to their more immediate and visible output. These include:

- new discoveries, patents,
- broader scope of research and ability to address more complex problems (Beaver 2001),

- enhanced scientific productivity using different measures of productivity. The most popular measure cited in the literature and in practice is scientific publications. For instance, Katz and Hicks (1997) found that papers involving collaboration with a foreign institution have greater impact (defined as average citations per paper) than papers with collaborations with an author from the same or another domestic institution. Bozeman (2000) noted that other measurements of the impact of research collaboration on scientific productivity, such as increments to scientific capacity and impact on scientific and S&T human capital are much less straightforward. S&T human capital is defined as the sum of scientific and technical and social knowledge, skills and resources embodied in a particular individual. In addition, he remarks that there is an underlying assumption that collaborative activity increases research productivity, yet few studies have actually tested that proposition,
- enhanced visibility and credibility (Katz and Martin 1997; Beaver 2001; Niks 2004),
- increased efficiency and effectiveness, performance, synergy, flexibility (Liebeskind, Qliver *et al.* 1996; Beaver 2001),
- access to data, a growing body of knowledge, richer knowledge, knowledge transfer, especially tacit knowledge, interorganizational learning, training of graduate students (Katz and Martin 1997; Melin 2000; Niks 2004; Cummings and Kiesler 2005; Huxham and Hibbert 2005),
- a source of stimulation and creativity, of cross-fertilisation of ideas and “intellectual companionship” (Katz and Martin 1997), higher scientific quality and accuracy as errors are more readily detected when several different individuals with different

perspectives discuss data and/or theory, hence reducing risk and increasing chances of success (Beaver 2001),

- access to unique resources and access to a wider network of human capital (Katz and Martin 1997; Melin 2000; Wagner, Staheli *et al.* 2002; Agrawal, Cockburn *et al.* 2003; Mahroum 2005). Worth noting, Agrawal, Cockburn *et al.* (2003) studied mobility of scientists. They found that when scientists move between locations, their social ties that facilitate knowledge transfer survive geographical separation. ISCs often include the use of graduate and post-doctoral students. Therefore, nations that participate in ISCs are able to attract and retain the highly trained scientists that are drawn to such opportunities. In his review of research and theory on technology transfer, Bozeman (2000) points out the value-added of students as knowledge transfer agents and their enduring links as the social glue holding together many faculty scientists, government laboratories, and the firms they work with.

Not surprisingly, these benefits exhibit considerable overlap with the previous list of motives to engage in ISCs. Moreover, many of these benefits are interconnected and interdependent. Differences in the scope and breadth of benefits accruing from small ISCs versus larger-scales ISCs have not been explicitly explored in the literature.

2.2.2.2 *Political benefits*

A broad range of direct and indirect political benefits can be derived from ISCs. A challenge, of course, is the definition of political benefits. In the context of large-scale ISCs, such benefits generally refer to gains of national importance. Among them:

- leverage of national research funding and new perspectives on science informing S&T policies and priorities (Wagner, Staheli *et al.* 2002),
- enhanced public goods (Nelson 2006). For instance, knowledge is considered a global public good,
- S&T capacity building in developing countries. Several developed countries have set specific investment benchmarks in ISCs with developing country partners. Under the previous federal government, Canada had set a target of 5% of Canadian federal R&D expenditures to help meet the challenges of the developing world. This is an ambitious goal given that currently, at 2.8% of federal R&D expenditures, Canada has one of the lowest rates of expenditures in ISCs with developing countries. Therefore, such collaboration would have to be mutually beneficial in order to favour sustainable development (Government of Canada 2005),
- to inform and excite the public about science and to inspire the next generation of young scientists as well as to build trust and confidence in the broader public towards science (CSIRO 2003).

A less obvious and perhaps elusive benefit is the impact of science on foreign policy, that is, science can be a potentially powerful tool for improving international relations. Likewise, foreign policy can impact science development by either supporting or hindering ISCs. In spite of the fundamentally different dynamics between science and foreign policy, increasing overlaps and convergence are emerging. Most funding for science is provided by governments and spent within national borders and projects, such

as the International Space Station and Arctic Research, but still creates both international and national political goodwill (Wagner 2002).

2.2.2.3 Benefits of a science-based country image

Some of the beneficial aspects of ISCs enhance the scientific image of a country. For instance:

- active involvement in ISCs can enhance the visibility of a country,
- successful ISCs are responsive to national goals. Wagner, Staheli *et al.* (2002) drew lessons from successful ISCs via four extensive case studies involving Canada, Japan, Korea, and countries of the EU. An important finding was that “government support for ISC was most successful when it was responsive and accountable to scientific and national goals” (Wagner, Staheli *et al.* 2002, p. 43). In this sense, the authors highlight the importance for policy makers considering ISCs to articulate political benefits that will accrue from participation, in addition to the scientific benefits,
- a leadership role in major international science facilities is often both an indication, as well as a result of being the world’s best in a science domain. Such facilities attract hundreds of millions of dollars of direct investment as well as increased resources and opportunities. The reputation for being absolutely the world’s best further enhances the quality of an organisation (CSIRO 2003).

2.2.2.4 Industry spillover effects

Benefits that accrue to collaborating firms are extensively covered in the R&D collaboration literature on interfirm collaboration and in the strategic alliance literature. A recent study of particular relevance to ISCs is that of Van Looy, Debackere *et al.* (2006) who performed a bibliometric analysis to examine the relationship between national

scientific capabilities and technological productivity within six emergent industrial fields. They reported that countries performing better on a technological level are characterized both by larger numbers of publications and by numbers of involved institutions (private and public), suggesting beneficial effects of scientific capabilities shouldered by a multitude of organizations.

Hagedoorn, Cloudt *et al.* (2005) empirically studied the effects of R&D network ties strength on technological performance of high-tech industries using three thousand R&D partnerships in four high-tech industries (pharmaceuticals, computers, semiconductors, and telecom) during the period 1990-2001. They found that “companies with well-embedded R&D network ties, characterized by solid, reciprocal, dense, and long-term trustworthy relationships do seem to benefit from the network externalities created by their R&D partnerships with a variety of companies” (Hagedoorn, Cloudt *et al.* 2005, p. 25). The authors highlighted the importance of internationally diverse knowledge sourcing to these high-tech industries. Similar findings are reported in Contractor, Kim *et al.* (2002) on the international pharmaceutical and chemical industries, where international R&D alliances yield higher innovative returns than domestic alliances.

The literature review did not uncover specific theoretical or empirical studies of spillover effects of large-scale ISCs to industry, especially from public research laboratories, with the notable exception of Autio, Hameri *et al.* (2004). Using a case study approach, Autio, Hameri *et al.* (2004) researched the industrial knowledge benefits accruing to three private sector suppliers in the construction of the Large Hadron Collider (LHC) project at

CERN. The LHC is the largest particle accelerator in the world. Building on the social capital framework of Nahapiet and Ghoshal (1998), the case evidence gave rise to 24 empirically testable theoretical propositions. The study focused on the theoretical framework to explain why and how big-science centers might operate as learning environments for their industrial supplier companies, but it is limited to the context of CERN. Important insights were raised in the area of benefits to firms collaborating with big-science centres from knowledge networks, knowledge spillovers, and technological learning.

Kaufmann and Tödtling (2001) studied the importance of systemic diversity for innovation. Analyzing innovation systems of several European regions, they found that linking firms to non-business systems enhances the potential for innovation in general, and for radical innovation in particular. It is believed that private industry can benefit at various stages of ISCs, both upstream as a collaborator and downstream with the development and commercialization of intellectual property generated from the collaborations. Indeed, many ISCs involve the development of new technologies that may create strategic opportunities for the industries involved. For instance, in the case study mentioned above, the highly specialized magnets required for the Large Hadron Collider at CERN and supplied by ALSTOM Canada opened the doors to new industrial capabilities for that company (Autio, Hameri *et al.* 2004).

Three other lines of inquiry about potential benefits from ISCs are believed to be of particular interest to science policy makers and scientists but are currently lacking in the literature:

- whether ISCs can help firms gain access to foreign markets as suggested in the strategic alliance literature,
- the potential spillover benefits of country image as a science leader to the profile of the country's industry as innovative,
- to what extent are the findings from Hagedoorn, Cloudt *et al.* (2005) on effects of R&D network ties strength on technological performance of high-tech industries applicable to industries involved in large-scale ISCs.

2.3 Formation of ISCs: Partner Search and Selection Criteria

Having identified the need to collaborate, scientific collaborators or partners must be identified. Systematic partner search is emphasized in the literature as one of the key conditions for successful alliances (Kuada 2002; Overby 2005). The resource-based view claims that access to strong resources forms the basis of competitive advantage (Dyer and Singh 1998) and collaborative advantage (Huxham and Hibbert 2005). This section will examine selection criteria for scientific partners by exploring both relevant country characteristics of partners and people characteristics of partners and their scientists.

2.3.1 Country Characteristics

The characteristics of a country can be expected to be of significant importance in the selection of scientific partners in increasingly larger scale ISCs. These characteristics can

be explored by drawing from several streams of literature, particularly the strategic alliance literature, the country image literature, and the national innovation system literature.

2.3.1.1 Characteristics from the strategic alliance literature

The strategic alliance literature covers interorganizational cooperative strategies, marketing alliances, research and development alliances, and international alliances. This stream of literature is well established and has extensively covered motives, formation, operation and issues. Moreover, and building on the resource-based view (RBV), more recent strategic management literature emphasizes a relational or relationship-centered view of interorganizational exchange relationships (Madhok 1995a,b; Dyer and Singh 1998; Madhok 2005). An integrative perspective of the various theoretical frameworks underpinning alliances has evolved in the literature over the years.

Given the newer emphasis on the relationship-centered view, the concept of social exchange is relevant to the study of ISCs. According to social exchange theory, people engage in social exchanges because of scarcity of resources, with the expectation to increase resources through the exchange. Therefore, social exchange allows parties to exchange those resources that are difficult to obtain through economic exchange, hence its link to the resource-based view. Drawing from the sociology literature, social exchange is defined as “voluntary actions of individuals that are motivated by the returns they are expected to bring and typically, in fact, bring from others” (Blau 1964 in Das and Teng 2002). Social exchange is less formal and more uncertain than economic

exchange. Social exchange theory has been applied at the individual, organizational, and interorganizational levels. Believing that social exchange plays a prominent role in strategic alliances, Das and Teng (2002) have attempted to develop a more general social exchange-based theory of alliances by contrasting social exchange theory with transaction cost economics and the resource-based view in examining major processes within strategic alliances, that is, formation, operation, and structure. Specifically, they used strategic emphasis and relative importance of social exchange as two determining factors to construct a typology of various kinds of alliances. The focus of their research was on one-to-one relationships in dyadic alliances. Das and Teng (2002) concluded that "...while economic exchange tends to be more efficient with tangible resources (e.g., physical and financial resources), social exchange is more effective with intangible resources (e.g., reputation and know how)" (Das and Teng 2002, p. 457). However, social exchange theory has not been systematically applied to alliances in general and in particular alliances involving multiple organizations.

Strategic alliances entail the pooling of specific resources and skills by partners to achieve common goals (Varadarajan and Cunningham 1995). Therefore, the ability of any actor to join distributed collaborative projects depends largely on their attractiveness as a partner (Wagner 2005a). Kuada (2002) raised the following attractiveness factors as important in the selection process of joint venture partners: financial resources, technology, international experience, complementarity of resources and management styles. He acknowledged that these factors may be of varying importance to firms in different industries, in different countries, and with different ownership policies.

A number of theories, including the resource-based view, resource dependence, and transaction cost analysis, recognize the importance of reputation for organizations for partner selection. Reputation and credibility are considered especially important factors in the selection of collaborators, with research team reputation being a key element in securing access to facilities and equipment (Smith and Katz 2000). Reputational information, i.e., signals that individuals interpret, is a proxy and sometimes a substitute for experiential information used by decision makers in deciding with whom to collaborate (Andersen and Sorensen 1999). A positive reputation can reduce the search for a partner (a transaction cost perspective), and is considered a valuable intangible asset (a resource-based perspective) (Saxton 1997). The concept of reputational information in relation to decision makers' choice of interorganizational partners has been investigated (Andersen and Sorensen 1999; Christiansen and Vendeke 2003). Andersen and Sorensen (1999) in particular have argued that reputational information plays an important role in the development of a person's image of another person, a situation or a firm. Thus, a positive reputation means that others see the probability of opportunistic behaviour as less likely (Buckley and Casson 1988).

Overall, there is limited coverage of the role of reputation and reputation building in ISCs, with the exception of Christiansen and Vendeke (2003) who included the role of reputation building in their empirical study of factors and effectiveness measures in interorganizational R&D projects. They concluded that reputation building is an important factor in R&D collaboration among partners with little or no prior knowledge of each other. However, it must be kept in mind that this was a small study of only six

Danish firms. In the context of ISCs, elements of reputation would include knowledge, equipment and facilities, collaborative behaviour, and scientific productivity.

In summary, literature on partner selection in dyadic arrangements, such as interfirm strategic alliances and joint ventures, is well developed. However, there is limited work on the selection of participating countries in large-scale ISCs. Little research has focused on who scientists or science organizations should partner with to effectively conduct research and derive desired benefits (Overby 2005). Country characteristics derived from the strategic alliance literature and believed important in ISCs would include: technology level, complementarity of resources, financial resources, and reputation.

2.3.1.2 Characteristics from the country image literature

The influence of the image of a country, including those related to reputation, cannot be ignored in the selection of foreign scientific collaborators. An image is a mental picture used to summarize complex information. It can be defined as “a collection and judgment of both intrinsic and extrinsic attributes of objects and classes of objects” (Papadopoulos and Heslop 1992). Numerous studies have demonstrated the impact of a country image and reputation on several types of decisions involving international business and consumers, buyers, and investors concerning whether or not to engage directly or indirectly with those in other countries (often termed country-image effects or country-of-origin effects). Papadopoulos and Heslop (2000) studied the international competitiveness of Canadian products from the point of view of foreign consumers and found that despite Canada’s strong country image, Canadian products seem to be losing ground in terms of buyers’ mind share. They also reported in a study in 1993 that Canada

was not viewed as a country with significant depth in technology products and processes (Heslop and Papadopoulos 1993). Despite the critical importance of this field of research, there has been no recent research.

The country-image effect has been studied to a lesser extent in industrial settings compared to the research on consumers. However, research on both consumer and industrial buyers and also on international business investors (Papadopoulos and Heslop 2001) overwhelmingly concludes that country-of-origin images influence decision-making processes.

Country image is emerging as a critical feature in the global arena. Geographic regions, including countries, cities and regions, can be branded to make people aware of the location and to link desirable associations to attract tourists, consumers, immigrants and businesses (Keller 2003). The image of a country as projected to the world at large can also affect the population of that country. Anholt (2002) claims that a proper national branding campaign can unite a nation into a common sense of purpose and national pride. The Anholt-GMI Nation Brands Index each quarter polls 10,000 consumers from its worldwide five million-strong market research panel on their perceptions of the culture and heritage, people, tourism, exports, governance, investment and immigration of several countries (www.nationbrandindex.com). In its most recent survey of consumers in 35 developed and developing countries, Anholt-GMI Nation Brands Index ranked Canada in third place in the overall rank order, assessing Canada as one of the world's best places to live and invest. Globally, the Canadian government is seen as politically

neutral and trustworthy. Canada ranked seventh on perceived strength in science and technology and fourth on being a good place to study. However, Canada ranked 18th in the area of culture and heritage. Canadians, as a people, have made quite a positive impression. A large part of the world's perceptions of Canada was attributed to how people feel about Canadians (Anholt 2002, 2006). In the area of product branding, the survey corroborates findings from Papadopoulos and Heslop (2000) with Canada ranking relatively low in product branding.

With internationalization, the main concern for many governments is whether their local research environments appear prominently on the international map of scientific exchanges. For instance, Mahroum (2005) analyzed factors related to what is termed the "brain drain" across OECD countries. He found that cultural barriers and the image of a country have surfaced as possible barriers to accessing scientific talent from overseas. For example, Germany is perceived as being rigid and unfriendly to foreigners. Meanwhile, the U.S. is perceived as being under constant terrorist threat. These perceptions, coupled with strict immigration control and growing suspicions towards foreign populations, may contribute negatively to the image and the reputation of the U.S. as an attractive destination for highly skilled persons. A Canadian example includes a recent small internal survey among five of the networks of the Networks of Centres of Excellence (NCE). Results shared verbally with the researcher indicated that the overarching purpose of international collaborations was to exchange knowledge and research expertise with foreign constituencies in order to enhance Canadian research but also to raise the profile of the Canadian research in an international milieu. Therefore, an

important objective of this current research is to explore the concept of both cognitive and affective aspects of country image relevant to partner selection for ISCs.

2.3.1.3 National innovation systems and country image

The literature on national innovation systems (NIS) emphasizes the interconnectedness between principal actors of a nation i.e., firms, public and private research organizations, government and other public institutions, along with the forms, quality and intensity of these interactions. A national system of innovation is defined as a set of institutions, which jointly and individually contribute to the development and diffusion of new technologies and provide a framework for the implementation of government policies influencing the innovation process (Metcalf 1995; Wolfe and Gertler 2003). Central to this literature is the generation, diffusion and use of knowledge, hence its relevance to ISCs.

The national innovative capacity, a crucial element of any national innovation system, is the ability of a country to produce and commercialize a flow of innovative technology over the long term. This ability depends on the strength of a nation's common innovation infrastructure, the environment for innovation in its leading industrial clusters, and the strength of linkages between these two areas (Porter, Stern *et al.* 2000). Dimensions of a common innovation infrastructure include investment in basic research, tax policies, supply of risk capital, aggregate level of education in the population, pool of talent in S&T, information and communication infrastructure, protection of IP, openness to international trade and investment, and overall sophistication of demand.

Carayannis and Laget (2004) note that knowledge specialization is a key feature which differentiates one country's specific national innovation system from those in other countries. Certain nations, especially smaller nations, may show a bias in their production of knowledge and technologies towards certain areas of innovation as a means of more strategically managing the limited resources available to their national innovation systems. Reinforcing this viewpoint, Wagner and Leydesdorff (2004) noted that scientifically advanced nations invest in a portfolio of research by balancing scientific opportunity and national need with expectations of social and economic returns. Furthermore, bibliometric data confirms that patterns of scientific strengths and weaknesses are strongly influenced by the nature of the societal and technological problems to be solved (Pavitt 1998). This line of thought points to the importance of a strong national science policy for relevant scientific investments.

There is an increasing interest by science policy makers in ISCs (Moed, De Bruin *et al.* 1991; Katz and Hicks 1997), as evidenced by the relatively recent explosion of initiatives aimed at promoting and supporting ISCs. Governments of most scientifically advanced countries spend between five and twenty percent of the science budgets on international science (Wagner 2002). Some examples of international science include funding initiatives by agencies such as the National Science Foundation (NSF) in the U.S., the Framework Programmes in the EU (Cummings and Kiesler 2005), the Canadian Institute for Health Research (CIHR) and the National Science and Engineering Research Council (NSERC) in Canada. Researchers have been trying to assess the benefits and issues of such science policies related to funding international science. On the benefit side,

Wagner and Leydesdorff (2005a) has shown evidence of effects of political influences and special programs on networks of ISCs. For instance, the policy of ISC of the EU is influencing the growth of the network in that region. Other examples are special development aid programs between Scandinavian countries and Latin American and African countries that may help explain the links appearing among these countries. Looking at funding of ISCs, Cummings and Kiesler (2005) conducted a study of 62 scientific collaborations supported by a program of the U.S. NSF and found the following three main funding related issues: the lack of long term funding, the practice of encouraging a funding target and then cutting budgets, and the lack of budget to support infrastructure for ISCs.

Foreign policy and science policy are operating in an increasingly overlapping international space as foreign policy faces issues with a scientific component. Examples of global issues requiring both types of policy include genetically modified organisms (GMO), stem cell research, global security, and climate change. Better coordination among science-policy makers across nations may be beneficial to all parties to help the governance of controversial international science issues. An example of a coordination group is the Global Science Forum of the OECD. The Global Science Forum brings together science policy officials from OECD countries. The delegates seek to identify and maximise opportunities for international cooperation in basic scientific research (Wagner 2002; Wagner, Staheli *et al.* 2002)

Large-scale ISCs are increasingly carried out through distributed global collaborations and supported by collaboratory technologies. Therefore, a feature of such collaborative scientific enterprises is that they will require access to very large data collections, very large-scale computing resources and high performance visualisation technologies. Cyberinfrastructure refers to infrastructure based upon distributed computer, information and communication technology. It has been defined by the NSF as a tool for building digital environments that support collaboration and interaction among people, data, information, and tools. Cyberinfrastructure is believed to be to the *knowledge* economy what infrastructure was to an *industrial* economy. Other terminologies for cyberinfrastructure-enabled environments include grid community/network, computer-mediated telecommunications infrastructure, virtual science community, and e-science community (David 2004). Examples of cyberinfrastructure include the Network for Earthquake Engineering Simulation (NEES), the Grid Physics Network (GriPhyN), and the Space Physics and Aeronomy (the branch of science concerned with the properties of the upper atmosphere) Research Collaboratory (SPARC) in the U.S. (Atkins, Droegemeier *et al.* 2003). In Canada, an example would be the project NEPTUNE mentioned before. The extent and quality of a country's cyberinfrastructure can then be considered as important as the traditional brick-and-mortar scientific infrastructure.

Drawing from the NIS literature, elements of NIS that influence country image can be grouped under the following key characteristics of resources, processes and people:

Resources:

- scientific infrastructure,
- cyberinfrastructure,

- scientific talent,
- education and training system,
- supporting institutions,
- networks.

Processes:

- government funding,
- macroeconomic and regulatory context,
- supportive government policies: science policy and foreign policy.

People (covered in the next section):

- open,
- trustworthy,
- tolerant,
- culturally similar.

In summary, there is no specific research on factors affecting the choice of country partners for ISCs, including country image and its impact on international scientific collaborations. Yet the attractiveness of a country as a scientific partner —its citizens and scientists, its collaborative reputation, and other determinants such as science policy, scientific capacity, infrastructure, education system, even its foreign policy – are part and parcel of a country image. Given the global nature of science and strong emergent players such as China, India and Brazil, a relatively small country like Canada may find it difficult to attract international scientific partners. Consequently, if it pays insufficient attention to its international image among science managers in universities, government and the private sector, Canada may be reduced to insignificance in the science arena, despite several strong areas of world-class research.

2.3.2 People Characteristics

This section will explore characteristics of people of a country and its scientific community that would appear desirable in selection of ISC partners, drawing from three streams of literature: 1) social network theory; 2) trust; and, 3) social capital.

2.3.2.1 Perspective from social network theory

An institution and its researchers do not work in isolation but within broad and extensive research networks. Social network, first coined in 1954 by J.A. Barnes, is a structure among actors, mostly individuals or organizations, indicating the ways in which they are connected through various social familiarities. According to social network theory, a network is a set of social system members or nodes connected by links or ties that indicate the relationships (or lack of relationships) among them. Bridging refers to external relations, whereas bonding refers to internal ties (Adler and Kwon 2002).

Liebeskind, Oliver *et al.* (1996) define a social network as “a collectivity of individuals among whom exchanges take place that are supported only by shared norms of trustworthy behaviour.” Studying sourcing of scientific knowledge of two highly successful new biotechnology firms through social networks, they found that the use of boundary-spanning social networks increased both the learning and flexibility of the firms in ways that would not be possible within a self-contained hierarchical organization. For example, with business firms, Blakenburg Holm and Eriksson (2000) in Chetty and Patterson (2002) cite bridgehead relationships involving firms tapping into the networks of their current business partners to expand their own business networks. Through bridgehead relationships, the crucial trust-building phase of a new relationship

may be reduced as the new member gains a level of credibility due to the already established reputation with a common partner. McEvily, Perrone *et al.* (2003) talk of trust transfer, in which trust in a third party serves as a proxy for trust in the unknown counterpart.

A social network is a broad concept that has been extensively covered in the general business literature and, in particular, in the strategic alliance, entrepreneurship, innovation, interorganizational learning, organizational studies, social capital, and research collaboration literature (Buckley 1988; Liebeskind, Oliver *et al.* 1996; Kogut 2000; Adler and Kwon 2002; Contractor and Lorange 2002a,b). In a recent study of micro level of research collaboration through a survey of 195 Swedish university researchers, Melin (2000) noted that almost all of the informants emphasized the importance of networks in one way or another.

Embeddedness is an important concept in the network approach. Embeddedness refers to organizations' relations with and dependence on various types of networks. Halinen and Tornroos (1998) defined the dimensions of embeddedness as temporal - past, present and future; spatial - location and organisation of activities; and representational - members representing their country, industry or firm to other network members. Fletcher and Barrett (2001) and Halinen and Tornroos (1998) maintain that examining networks in the context of embeddedness allows the study of the evolution of such relationships between the major actors over time – how relationships are formed, maintained, and broken.

Central to the social network theory is the concept of tie strengths (Granovetter 1973). Granovetter analyzed network ties in terms of a movement along a continuum from weak to strong ties. This continuum is a function of the amount of time, emotional intensity, intimacy, and reciprocity within a relationship between network actors, as well as the degree of similarity or dissimilarity of social circles. Granovetter's basic argument is that a weak tie generates more relevant new information to a network actor than a strong tie. The rationale is that strong ties may lead to a high degree of redundancy, while individuals or firms connected by weak ties are more likely to be dissimilar because they are not embedded in the same interconnected network of partnerships that are, to some extent, shaped by similarities. This exposure to different approaches and new perspectives can enhance important innovative skills, such as the ability to generate technological alternatives, to engage in flexible thinking, and to find unexpected knowledge spillovers (Liebeskind, Oliver *et al.* 1996; Hagedoorn, Cloudt *et al.* 2005).

The strength of ties is, however, a topic of debate. Several studies have advocated that strong ties are preferable to weak ties. The arguments are that strong ties provide a strong social environment and mutual support for network players, create relational trust and reciprocity in information exchange, information transfer and learning, and enable better adaptation to environmental changes. Only a small number of studies have concentrated specifically on the effect of strong and weak ties in an interorganizational network setting, with none specific to ISCs. Despite widespread excitement about dispersed collaboration, e.g., virtual team, eScience, and cyberinfrastructure, Cummings and Kiesler (2005) believe that there are still a number of challenges encountered by

scientists working collaboratively across institutions. In their view, theories of innovation and social networks could benefit from further understanding of how weak ties change into strong ties during the collaboration process, and how groups with comparatively weak ties can achieve innovative outcomes.

Some are advocating a mix of strength of ties for innovative outcomes. In particular, Hagedoorn, Cloudt *et al.* (2005) found that a combination of stronger and weaker R&D ties, with elements of both social embeddedness and international diversity, to be most beneficial for the technological performance of high-tech firms in the following industries: pharmaceuticals, computers, semi-conductors, and telecommunications. Others believe that contextual factors should determine the type of ties. In her bibliometric analysis of six ISCs, Wagner (2005b) found that “weak ties and shifting networks are preferable to strong ties and stable networks when the goal of an activity is to encourage new knowledge creation. Strong ties and geographically proximate collaboration results in rich communication. However, the research shows that, eventually, close collaborators begin to think alike, stifling creativity and innovation” (Wagner 2005 b, p. 22). This range of results points to the richness of the concept and the need to further study tie strength in a variety of environments such as large-scale ISCs.

On the aspect of governance structure, Gomes-Casseres (1994) believes that without some collective governance, the network may become only a disorganized collection of alliances. In his view, the structure should provide incentives for members to collaborate.

In addition, the effectiveness of the network and the fate of individual members will be influenced by how the network is governed and how control is distributed. This view is also shared by Varamaki and Vesalainen (2003) who focused on the degree of formality and decision-making style in their network management framework.

The configuration of a network structure determines the pattern of linkages among members and includes such elements as density and connectivity, features associated with flexibility and ease of information exchange. Although not central to this research, over two decades of technology evolution have led to a rich variety of computers and network tools to support ISCs and especially collaboratory forms of ISCs. Earlier in this review, the collaborative pattern of scientific collaboratory was introduced. Advances in ICT relevant to ISCs include the Internet, tools such as the Semantic Web designed to make web pages understandable by computers to enable the search of websites in a standardized ways, scientific databases in areas from atmospheric modeling to bioinformatics, and Internet-driven genomics research, to name but a few. With such advances, a significant body of knowledge has recently developed around the concept of computer-mediated communication (CMC), given that these technologies have become so central to scientific work. Fields such as particle physics and mathematics have relied on CMC for several decades (Walsh and Bayma 1996). In numerous fields new distributed-knowledge environments are becoming essential for moving to the next frontier of research. Yet, a recent report from the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure raises the lack of appreciation of social and cultural barriers, and the lack of appropriate organizational structures among a

variety of reasons for which cyberinfrastructure may not live up to the vast opportunity to create new research environments (Atkins, Droegemeier *et al.* 2003).

Several studies have explored the effects of CMC in collaboration (Walsh and Bayma 1996; Walsh, Kucker *et al.* 2000, Bhagat, Kedia *et al.* 2002, Sonnenwald 2003, Chi and Holsapple 2005). Generally, it is found that CMC has an important impact on the growth of collaboration and is facilitating more collaboration, particularly more remote collaboration. In addition, a consistent relationship between CMC use and scientific productivity has been found in the few systematic surveys of CMC use in science (Walsh 1998; Finholt 2003).

Although many studies (Gallié and Guichard 2002, Finholt 2003) have suggested that the growth of the Internet and the Web are creating more possibilities to find potential collaborators, recent research suggests that these technologies cannot be considered as a driver for the initiation of collaborations, but only as a facilitating agent (Wagner and Leydesdorff 2004). The overwhelming majority of ISCs begin with a face-to-face meeting, visibility at international conferences, workshops and other venues, highlighting the importance of direct communication and interpersonal relationships (Laudel 2001; Gallié and Guichard 2002; Finholt 2003; Cummings and Kiesler 2005; Wagner 2005). Further, technology has not yet conquered distance and the challenges of coordination (Sonnenwald 2003; Cummings and Kiesler 2005) so that scientists can effectively use one another's ideas and expertise without frequent face-to-face interaction.

Other research on CMC relates to the aspect of coordination within ISCs. Cummings and Kiesler (2005) suggest that new approaches may be required to coordination to get the work done and to foster trust in multidisciplinary projects. They based their conclusion on an assessment of the coordination mechanisms and project outcomes of 62 large-scale, multidisciplinary and multi-institutional (primarily universities) collaborations funded by the U.S. National Science Foundation (NSF). Although this research was confined to American institutions, the findings are certainly relevant to ISCs elsewhere.

In its study of best practices in ISCs, the OECD (2003a) found that a common feature of successful ISC is the emergence at an early stage of a “champion” for effective project coordination to overcome a variety of obstacles such as tensions arising from differing agendas and funding requirements. The OECD (2003a) reports that usually this would be a scientist with a background in the discipline, but more importantly, the leader must be a resilient individual who has the time, drive, tenacity, credibility, contacts, breadth of vision, and the ability to interact with the various stakeholders to see the project through. Ettorre (2000) adds awareness and openness to diversity, knowledge of how people work in groups, and being a team player. With diversity, she includes language, race, ethnicity, nationality, gender, disability, class, age and academic status. However, she acknowledges that social status of researchers and professors may differ from one society to the next. Reporting on her experience with EU ISCs, she believes that the effects of English as the dominant working language must not be underestimated. These findings raise the criticality of people characteristics in ISCs’ success.

In summary, desirable people characteristics for ISC partner selection from the social network theory, and taking into consideration the impacts of ICTs would include:

- well embedded in a variety of scientific and other networks,
- a mix of strong and weak network ties,
- willing and able to capitalize on ICT,
- strong communication skills,
- good inter-personal skills.

2.3.2.2 *Perspective from the trust literature*

An impressive body of knowledge on trust can be drawn on to apply to the study of ISCs.

At a general level trust has been defined as the *willingness to accept vulnerability based on positive expectations about another's intentions or behaviours* (Mayer, Davis *et al.* 1995). It involves both confidence in the partner's ability and faith in the partner's benign intentions (Huff and Kelley 2003). A seemingly intuitive concept, trust is, in fact, a multidimensional construct that encapsulates different levels such as individual trust, interpersonal trust, organizational (or internal) trust, external (or interorganizational) trust, "cognitive" or competence trust (related to competencies of the partners), and "emotional" or "goodwill" trust (related to intentions) (Rocco, Finholt *et al.* 2001). Further, trust includes related concepts such as trustworthiness, interdependence, and propensity to trust.

The concept of trust has been treated extensively in the business and academic literature and especially since the 1990s, with the recognition of the importance of interpersonal cooperation and teamwork in organizations and the increase in interorganizational

relationships. Trust literature of relevance to this research covers initial trust formation in new relationships (McKnight, Cummings *et al.* 1998), trust and ownership in joint ventures (Madhok 1995b; Madhok 2005), the impact of national culture on the development of trust (Doney, Cannon *et al.* 1998; Bhagat, Kedia *et al.* 2002; Huff and Kelley 2003), trust and performance (Zaheer, McEvily *et al.* 1998; Shrum, Chompalov *et al.* 2001), trust and reputation in R&D collaboration (Christiansen and Vendelev 2003), trust, proximity and ICT (Gallié and Guichard 2002), among others. McEvily, Perrone *et al.* (2003) cite the challenge of integrating the fragmented trust literature and the limited empirical research into trust in interorganizational relationships (Zaheer, Lofstrom *et al.* 2002). Without a doubt, trust is seen as a critical feature of contemporary organizational forms, such as strategic alliances, distributed groups, and knowledge-intensive organizations (McEvily, Perrone *et al.* 2003) and is seen as a “social lubricant.” Smith and Katz (2000, p. 73) note “the ultimate success factor in collaboration is mutual trust and overlapping interests rather than legal contract.” Trust as it relates to critical aspects of ISCs is discussed in the following sections.

Trust and the management of uncertainties and conflict

Fundamentally, ISCs are about knowledge creation. Given the complexity of science, a high level of uncertainty surrounds such collaborations. Therefore, trust is a fundamental prerequisite for effective international collaborations. For instance, trust is required to effectively share knowledge and to work out issues and conflicts that cannot possibly be covered in the terms of formal agreements. Trust provides a way to cope with risk or uncertainty in exchange relationships (Lane and Bachmann 1998).

Drawing from the economic, social, and organization streams of literature, advantages of trust in general, and for ISCS in particular, would include:

- reduction of transaction costs, reduction of conflict and of costs of negotiation between partners (Zaheer, McEvily *et al.* 1998),
- facilitation of interorganizational relationships (Doney, Cannon *et al.* 1998),
- facilitation of cooperation and coordination (Morgan and Hunt 1994),
- reduction of reliance on costly formal monitoring mechanisms to manage interdependence in the face of uncertainty (Kuada 2002; McEvily, Perrone *et al.* 2003),
- enhanced performance and a source of competitive advantage, increased flexibility and superior information exchange enabling greater responsiveness to environmental change,
- trust-based governance outperforming contracting or ownership as an efficacious means of coordinating economic exchange (Carson, Madhok *et al.* 2003),
- simplified decision making with trust operating like a “rule of thumb”, such that decision maker uses available information to formulate an expectation, rather than acquiring all of the relevant information to make a comprehensive, rational decision (McEvily, Perrone *et al.* 2003),
- more effective knowledge generation and dissemination (Adler 2001).

Although little researched, the downsides of trust may include:

- costs and risks of misplaced trust, as trust by itself does not guarantee trustworthy behaviour,

- systematic biases resulting in flawed judgments,
- costs involved in creating, upholding, and maintaining trust (McEvily, Perrone *et al.* 2003).

Trust, Data Sharing and Intellectual Properties Rights (IPRs)

Two areas of ISCs fraught with conflict are data sharing and Intellectual Property Rights (IPRs). ISCs are critically dependent upon effective collection, analysis and sharing of research data. Data sharing is important for the confirmation of research findings, and for scientists to build on the work of others. David (2004) and Nelson (2006) are strong proponents of the openness of science, arguing that keeping science open is the most effective policy for enabling the public to draw practical benefits from it. This perspective is certainly encouraged by the OECD as evidenced by their template for establishing and managing ISC that states: “The collaboration should encourage the free dissemination of data and data manipulation tools” (OECD 2005, p. 15).

This being said, there are inherent difficulties in such a worthy goal. Birnholtz and Bietz (2003) have researched the way data is created and used in three distinct scientific disciplines: earthquake engineering, HIV/AIDS research, and space physics, with the view to inform the design of data management and sharing systems. As expected, data collection varied by type of research, either as relatively constant streams over long periods of time, as in HIV/AIDS research, or from discrete events, as in earthquake engineering. The authors found that data can also be both a gateway into communities of practice and an indication of status. Further, trust and existing social networks played an

enabling role in the willingness of scientists to share data. Their findings revealed three key obstacles to efficient data sharing in ISCs:

- the willingness to share. Competition for reputation in science is intense, and data carries “monopoly rents” for the owner in the form of scientific publications, grants and access to students,
- locating shared data. Scientists must find out who has the data and negotiate or develop trusting relationships to gain access,
- using shared data. Much of the knowledge needed to make sense of data sets is tacit. Knowledge transfer is a highly social process of learning practices not easily documented.

Larger ISCs can be comprised of thousand of scientists and involve the creation and use of very large data sets. Data sharing in these cases is not just the exchange of finalized data sets. Birnholtz and Bietz (2003) concluded that “as the conduct of science becomes larger and projects involve more people, data sets also get larger, responsibility for them is diffused, and the social norms around how data is produced and consumed will change” (Birnholtz and Bietz 2003, p. 9). Data sharing in larger ISCs is likely making trust more important.

Similarly, Finhold (2003) reviewed U.S. based collaboratories, such as the Space Physics and Aeronomy Research Collaboratory (SPARC) and the Network for Earthquake Engineering Simulation (NEES) 2001-2014. He related that the experience with collaboratories indicates the enormous difficulties of supporting complex group work in

virtual settings. On the benefits side, impacts have been noted in the higher number and type of participants in scientific work. Further, participants were more diverse both in terms of experience and expertise.

Evidence suggests that collaboratories can increase the pace and efficiency of some scientific tasks, for instance in AIDS research and space physics, and help bridge the gulf that exists in many fields. Collaboratories also seem to produce a larger field of view, encouraging a more global orientation. Challenging aspects of collaboratories include agreement on sharing and use of data, sharing of credit, and the need to be explicit about information that is normally tacit when co-located. Early attention to the collaboratory concept stressed the importance of remote access to and control of remote instruments. However, Finholt (2003) stressed the human and behavioural aspects of collaboratories, suggesting them as novel social arenas to expand participation in science.

On the issue of protection of intellectual property, ISCs have to contend with the variety of IP regulations and practices of the collaborating countries on ownership of research results (OECD 2003a). It is generally agreed that IP issues are more likely to occur in collaboration closer to “applied” research. More and more though, there is a blurring of the distinction between “basic” and “applied” research. Procedures for dealing with IP issues should be recognized from the outset and captured in the governance documentation. Studying collaboration propensity, Birnholtz (2005) contrasted two theoretical approaches – the social and cultural studies of science and the organization and coordination theories – in a survey and interviews of academic researchers in three

scientific fields. Results supported a focus on work attributes, that is, characteristics such as resource concentration and the need for coordination, as more important in determining collaboration propensity than cultural factors, such as competition for individual recognition and concerns about intellectual property. He concluded however, that to better understand collaboration propensity, there is a need for more directed social studies of scientists, with a focus on the nature of their work and their institutional context, to complement the value gained from more broadly construed cultural and social studies of science.

“Trust-needs-touch” hypothesis

Several studies have incorporated the notion of trust and ISCs or R&D collaborations. Gallié and Guichard (2002) studied the impact of trust, ICT and geographically distant networks in space physics. The notion of cognitive proximity, that is a common base of knowledge that allows partners to technically understand each other, and organizational proximity, the share of common organizational rules, are raised as prerequisites to facilitate the building and maintenance of trust. They have verified the “trust needs touch” hypothesis, that is, the importance of face-to-face interactions and geographical proximity with regards to trust formation and maintenance, in spite of great advances in ICT. In fact, the authors see geographical proximity as the most constraining prerequisite to the building of trust in collaboration. As a focused case study research, their research was exploratory. Still, this finding has been echoed by several others. Another study supporting this hypothesis is that of Rocco, Finholt *et al.* (2001) who, building on McAllister's (1995) research on interpersonal trust relationships, empirically found

higher levels of emotional trust (e.g., openness toward others) toward local workers than toward distant workers in a geographically distributed telecom company, but found no difference in terms of cognitive trust (e.g. individual beliefs about peer reliability and dependability). Moreover, they showed that interpersonal factors, such as trust, played a role in the performance of complex cognitive tasks, in this case software development, even when these tasks were governed by a highly structured work process. The establishment of effective international relationships requires time and repeated “high context” face-to-face interaction.

By contrast, Shrum, Chompalov *et al.* (2001) believe that trust between individual scientists is decreasing in importance in the contemporary scientific world where multi-organizational collaborations are required. They contend that one difficulty with the literature on trust is the general failure to distinguish between what they call the “foundational” varieties of trust that are necessary for any cooperative social enterprise, and the more complex varieties of trust characteristic of modern scientific organization. Their key point is that in scientific collaborations, the relationships of interest are often between structural components such as teams. The authors backed their belief with a study of trust, conflict and performance in 53 collaborations in physics and related sciences, including several collaborations that were “computer-mediated”. They posit that “the role of trust in Big Science has been greatly exaggerated: the organization of relations between structural elements such as research teams is more significant for the functioning of modern scientific collaborations” (Shrum, Chompalov *et al.* 2001, p. 3). The methodology, a mixture of historical information and interviews, and reporting of

findings of this ten-year study are ambiguous. In addition, the selection of relatively successful collaborations introduced an inherent bias. However, several findings are worthy of consideration, such as, collaborators with prior ties have no greater overall trust than those without such relations, and the failure to find a relationship between interpersonal trust and self-reported performance.

Interpersonal, interorganizational and institutional trust

Salient to the study of ISCs, Zaheer, Lofstrom *et al.* (2002) have built on the recent conceptual and empirical distinction between interpersonal and interorganizational trust. This distinction shifts the level of the trustee and trustor from an individual to the organization. Although it is empirically established that these different forms of trust are connected, there is a limited understanding of the complex nature of the link between them. Using an inductive theory building approach, they developed propositions related to the differences in the nature of interpersonal trust for individuals at different hierarchical levels and the effect of roles on interpersonal trust between boundary spanners at different hierarchical levels. They also studied the link between interpersonal and interorganizational trust. Researching six cases of interfirm alliances in the biotechnology industry, their findings suggested that role distinction has an effect on trust. Zaheer, Lofstrom *et al.* (2002, p. 372) posited that “top managers occupy roles that involve greater uncertainty and often a more holistic perspective than those at lower levels, factors that are likely to influence how they develop trust in other top managers and the effect of this trust once created.” Further, and somewhat counter-intuitively, “CEOs seem to place their bets on a number of personal dimensions, rather than

dimensions that reflect the CEO's role as representative of an organization" (Zaheer, Lofstrom *et al.* 2002, p. 372). Although the nature of the interrelation between interpersonal and interorganizational trust was not fully investigated, overall, it was found to interact in complex ways over the course of the alliance, playing a buffering role in enabling smooth alliance operations. The essence of their findings was that individuals prefer to ascribe untrustworthy behaviours to the other organization rather than to their individual counterparts, so as not to damage the working relationship.

An avenue of interest for the importance of trust in ISCs is that of Dakhli and de Clercq (2004). The authors built on the work of Rousseau, Sitkin *et al.* (1998) on deterrence-based (i.e. utilitarian), calculus-based (i.e. rational), and relational-based (i.e. emotional) forms of trust, and studied the effects of human capital and social capital on innovation at the country level. They examined two dimensions of trust, with each dimension referring to a different focus, i.e. individuals or organizations. The first dimension, interpersonal trust, relates to the trust that people have in others in any given society and includes both the calculus-based and relational-based areas of trust. The second dimension relates to trust people have in institutions or organizations in the given society, or institutional trust that captures the deterrence basis for trust. They provide the following example: "In societies that have effective patent-registration and protection laws, one may be more willing to enter in co-operative relationships, e.g. a joint R&D project, knowing that there are credible and efficient mechanisms that will deter a partner from any possible breach of trust. On the other hand, where patent laws and institutions are ineffective or, even worse, absent, one may be more likely to focus on co-operating with those partners with

whom one maintains a stronger interpersonal trusting relationships” (Dakhli and de Clercq 2004, p. 113). All three levels of trust – interpersonal, interorganizational and institutional, are believed important in the context of ISCs.

Culture and trust interaction

Trust has also been discussed as a cultural variable whereby societies’ propensity to trust differs. Such cultural differences are relevant in studying cross-cultural ISCs. Several authors have researched how culture and trust interact, the role of cultural affinity, and the moderating role of culture on collaborations. This is premised on the notion that societal norms and values that guide people’s behaviour and beliefs (e.g., Hofstede 1980) influence whether and how trust is established. Doney, Cannon *et al.* (1998) investigated the influence of national culture on the development of trust and suggested that the processes used to make decisions about whether to trust and who to trust were dependent on national culture.

The individualism and collectivism characteristics of national cultures have been prominent in organizational sciences following the seminal work of Hofstede (1980). Bhagat, Kedia *et al.* (2002) believe that the social patterns of individualism and collectivism influence how members of a culture process, interpret, and make use of a body of information and knowledge. The moderating role of these cultural patterns introduces complexities into the cross-border transfer of organizational knowledge. Their theoretical framework encompasses the types of knowledge, the nature of transacting cultural patterns (individualism and collectivism), the cognitive style of individuals, and

their impacts on the effectiveness of cross-border knowledge transfer. They claim that their approach was one of the first integrative attempts to provide some theoretical guidance in delineating the role of cross-cultural variations in the cross-border transfer of knowledge.

Another recent and relevant study is that of Huff and Kelley (2003) who have empirically studied the levels of organizational trust of seven individualist and collectivist nations in the banking industry. Contrary to the popular view that collectivist cultures are more trusting, their hypothesis that average trust within organizations would be higher for organizations from collectivist than from individualist cultures was not supported. While collectivists place a premium on relationships, certain aspects of collectivist cultures, such as their sharp distinction between members of in-groups and out-groups, can inhibit trust formation. Kuada (2002) noted that a low level of trust combined with poor cross-cultural communication competence can lead to erroneous assumptions. Therefore, cultural sensitivity and intercultural competence serve to improve trust between cross-national partners and thereby enhance the prospects of successful interfirm collaboration (Ettorre 2000; Kuada 2002). This is clearly an area of relevance to large-scale ISCs. More and more, Canadian scientists are collaborating with foreign research institutions in countries such as Taiwan, China, India, and Brazil with vastly different cultures from their American and European scientific partners.

Trustworthiness, reputation and trust

Christiansen and Vendele (2003) noted that the relationship between trust and reputation is not widely treated in the context of collaborative R&D ventures. The historical trustworthiness of parties in previous interactions helps produce a reputation. Their analysis of data from six Danish firms involved in R&D collaboration found reputation building to be an important selection mechanism, as collaborative reputation can be an “entry ticket” to the projects. Clearly, in this small study they concluded that reputation is important and hence reputation of a country and its scientists would appear to play an important role for the creation of trust in the scientific domain.

A similar perspective of trust as a selection mechanism is taken by Knorr-Cetina (1999). In her seminal ethnographic study of high-energy physics she found that within collaborations, trust classifies participants not in terms of the money they bring to an experiment but rather in terms of what is known about them i.e., whose work can one build upon, whose results are believable, and who does one wish to cooperate with, and, alternatively, who does one wish to avoid.

Tsai and Ghoshal (1998) posit that “as trusting relationships develop inside a network, actors build up reputations of trustworthiness that may become important information for other actors in the network.” Hence, trust is viewed as an attribute of a relationship, but trustworthiness is considered an attribute of an individual actor involved in the relationship. In an analysis of fifteen business units of a large company, the authors found that trustworthiness had significant effects on resource exchange and combination, which in turn had a significant effect on product innovation.

2.3.2.3 *Perspective from the social capital literature*

A highly relevant concept to the study of ISCs is that of *social capital*, defined by the OECD (2001) as “networks together with shared norms, values, and understandings that facilitate cooperation within or among groups” (Helliwell 2002). Social capital can be considered as “the goodwill that is engendered by the fabric of social relations and that can be mobilized to facilitate action” (Adler and Kwon 2002). It is a concept of reciprocal, trust-based exchange of resources based on reputation. According to Lin (2001), and following from the accepted definition of capital as representing investments that have associated with them expected returns in the market place, social capital is simply “... investment in social relations with expected returns” (Lin 2001, p. 6). Lin further suggests that social capital is valuable because it provides individuals in any organizational, institutional or societal system with multiple advantages: 1) it facilitates the flow of information, 2) it exerts an influence on agents who make decisions with respect to these actors or individuals; 3) it provides individuals with social credentials; and 4) it builds identity and recognition for the individuals, or reinforcement.

Social capital confers benefits to both individuals and firms. Ample studies have researched or built on this concept. Social capital is even making its way into public policy in government as evidenced by the recent Canadian report, “Social Capital as a Public Policy Tool” (Policy Research Initiative 2005). Adler and Kwon (2002) believe that, like other forms of capital, social capital can either be a substitute for or a complement for other resources. The authors state “social capital lens can reveal features of reality that otherwise remain invisible” (Adler and Kwon 2002, p. 20).

In spite of its increasing popularity and basic agreement that social capital is derived from social relations, the concept of social capital is not entirely clear, especially the specific aspects of social relations that create social capital. For instance, there is confusion in the literature as to the relationship between norms, trust and social capital (Lin 2001). In their comprehensive review of the social capital literature, Adler and Kwon (2002) found that trust has been alternatively treated as social capital, as a source of social capital, as a form of social capital, and as a collective asset resulting from social capital. They argue that trust is a key source of social capital, an aspect that this research investigated.

In the early years of the development of the resource-based view (RBV), it was thought that resources were contained entirely within the firm boundary. Recently though, the RBV has been expanded to encompass a network perspective (Dyer and Singh 1998). Therefore, social capital does fall in the category of a firm resource as it fulfills the characteristics of the fundamental principles of the RBV, that is valuable, rare, imperfectly mobile, imperfectly imitable and non-substitutable resources.

A helpful framework for understanding social capital is offered by Nahapiet and Ghoshal (1998). They define social capital as “the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual or social unit”, hence comprising both the network and the assets that may be mobilized through that network (Nahapiet and Ghoshal 1998, p. 243). Implicit in this definition is the idea that social capital is an evolving resource that is shaped by social interactions between two actors on a dynamic basis. They believe that

social capital increases the efficiency of action and encourages cooperative behaviour. They posit, therefore, that the concept is central to the understanding of institutional dynamics, innovation, and value creation.

Nahapiet and Ghoshal's (1998) research focuses on the interrelationships between social capital and the creation of intellectual capital on the one hand, and on the co-evolution of social and intellectual capital as underpinning organizational advantage on the other hand. Three distinct dimensions of social capital are defined in their framework – the structural, the relational, and the cognitive dimensions of social capital. They do acknowledge, however, that these dimensions are conceptual distinctions with complex interrelationships between the three dimensions in practice. Figure 2 illustrates their framework.

Figure 2. Social capital framework (Nahapiet and Ghoshal 1998, p.251)

In this model, the structural dimension of social capital refers to the overall pattern of connections among actors. The cognitive dimension refers to resources providing shared representations, interpretations, and systems of meaning among parties. Finally, the relational dimension refers to the assets created and leveraged through relationships.

Although their primary aim has been to suggest that social capital influences the development of intellectual capital, Nahapiet and Ghoshal (1998) recognize that the pattern of influence may be in the other direction. However, the goal, as it is in this research, is to focus on determinants of intellectual capital. Therefore the relevant direction is the main one posited by Nahapiet and Ghoshal (1998).

In their analysis of value creation, Moran and Ghoshal (1996) identified three conditions that must be satisfied for combination and exchange of resources to take place. First, opportunity must exist to make the combination or exchange. Second, the parties involved must anticipate that interaction will prove worthwhile, even if they remain uncertain of what will be produced or how. Third, parties must be motivated to make such resource deployments or to engage in the pursuit of knowledge activity. Nahapiet and Ghoshal (1998) added a fourth condition: the capability to combine information or experience must exist, that is, the absorptive capacity of organizations.

Other researchers have since built on the Nahapiet and Ghoshal framework to study value creation in intrafirm networks (Tsai and Ghoshal 1998), knowledge acquisition and exploitation in young technology-based firms (Yli-Renko, Autio *et al.* 2001), industrial knowledge spillovers in big-science centers (Autio, Hameri *et al.* 2004), knowledge transfer between network members (Inkpen and Tsang 2005), and creativity for new product development (NPD) project teams (Chen, Chang *et al.* 2006). These studies provided empirical support for Nahapiet and Ghoshal's (1998) framework and enrich the

understanding of the broad concept of social capital. None, however, has specifically applied the framework for the study of large-scale ISCs.

Tsai and Ghoshal (1998) in particular examined the relationships among these three dimensions of social capital and the patterns of resource exchange and product innovation. They formulated seven hypotheses based on Nahapiet and Ghoshal's model and empirically tested them through a survey among 15 business units of a large multinational electronics company. Figure 3 illustrates their model. Solid lines indicate significant paths found in the research. Dashed lines indicate non significant paths that were not supported.

Figure 3. Social capital and value creation (Tsai and Ghoshal 1998)

Their findings support Nahapiet and Ghoshal's proposals about an association between the three dimensions of social capital and firms' value creation. These authors have found that social interaction and trust are significantly correlated to product innovation.

However, results did not confirm a significant relationship between social interaction and shared vision, possibly due to deficiencies in the operationalization and measurement of shared vision. In addition, the study had other limitations. For example, in spite of the small sample size, structural equation modeling techniques were used, and each construct had very few measures. However, this study provided empirical support for Nahapiet and Ghoshal's framework, and their model was considered a strong base for the study of ISCs.

More recently, Inkpen and Tsang (2005) extended the social capital framework of Nahapiet and Ghoshal (1998) by examining how the social capital dimensions of networks affect the transfer of knowledge between network members and attempting to integrate the diverse literature on networks and knowledge transfer. They differentiated among three common network types – intra-corporate networks, strategic alliances, and industrial alliances. They argued that network behaviours in the three network types are different. A particular challenge they were confronted with in trying to map these three network types within the social capital framework were differences in how such terms as knowledge transfer and learning have been used in the literature.

In summary, social capital is gaining prominence as a concept that provides a foundation for describing and characterizing the relationships of an organization or set of organizations. Benefits from social capital include access to information, influence, control, power, and solidarity. The detrimental beneficial aspects include conformity, potential exclusion of outsiders, downward-leveiling norms, and drain on resources

(Adler and Kwon 2002; Policy Research Initiative 2005). However, there remains widespread uncertainty about the meaning and effects of social capital (Inkpen and Tsang 2005), and empirical evidence of social capital importance is still sparse (Lorenzen 2005). The impact of social capital as a value creation mechanism has not been fully explored (Edelman, Bresnen *et al.* 2004), especially in interorganizational settings and with more broadly defined value-creation activities (Tsai and Ghoshal 1998).

2.3.3 Attractiveness of Canada as a Scientific Collaborator

A significant proportion of Canadian scientific research takes place within multi-disciplinary partnerships and networks formed by researchers in private industry, government research institutions or academia. As members of the international science community, Canadian researchers have a high level of interaction with their international counterparts. Figure 4 below is illustrative of the relative importance of countries among Canadian bilateral international collaborations in 2004 (Government of Canada 2006).

Figure 4. Canadian bilateral ISCs, 2004 (Government of Canada 2006)

Source: Compiled by Science-Metrix using data from the Observatoire des sciences et des technologies, Montreal, Quebec (SCI database)

At the macro-economy level, Canada enjoys a strong and stable economy, leading the G-7 in terms of economic growth since 2000. Canada's strong fiscal position, modest inflation (2.4% between 2000 and 2005), and low interest rates have contributed to its thriving S&T climate and led to more spending on R&D and education (Government of Canada 2006).

As a scientific collaborator, Canada has a lot to offer. A recent report from the Government of Canada (2006) highlights Canada's R&D excellence, its partnerships and strong formal and informal networks, sophisticated workforce, government's science-based departments and agencies (SBDAs), and strategic programs:

- **R&D Excellence:** There is good evidence that Canada's science and technology expertise is world-class and productive (OECD 2003b). Canada has strengths in a variety of sectors, including pharmaceuticals, ICT, food and biotechnologies,

health research, aerospace, advanced manufacturing, energy, and resource and environmental technologies. Canada also boasts world-renowned clusters such as the world-class biotechnology clusters in Montréal, Toronto and Vancouver, and the largest agricultural biotechnology cluster in Saskatoon, the Canadian Light Source, Canada's national facility for synchrotron light research, also in Saskatoon, life sciences in Winnipeg, and clusters across Canada in ICT, advanced manufacturing, and resource technologies.

- **Partnerships and networks:** A prime example of scientific networks is the federal Networks of Centres of Excellence (NCE). Launched in 1989, the NCE are unique partnerships among universities, industry, government and non-governmental organizations. There are currently nineteen nation-wide, multidisciplinary research networks working in the areas of health, human development and biotechnology, ICT, natural resources and engineering and manufacturing. Over the past 15 years, the networks have launched 111 spin-off companies, and its researchers have filed nearly 1,000 patents (Networks of Centres of Excellence 2006).
- **Sophisticated workforce:** According to the IMD (2005) World Competitiveness Yearbook, Canada has been ranked with the highest percentage of population with post-secondary education in the world. Further, seven Canadian business schools are ranked among the top 100 Management Schools in the world according to a 2005 survey by the Financial Times (UK). However, Canada has several

workforce challenges. In the coming decades, Canada's population is expected to age more rapidly than that of other industrialized countries and by 2026, one in five Canadians will be 65 years of age or older (Health Canada 2002). Canada's population growth will stagnate and may even decline by 2026 if immigration rates do not increase significantly. Therefore, an aging workforce, expected high retirement rates, and the fact that Canada continues to lag behind leading OECD countries in science and engineering degrees and in graduation rates at the PhD level (less than 1% of university graduates receiving a doctoral degree in 2000) means that Canada will become increasingly dependent on immigration to fill needs for specialized skills and sustain labour force growth in the long term (OECD 2004).

Consequently, attracting and retaining scientific, engineering, and technical workers will be especially challenging as labour market opportunities for graduates in science and engineering are neither extensive nor varied, largely due to the low level of research and innovative capacity in the Canadian private sector (OECD 2004). Canada will need to rely on foreign talent, likely coming from China, India, Pakistan, the Philippines and other transitional economies. While foreign talent can bridge supply gaps in OECD countries, including Canada, it may not be a permanent and acceptable replacement for national investment in the science and technology workforce. Therefore, Canada and other economies facing similar challenges stand to gain from participation in ISCs as a mechanism to attract and retain world-class talent.

- **Science Based Department Agencies (SBDAs):** The federal government plays four roles in Canada's S&T – as funder, facilitator, performer, and regulator. There are more than twenty federal organizations performing and/or funding R&D and 120 federal research laboratories. With \$803 million in S&T expenditures in 2004/05, twenty research institutes and ten technology centres, the National Research Council (NRC) is the largest federal S&T performer (Statistics Canada 2005). The NRC also represents Canada in more than 39 international scientific unions. Pierre Coulombe, President of the NRC states: "Canada's future depends increasingly on its ability to take maximum advantage of international opportunities. By participating in ISCs, the NRC strives not only to enhance Canada's access to knowledge, technology and research networks, but also to provide global opportunities for Canadian firms and entrepreneurs" (Government of Canada 2006, p. 16). Other federal SBDAs, such as Agriculture and Agri-Food Canada, Environment Canada, Natural Resources Canada, Fisheries and Oceans Canada, and Health Canada, also support research centres across Canada and actively participate in ISCs.

On the downside, it is believed that Canada lacks a focused and coordinated effort among various levels of government and different departments of governments (Papadopoulos, Heslop *et al.* 2000). There is a lack of focus on innovation policy, strategy and execution – too many players working with different and sometimes opposing plans and policies.

- **Strategic research programs:** The federal government initiated in the early 1990s programs that have spurred vigorous growth in Canada's S&T communities, in turn attracting notice globally. According to KPMG's Competitive Alternatives 2006 study (KPMG 2006), Canada is currently leading the G-8 in terms of public sector investment in university-based R&D that attracts research partners from around the world. For example, a growing list of foreign multinationals feature among Canada's top 100 corporate R&D performers. In addition, Canada's government programs that support corporate R&D work performed in Canada are considered to be the most generous in the G-7. This, in turn, is lowering business and R&D cost structures, as evidenced by Canada leading the G-7 countries for low business costs, with a cost advantage of 5.5 percent over the U.S.

Genome Canada, the primary resource for genomics and proteomics in Canada, is another example of a recent program that is gaining international recognition. As evidence of the need to integrate science within a broader multi-disciplinary approach, Genome Canada also supports projects aimed at studying the ethical, environmental, economic, legal and social issues related to genomics research. Genome Canada has international agreements with leading European countries, the U.S. and Australia, and maintains its international networks through an in-depth project evaluation process.

To ensure sustained momentum, the Government announced stable five-year funding in 2005 for:

- the three granting councils that fund Canada's S&T researchers (Natural Sciences and Engineering Research Council NSERC, Social Sciences and Humanities Research Council SSHRC, and Canadian Institutes of Health Research CIHR),
- indirect costs of federally funded research at universities and research hospitals,
- world-class research facilities,
- research in genomics, environmental technologies, and intelligent systems and advanced robotics.

Table 1 below highlights some Canadian S&T funding dedicated to ISCs (Government of Canada 2006).

Table 1. Selected Canadian S&T funding dedicated to ISC (Government of Canada 2006)

The Department of Foreign Affairs and International Trade's Going Global S&T Program is specifically designed to promote and enhance Canada's international S&T. This program supports Canadian researchers from private companies, universities and non-government research centres in accessing international R&D collaborative opportunities through the development of partnerships with key players in other countries.
The Department of Foreign Affairs and International Trade also administers the new International Science and Technology Partnerships Program (ISTPP). This five-year, \$20 million program is aimed at building S&T relationships with selected countries (Israel, India, China, and Brazil) to foster and support bilateral research projects and stimulate bilateral networking to further new partnerships for the commercialization of research and development
The Natural Sciences and Engineering Research Council supports international cooperation through most of its regular programs. A case in point is the Special Research Opportunity Program, which enables researchers to pursue and respond quickly to breakthrough research opportunities with the clear potential for significantly advancing a discipline that could open a new area of activity or lead to new technological advances of benefit to Canada.
The Canadian Institutes of Health Research has dedicated support for international collaborations through the International Opportunities Program. The program offers two types of one-time funding grants, the Development Planning Grant to initiate projects and the Collaborative Research Projects Grant to sustain collaboration.
The Canada Foundation for Innovation's research infrastructure investments of \$2.9 billion in almost 4,000 projects is creating a strong and vibrant research environment in Canada. It is also helping to build new international networks and partnerships, particularly through its international funding programs.

Source: Government of Canada 2006, p. 5.

- **Infrastructure:** Canada is renowned for its advanced internet technology and broadband, such as the new ultra-high bandwidth connection between Canada's national research and education network and the California state education network. This new network will facilitate R&D cooperation in critical fields of research such as stem cell and infectious diseases (www.canarie.ca/press/releases/06_06_22.html). On the other hand, Canada's overall critical infrastructure is aging (Interdepartmental Working Group on Commercialization 2004). The Conference Board of Canada in late 2004 pegged the infrastructure gap – the difference between what Canada is fixing and improving and what is “falling by the wayside” – at between \$50 billion and \$125 billion (Fixing Canada's Productivity Gap 3, The Globe and Mail, Nov. 8, 2005).
- **Productivity and competitiveness:** Despite strong economic growth, Canada suffers from low and slipping productivity and competitiveness. The Global Competitiveness Report 2005-2006 of the World Economic Forum ranks Canada 14th on the growth competitiveness index in 2004-2005. Canada's productivity is declining and is currently ranked 13th in the world in the OECD (2004 data) - going from an average of 4% productivity growth per year in the period 1946-1973 to 1.4% in the period 1973-2003. While the US is increasing its productivity, Canada is falling further behind. Productivity and competitiveness are important aspects of a country's welfare as productivity shapes the competitive position of nations and low productivity leads to lower standards of living.

In summary, Canada has the potential for an excellent scientific reputation based on R&D excellence, national and international networks, a sophisticated workforce, strategic research programs and science-based government departments. However, its shortcomings in areas such as declining population and aging workforce, aging infrastructure, low productivity and competitiveness could hamper both its performance and its image among foreign scientists and research organizations and hence, its attractiveness as a scientific collaborator. Further, the world is not standing still and emerging nations such as China and India are quickly elevating themselves to be key scientific players.

2.4 Outcomes from ISCs

Section 2.2.2 addressed the desired benefits from ISCs. These benefits and outputs can lead to desired outcomes for participating organizations and for society as a whole. It is widely recognized that ISCs create value in terms of scientific, political and industrial benefits. Many scientific discoveries that have emerged from ISCs are benefiting humanity, fuelling innovation and providing economic returns. The types of outcomes desired from the work and working of ISCs can be grouped into value creation in the form of intellectual capital, political spillover benefits and industrial spillover benefits.

2.4.1 Intellectual Capital

In the context of large-scale ISCs, an important value creation is intellectual capital, defined by Nahapiet and Ghoshal (1998) as “the knowledge and knowing capability of a

social collectivity.” The dimensions of intellectual capital include knowledge. Scholars have differentiated between types of knowledge. Perhaps the most-cited is Polanyi’s distinction of explicit (knowing what) and tacit (knowing how) knowledge. Other types are individual vs. social knowledge, with Nelson and Winter (1982) asserting that social knowledge is more than the aggregation of individual knowledge.

Knowledge is generally created via new combinations, incrementally or radically, and via exchanges among the various parties holding such knowledge. The combination and exchange of knowledge are complex social processes. Therefore, social capital is regarded as creating and sharing knowledge and transferring tacit knowledge. The co-evolution of social and intellectual capital underpins organizational advantage (Nahapiet and Ghoshal 1998).

2.4.2 Political Spillovers

Societal and strategic outcomes are less documented than intellectual outcomes, at least quantitatively. Yet, several fields of large-scale ISCs have a strong “public good” component. For example, in the field of earth observation, satellites, such as LANDSAT, are primarily artefacts for producing public-accessible data. This data, in turn, can help large countries, such as Brazil in which long-term monitoring of environmental and urban patterns plays a very important role in public policy issues (Camara and Perondi 2002). Therefore, large-scale ISCs can assist nation-wide policymaking but also diplomatic and economic relations among participating countries. Targeted research collaborations can be formed with non-traditional partners in order to build trusting relationships across

political borders (Wagner 2002). Another important outcome is the contribution of large-scale ISCs to a country's national pride and image.

2.4.3 Industrial Spillovers

The knowledge-based view of the firm depicts firms as repositories of knowledge and competencies (Kogut and Zander 2003). Knowledge creation and innovation result from new combinations of knowledge and other resources (Cohen and Levinthal 1990). Exposure to many different external contacts is essential to learning in the new competitive environment (Zahra and George 2002). Social network theories and theories on innovation in social systems suggest that linking firms to non-business systems enhances the potential for innovation in general, and for radical innovation in particular (Kaufmann and Tödtling 2001). Autio, Hameri *et al.* (2004) have highlighted the important links between social capital, knowledge acquisition, and knowledge exploitation in young technology-based firms.

Drawing on social network, social capital, and interorganizational learning theories, Autio, Hameri *et al.* (2004) examined knowledge spillovers accruing to industrial partner companies in big-science-industry dyads. Building on Nahapiet and Ghoshal's framework, these authors derived twenty-four theoretical propositions and case evidence of industrial spillovers from big-science centres. Specific outcomes of interest to the research related to 1) enhanced technological learning and competencies, 2) network extension and boundary-crossing links allowing access to new international and big-science markets, 3) interorganizational learning, 4) international prestige of big-science centres acting as valuable references for the firms, 5) informal access to complementary

resources, and 6) reduction of uncertainty inherent in technological innovation. Limitations of this study included generalizability of the findings, since it was limited to the context of CERN and the Large Hydron Collider experiment. Moreover, the centre they studied may not be considered a true ISC as it pertains to industrial suppliers to CERN. Hence, it should be viewed more from a technology transfer perspective than a scientific collaboration. In spite of these limitations, several of the propositions were valuable in the design of the survey instrument for the current study.

Some have discussed potential impacts of ISCs on national innovation systems (NIS). Within the NIS perspective, ISCs, and in particular collaborations which extend across institutional sectors (i.e. public-private collaborations), are viewed as either increasing or eroding differences in national technological capabilities – generalized as “techno-globalist” versus “techno-nationalist” arguments (Ostry and Nelson, 1995 in Carayannis and Laget 2004). The techno-globalist perspective views ISCs as a natural trend towards internationalism in research, where NIS are increasingly integrated into a global research network. On the other hand, the techno-nationalist perspective views such collaborations as a way to compensate for technological weaknesses in home countries by tapping overseas research capabilities, thus leading to a convergence in transnational technological capabilities.

This dichotomy is partly reconciled by Wagner (2005a) who shows ISCs as a networked system that seems to thrive on weak ties, self-organizing around incentives at the level of the researchers. She believes that the organization of these ISCs happens outside of and

additive to formal government programs, and that without these self-organizing networks of researchers, international collaboration would be limited to a few megascience projects. She sees this process as influencing the organization of science and increasing the efficiency of the knowledge-creating process by connecting and leveraging capabilities. She believes that the national innovation systems may lose out, at least in the near term, since they will not provide local spillovers that are often associated with local research centers, lending credence to the techno-globalist perspective. However, the full effects on national innovation systems of the shift to emerging global system are not clear. For instance, the institutional capacity that a country possesses may affect its ability to access and retain the results of knowledge created in the global network (Wagner and Leydesdorff 2005a).

In summary, industrial spillover benefits from large-scale ISCs among government research institutions have not been extensively researched to date with only a handful of studies in limited context such as CERN and focused research areas such as knowledge transfer and interorganizational learning.

2.5 A Summary of Key Directions

The increasing internationalization of science and an increased role for science in international affairs are trends that are widely acknowledged. There is also recognition that complex issues that span the globe such as health, aging, pandemics, natural disasters, poverty, the environment, can only be addressed with intense and highly networked multi-disciplinary and multi-country teams incorporating physical and life

sciences with other fields such as social sciences and the humanities. ISCs are growing as a percentage of all scientific activity and can take a number of forms (Wagner, Brahmakulam *et al.* 2001). New dynamics are at play hence the need to enhance understanding of ISCs.

Armed with an understanding of the strengths and gaps in past and recent studies of ISCs in general and large-scale ISCs in particular, it becomes apparent that there is considerable knowledge on the existence and factors that predict collaboration success. However, there is no specific body of research covering scientific collaboration in general, and large-scale ISCs in particular. Rather, various theories and research streams can be sourced to underpin the study of the phenomena of ISCs in a more holistic fashion, namely underlying theories and literature regarding strategic alliances, such as the resource-based view and its two extensions, the relational view and knowledge-based view, social exchange, country image, national innovation system, social network, trust, and social capital.

It is apparent from the literature review that each of these streams has undergone transformation over the years. From the strategic alliances literature, transaction cost analysis (TCA) of Williamson (1975) has been influential and has been applied across a wide range of issues. However, it remains fundamentally grounded in a market-failure framework and focused on the effects of opportunistic behaviour on firms (Conner and Prahalad 1996). Progressively, an organizational advantage perspective has emerged with the resource-based view of the firm. The resource-based view of the firm includes a

broader set of factors driving the formation of strategic alliances and defines specific characteristics of valuable resources leading to sustainable competitive advantage. An extension to that theory, the relational view, has added the concept of difficult-to-imitate capabilities embedded in dyadic and network relationships (Dyer and Singh 1998). Finally, the knowledge-based view, another extension of the resource-based view, has added knowledge as a source of sustainable competitive advantage in firms (Kogut and Zander 1992; Spender 1996). Through this evolution, a shift is noted from a competitive perspective to a competitive-collaborative balancing act among partners, hence the importance of social exchange theory. As well, the value of intersecting these theories with the concept of social capital becomes apparent as the acquisition and exploitation of knowledge are predominantly social processes (Kogut and Zander 1992).

The second stream of literature, the literature on country image, has been built over forty years and has progressively evolved from products and consumers to industrial settings, albeit to a lesser extent, and to geographic regions. It is now well recognized that the image of a country as projected to the world-at-large influences decision-making. However, research on the impacts of country image on ISCs, and particularly on the selection of international scientific partners, is non-existent. Yet there is a need to link various fields of research such as national innovation systems, social network theory and trust with country image to broaden the understanding of mechanisms and impacts of such collaborations.

The third stream of literature of relevance to the research, social capital, has also progressed enormously since its relatively recent inception. Originally viewed as benefits accruing to individuals from their social ties, the concept has evolved into organizational social capital and is a key component of the knowledge-based theories of the firms (Edelman, Bresnen *et al.* 2004). Social capital is now viewed as an important resource, like other forms of capital (Adler and Kwon 2002). A significant development has been the social capital framework of Nahapiet and Ghoshal (1998) who identified three distinct dimensions of social capital: structural, cognitive and relational. This framework has proved beneficial in linking social capital, intellectual capital, and the organizational advantage. Although alternative social capital frameworks exist, Nahapiet and Ghoshal's (1998) framework integrates many of the social capital facets discussed in previous work. The framework is useful for examining social capital at the organizational level. It also incorporates a cognitive dimension and establishes a relationship between social capital and intellectual capital (Inkpen and Tsang 2005). This framework has allowed more complex models and relationships to be analyzed, using advanced statistical analysis. Several researchers have capitalized on this framework to study the relationships between social capital and value creation in a variety of contexts.

Trust is central in the social capital literature. There is no doubt that the ability to develop trusting relationships among global partners continues to increase in importance (Huff and Kelley 2003). In this sense, a shift is noted in research attention from trust in dyadic relations to trust in aggregate social systems. Potential trajectories of new research of specific relevance to ISCs include questions around the influence of trust on a reputation

of an organization, how trust can be signalled or used strategically, the role of interorganizational trust in the operation of ISCs, and the role of trust in promoting new organizational arrangements conducive to innovation and value creation (McEvily, Perrone *et al.* 2003). As well, better understanding of the differences in institutional contexts and mechanisms across countries and cultures, and how these impact the level and functioning of trust and ultimately their link to performance are potential areas of research (Madhok 2005).

Several characteristics and success factors of ISCs are extensively covered in the literature. However, empirical evidence is largely obtained from bibliometric analyses of co-authorship, citations and patents. Other studies of ISCs have used a small number of case studies. Others still have focused on industrial R&D collaboration or on ISCs in narrowly defined context – scientific fields, organizations, and/or countries. These studies have certainly contributed to a better understanding of ISCs. However, there are several weaknesses in the empirical study of ISCs. Most studies emphasize dyadic relations and typically intrafirm (e.g., business units of a multinational firm), are concentrated in specific scientific fields such as High Energy Physics (HEP), Earth Observations (EO), and space research, and have a narrowly defined focus. There is little theory application to the study of partner selection and functioning of ISCs.

Based on this review of these distinct streams of literature and emerging thought, Chapter 3 now presents an approach that integrates these streams in an attempt to improve overall conceptualization of large-scale ISCs.

3 THEORETICAL APPROACHES AND RESEARCH QUESTIONS

This chapter discusses the objectives, research questions, theoretical approaches, and the research framework developed to address these questions. The research attempts to fill some of the conceptual and empirical gaps in the current literature on ISCs by integrating a number of theoretical perspectives. The overall purpose is to contribute to the understanding of ISC formation and functioning that would benefit a nation in positioning itself for successful involvement in ISCs. Given the lack of existing theory that explicitly addresses ISCs, one important step in the process and goal of the research was the identification of a suitable theoretical approach for the purpose of the research.

3.1 Objectives

This research explores large-scale, publicly-funded international scientific collaborations in scientific fields of strong interest to Canada, that involve Canadian and foreign government laboratories from selected developed and emerging economies. In the context of this research and building from the OECD's definition of Big Science (OECD 1993), ISC is defined as *geographically dispersed scientists offering complementary expertise and resources to jointly contribute to a common scientific research endeavour*.

The research study encompasses four key objectives:

1. To explore what desired benefits drive the formation of large-scale ISCs among government research laboratories in Canada and abroad.

2. To assess the desired characteristics of international partners in such collaborations and the attractiveness of Canada as a scientific partner.
3. To delineate the nature and extent of value-creation from large-scale ISCs.
4. To test the pattern of relationships among the components of the integrative framework of interorganizational social capital in ISCs .

The study focuses on Canada and its major international scientific partners in scientific areas of national and global importance.

3.2 Research Questions

Based on the literature review, the following three theory bases were selected for the study of large-scale ISCs: 1) strategic alliance literature, in particular the resource-based view of the firm (RBV); 2) social capital; and 3) country image. By combining key constructs from these theory and research streams and exploring interrelationships among them in the context of large-scale ISCs, a richer framework augmenting the understanding of ISCs is derived. Drawing on this wide body of literature, the study represents the triangulation of the views and perspectives of these three streams in the specific context of large-scale ISCs and is aimed at answering the following research questions related to the key objectives:

Objective 1: To explore what desired benefits drive the formation of large-scale ISCs among government research laboratories in Canada and abroad.

- What are the expectations of scientific collaborators in terms of scientific benefits?

- What other desired benefits drive the formation of large-scale ISCs?

Objective 2: To assess the desired characteristics of international partners in such collaborations and the attractiveness of Canada as a scientific partner.

- What are the desired characteristics of scientific collaborators at the country level?
- What are the desired characteristics at the scientist level?
- Based on desired characteristics of countries and scientists, how attractive is Canada as a scientific collaborator?

Objective 3: To delineate the nature and extent of value-creation from large-scale ISCs.

- What are the nature and extent of the outcomes of ISCs?
- What are the perceived outcomes and spillover effects to industry?
- What are the perceived political spillovers from ISCs?

Objective 4: To test the pattern of relationships in the framework.

- What are the relationships among the various dimensions of social capital in the ISC context?
- What are the relationships among the various dimensions of social capital and the assessment of scientific collaborators?
- What are the relationships among the various dimensions of social capital and the perceived effectiveness of the collaboration?

- What are the relationships among the characteristics of scientific collaborators, the quality of the collaboration and the outcomes from the collaboration?

The benefits of the research corresponding to the specific objectives outlined above are fourfold.

1. Each of the main streams of research of interest (strategic alliances, country image, and social capital) will benefit from the findings of the study as another application of the theoretical foundations of each area.
2. This empirical research is the first time that key aspects of strategic alliances, country image, and social capital have been assessed within the same study, enabling the examination of interrelationships among the three concepts.
3. The study provides much needed empirical evidence of the importance of social capital as a value creation mechanism in ISCs in interorganizational and multi-country settings, and explores more broadly defined value creation activities.
4. Implications can be drawn from the empirical results, enabling policy and strategy recommendations for a nation's successful involvement in large-scale ISCs.

3.3 Research Framework and Hypotheses

Before focusing on the research framework, it is helpful to situate the research in a broader frame of reference. Large-scale ISCs form and operate within a complex global environment. Global issues can be the prime driver of their formation. Collaborations form and develop among countries and their scientists. Collaborators are selected by their peers and science managers from several countries, with characteristics from both the

countries and its scientists expected to play an important role in the selection. The management of large-scale ISCs includes not only the scientific endeavour but related social processes for interaction, governance and coordination among collaborators, along with the technical infrastructure to support the collaborative effort. Several factors influence the operation, effectiveness, and success of ISCs. Among them, challenges can arise from cultural diversity, uncertainties related to resources, and legal environment specific to countries but also specific to each scientific field. Scientific benefits are considered a key outcome of ISCs. However, large-scale ISCs also create value for industry, either directly or indirectly, as well as political spillovers.

A broad view of social capital is taken given the overall approach of integrating concepts and constructs from the resource-based view, country image, and social capital in order to study selection of scientific collaborators and value creation from ISCs. In this regard, the social capital framework of Nahapiet and Ghoshal (1998) was considered the most useful as a basis for this purpose because of its relevance to the creation of intellectual capital and its applicability to interorganizational arrangements (Tsai and Ghoshal 1998). In addition, the research draws from the work of Tsai and Ghoshal (1998) on the role of intrafirm networks on value creation; Autio, Hameri *et al.* (2004) on industrial knowledge spillovers from big science centers; and Chen, Chang *et al.* (2006) on creativity for new product development (NPD) project teams. All three studies have built on Nahapiet and Ghoshal (1998) framework.

The constructs of interest from the literature review are mapped onto the three dimensions of social capital – structural, cognitive and relational, of Nahapiet and Ghoshal’s (1998) framework. The intent is to use the dimensions of social capital as aspects of the collaborative partner country to be assessed and to investigate the underlying foundational characteristics of the people and country that give rise to the social capital. The research framework shown in Figure 5 graphically outlines the hypothesized relationships between the three dimensions of social capital – structural, cognitive and relational – with the effectiveness of large-scale ISCs in terms of value creation.

Figure 5. Integrated Framework of Interorganizational Social Capital in ISCs

The research framework has been adapted for the context of large-scale ISCs from the research of Nahapiet and Ghoshal (1998) and Tsai and Ghoshal (1998).

3.3.1 Structural Dimension

Nahapiet and Ghoshal (1998) defined the structural dimension of social capital as the overall pattern of connections between actors. The close social interactions permit people to know one another, to share important information, and to create a common understanding related to task issues or goals, and to gain access to others' resources (Chen, Chang *et al.* 2006). Interactions are at the heart of ISCs at all stages but are especially important during moments of conflict and misunderstanding, with denser interactions required in the initial stages of the relationship to acquire confidence among partners and for norms and codes to emerge (Madhok 1995a). Network structures influence the range of resources and information that may be accessed. In this framework, important facets of this dimension are the presence or absence of network ties between actors, and network configuration, which describes the pattern of linkages in terms of density and connectivity (Nahapiet and Ghoshal 1998). In the context of large-scale ISCs, strength of ties is believed to be particularly relevant. However, there are few studies that concentrate specifically on the effect of strong and weak ties in an interorganizational network setting (Hagedoorn, Cloudt *et al.* 2005). Further, as pointed out in the literature review chapter, there are mixed findings about strength of network ties and results.

Network ties do not happen in a vacuum. In the context of large-scale ISCs, scientific networks emerge from national and global scientific infrastructure. The socially

embedded exchange relationships among scientists have direct effects on access to new knowledge and resources, and create novel combination and growth opportunities (Uzzi 1997). In line with the resource-based view of the firm (Barney 1991), distinct and competitive advantages of countries are considered important in the selection of scientific collaborators for large-scale ISCs, i.e., scientific resources and capabilities that are rare, valuable, nonsubstitutable, and difficult to imitate. At a country level, such resources and capabilities are elements of a country image related to innovation infrastructure and include key actors of the national innovation system, namely, government laboratories, universities, research centres, and the private sector. A country's perceived image for strength in S&T is believed to be an important determinant of overall perceptions of that country and may be a reinforcing factor in the overall attractiveness as an ISC partner. Countries with strength in S&T are regarded as modern and competitive, especially by younger, well-educated people (Anholt 2006).

Other important structural dimensions of an innovation infrastructure for effective large-scale ISCs can be expected to include: leading technology and industrial clusters; pool of talent in S&T; information and communication infrastructure; research output; and quality of linkages among actors. Further and consistent with a relational view of competitive advantage (Dyer and Singh 1998), positioning and embeddedness in networks that extend beyond a country's boundaries are likely to be a source of interorganizational competitive advantage. These networks give valuable access to resources and knowledge, facilitating the advancement of science.

3.3.2 Cognitive Dimension

The cognitive dimension represents the resources providing shared representations, interpretations, systems of meaning and shared goals between the network members (Nahapiet and Ghoshal 1998). In the context of large-scale ISCs, three facets related to this dimension are explored: country characteristics, scientist characteristics, and shared goals among scientific collaborators.

The country image literature emphasizes the association of images of products and images of the country of origin, i.e., the Product-Country Image (PCI) (Heslop and Papadopoulos 1993; Papadopoulos and Heslop 2001). Similarly, it is proposed that images of a scientifically advanced country can spill over to the images of that country's technology-based firms. The role of the image of countries as locations for investment (e.g., foreign direct investment) has also been acknowledged in the literature (Papadopoulos and Heslop 1992; Papadopoulos and Heslop 2001, 2002). For instance, a relevant insight from a survey of the voluminous research on PCI and their effects by Papadopoulos and Heslop (2002) indicated the different factors for consideration when examining foreign direct investment (FDI) decisions by technology-intensive firms. These firms are shifting their focus from factors of production to the need for effective networks of interconnected organisations including producers, their suppliers and contractors, R&D institutions, and highly skilled labour. In spite of the rich literature on country-of-origin image at the products level, few studies have attempted to study country image in the context of large-scale ISCs.

In more traditional scientific fields such as astronomy and HEP, the reputation of countries are typically well established and known. However, in emerging and converging scientific fields such as genomics, countries may have to vie for recognition of their capabilities. Hence, it is believed that the concept of country-image is of increasing importance in the competitive large-scale ISC arena. With emerging economies rising to scientific challenges, countries will increasingly need to develop positive images as potential credible scientific collaborators, especially in new and emerging scientific fields. In this context, the cognitive components of country image relate to the overall innovation environment: scientific reputation, investment in basic research, science and other government policies, protection of IP, education system, and openness to international trade, investment and collaboration. The affective components of country image capture the feelings and emotions of place image that are no less important since they serve as facilitators of interpersonal collaboration. Attributes include friendliness, comfort, security/safety, trustworthiness, pleasant and interesting. These attributes are derived from the product country image and the destination image literature (Nadeau, Heslop *et al.* forthcoming 2008). They are believed to be relevant to large-scale ISCs, given the social nature of exchange and the importance of a country being an inviting place to foreign scientific collaborators.

Characteristics of scientists themselves are believed to be important both for the selection of collaborators for large-scale ISCs and for effective collaborative effort. From the literature review, desirable characteristics of scientists include reputation (Christiansen and Vendele 2003), embeddedness in scientific and other networks, trustworthiness and

propensity to trust, collaborative propensity and readiness (Olson, Olson *et al.* 2005), willingness to share, inter-cultural competence, openness, tolerance, and inter-personal and communication skills. Another important attribute of scientists given that all large-scale ISCs include use of technology for both communication and core work, is technology readiness, that is, the fit of the technologies to the work and the users' capabilities (Olson, Olson *et al.* 2005).

Shared goals, the third facet of the cognitive dimension of social capital, represent the degree to which network members have a common understanding and approach to the achievement of network tasks and outcomes (Inkpen and Tsang 2005). Shared goals can reduce conflict and act as a bonding mechanism, helping collaborators to combine resources and promote innovation (Uzzi 1997; Tsai and Ghoshal 1998). In their analysis of factors that differentiated performance in project teams, Rickards, Chen *et al.* (2001) found that a shared vision provides team members with a sense of purpose and responsibility that motivates and sustains team progress. Further, in the strategic alliance literature, goal clarity reduces interpartner conflict and enables a foundation of common understanding (Das and Teng 2001). Shared culture refers to the degree to which common norms of behaviour govern relationships. For instance, members of an intracorporate network work under an overarching corporate culture, and strategic alliances are often formed on the basis of cultural compromise among the partners, given their usual distinct cultures (Inkpen and Tsang 2005). This is particularly relevant to large-scale ISCs where scientific collaborators have to deal not only with corporate

culture but also with the culture of their respective scientific fields and with a diversity of national cultures across geographical boundaries.

Another set of challenges for large-scale ISCs is the legal environment of participating countries. Countless issues arise around IP laws, rules and practices, ethics laws and norms that affect ISCs. These issues are presumed to be more prevalent in newer scientific fields, such as genomics. All of these create an environment where the establishment of shared goals can be arduous.

The full conceptualization of the hypotheses in the research framework, termed the Integrated Framework of Interorganizational Social Capital in ISCs, is presented below. The framework is operationalized in two forms: one for the study of individual-level country presented in Figure 6, and the other for the study of the collective ISC, presented in Figure 7. In the collective ISC framework, the emphasis is on the effect of collective resources, network, trust, shared goals and management of the ISC entity on the collaboration effectiveness rather than specific contributions by countries.

Figure 6. Research framework – Individual-Level Country

Figure 7. Research framework – Collective ISC

Linking structural and cognitive dimensions of social capital for the individual-level country framework, the following is hypothesized:

H1a: The perceived quality of a country's S&T infrastructure is positively related to that country's image.

H1b: The perceived quality of a country's S&T infrastructure is positively related to the perception of that country's scientists.

H1c: The extent of network ties of a country within the global scientific community is positively related to that country's image.

H1d: The extent of network ties of a country within the global scientific community is positively related to the perception of that country's scientists.

3.3.3 Relational Dimension

Drawing on Granovetter's work on structural and relational embeddedness, Nahapiet and Ghoshal (1998) described relational embeddedness as particular relations people have, such as respect and friendship, that influence their behaviour. They found that through these ongoing personal relationships people fulfill such social motives as sociability, approval, and prestige. Prior interactions and repeated ties are thought to contribute to the establishment of high levels of trust, and high trust is viewed as facilitating efficient cooperation and to foster creativity and innovation. The network literature on tie strengths has also documented the implications of strong interaction ties for trust and trustworthiness. An actor occupying a central location in a social interaction network is likely to be perceived as trustworthy by other actors in the network (Tsai and Ghoshal 1998).

Shrum, Chompalov *et al.* (2001) went further in exploring the concept of trust in scientific collaboration. Their key point is that in scientific collaborations, the relationships of interest are often between structural components such as teams. They argue that foundational trust embedded in dyadic relations is often distinct from the collective trust between social formations in scientific collaboration.

Dakhli and de Clercq (2004) studied the effects of human capital and social capital on innovation at the country level. The authors examined two dimensions of trust. The first dimension, interpersonal trust, relates to the trust that people have in others in any given society and includes both the calculus-based and relational-based areas of trust. The second dimension relates to trust people have in institutions in the given society. Another dimension of trust is relative to an organization, that is interorganizational trust. Zaheer, Lofstrom *et al.* (2002) believe that interorganizational trust is not the aggregation of interpersonal trust. However, they note the complex relationship between interpersonal and interorganizational trust.

A challenging aspect of researching the effect of trust in ISCs is the variety of forms of trust and related concepts of trustworthiness and reputation covered in the literature on the one hand, and the selection of the most relevant scheme of reference on the other. Based on the above, interpersonal, interorganizational and institutional trust in large-scale ISCs are incorporated in the research.

Linking structural and relational dimensions of social capital of the individual-level country framework, the following is hypothesized:

H2a: The perceived quality of a country's S&T infrastructure is positively related to trusting relationships with that country's scientists.

H2b: The extent of network ties of a country within the global scientific community is positively related to trusting relationships with that country's scientists.

H2c: The extent of social interaction is positively related to trusting relationships with that country's scientists.

Linking cognitive and relational dimensions of social capital of the individual-level country framework, the following is hypothesized:

H3a: The characteristics of a country are positively related to trusting relationships with that country's scientists.

H3b: The characteristics of a country's scientists are positively related to trusting relationships with that country's scientists.

H3c: The extent to which scientific collaborators from a country share the team's goals is positively related to trusting relationships with that country's scientists.

3.3.4 Resource Exchange and Combination

Moran and Ghoshal (1996) argued that all new resources, including knowledge, are created through two generic processes – combination and exchange. Knowledge creation involves making new combinations. Exchange is a prerequisite for resource combination when resources are held by different parties. The following sets of hypotheses link the three dimensions of social capital with the constructs of resource exchange and combination of both research frameworks.

Linking the structural dimension of social capital with resource exchange and combination, the following hypotheses are formulated.

Individual-level country framework:

H4a: The perceived quality of a country's S&T infrastructure is positively related to the attractiveness of that country as a scientific collaborator.

H4b: The perceived quality of a country's S&T infrastructure is positively related to the contribution of that country to the perceived effectiveness of the collaboration.

H4c: The extent of network ties of a country within the global scientific community is positively related to the attractiveness of that country as a scientific collaborator.

H4d: The extent of social interaction is positively related to the attractiveness of that country as a scientific collaborator.

H4e: The extent of social interaction is positively related to the perceived effectiveness of the collaboration.

Collective ISC framework:

H4f: The perceived quality of resources and capabilities in the ISC is positively related to the perceived effectiveness of the collaboration.

H4g: The perceived quality of network ties among collaborators of the ISC is positively related to the perceived effectiveness of the collaboration.

Linking the cognitive dimension with resource exchange and combination leads to the following hypotheses.

Individual-level country framework:

H5a: The characteristics of a country are positively related to the attractiveness of that country as a scientific collaborator.

H5b: The characteristics of a country's scientists are positively related to the attractiveness of that country as a scientific collaborator.

H5c: The extent to which scientific collaborators from a country share the team's goals is positively related to the contribution of that country to the perceived effectiveness of the collaboration.

For the collective ISC framework, shared goals and quality of the management of the ISC – management of data, management of intellectual property issues, and overall management and coordination – are believed important for the perceived effectiveness of the collaboration, based on the work of Madhok (1995b), Hara, Solomon *et al.* (2003), Andersen and Sorensen (1999) and Kuada (2002). The following is hypothesized:

H5d: The extent to which all scientific collaborators share the team's goals is positively related to the perceived effectiveness of the collaboration.

H5e: The perceived quality of the management of the ISC is related to the perceived effectiveness of the collaboration.

Linking the relational dimension of social capital with resource exchange and combination, drawing from Tsai and Ghoshal's (1998) model, it is hypothesized that:

Individual-level country framework:

H6a: The level of trusting relationships with a country's scientists is positively related to the attractiveness of that country as a scientific collaborator.

H6b: The level of trusting relationships with a country's scientists is positively related to the contribution of that country to the perceived effectiveness of the collaboration.

Collective ISC framework:

H6c: The level of trust among collaborators of the ISC is positively related to the perceived effectiveness of the collaboration.

3.3.5 Value Creation

The research builds on Nahapiet's and Ghoshal's framework and investigates the creation of intellectual capital from large-scale ISCs. However, this research expands their framework by also exploring the creation of political and industrial spillover effects from ISCs.

3.3.5.1 Intellectual capital

Intellectual capital represents a valuable resource and a capability for action based in knowledge and knowing (Nahapiet and Ghoshal 1998). In the context of ISCs, intellectual capital comprises scientific output. Several bibliometric studies on publications, citations and patents have demonstrated scientific output from ISCs. Generally lacking from such assessments are analyses of outcomes arising from scientific output. One such analysis is that of Schmied (1987) who classified and quantified primary and secondary economic effects of two big European research organisations (CERN and the European Space Agency). Practical payoff from scientific research often comes about by serendipity and can be challenging to foresee due to the basic nature of the research. Further, the results of scientific research are published and therefore are open for all to use and evaluate, making scientific knowledge cumulative (Nelson 2006). Nonetheless, outcomes from scientific output would include new fields of endeavour (Cummings and Kiesler 2005), input to the innovation process that will result in new or improved products or services (Schmied 1987), and even better governance of controversial international science issues, such as genetically modified foods (Wagner 2002).

3.3.5.2 *Industrial spillovers*

Exchange is at the heart of social interactions and knowledge creation. The relational view, as an extension of the resource-based view, maintains that competitive advantage derives not only from firm-level resources but also from capabilities embedded in dyadic and network relationships (Dyer and Singh 1998). By building relation-specific assets, knowledge-sharing routines, and effective governance mechanisms into relationships, firms can leverage their resources for knowledge acquisition and exploitation (Yli-Renko, Autio *et al.* 2001). Further, the knowledge-based view, another extension of the resource-based view, positions knowledge as a source of sustainable competitive advantage in firms, especially for technology-based firms (Kogut and Zander 1992; Spender 1996). Because the acquisition and exploitation of knowledge are predominantly social processes (Kogut and Zander 1992), social capital may be critical for the long-term success of technology-based firms.

It is believed that large-scale ISCs can benefit industry, directly and indirectly, in a variety of ways that need to be better explored (Autio, Hameri *et al.* 2004). This research therefore investigates the nature and extent of such benefits to industry from large-scale ISCs as well as spillover effects. Of particular interest are knowledge transfer, potential spillover benefits to industry of country image as a science leader, and access to foreign markets as suggested in the strategic alliance literature. In addition, this research investigates whether firms with well-embedded R&D network ties do benefit from the network externalities created by their collaboration in large-scale ISCs with government laboratories. An example of such network externality would be a firm's network extension from bridging into social networks of government research laboratories.

3.3.5.3 *Political spillovers*

Wagner (2002) noted the increased role for science in international affairs. Examples of political spillovers from ISCs include creating goodwill, gaining credibility as a reliable collaborator, and political capital. Other political spillovers from ISCs would be targeted research collaborations with non-traditional partners to build trusting relationships; demonstrating responsibility and accountability to national goals; improving international relations; and broader coordination of decision-making about science (Wagner 2002; Wagner, Staheli *et al.* 2002).

It is, therefore, hypothesized that:

Individual-level country framework:

H7a: The attractiveness of a country as a scientific collaborator is positively related to that country's contribution to the value creation from the large-scale ISC.

H7b: The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the total value creation.

H7c: The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the creation of intellectual capital.

H7d: The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the creation of industrial spillovers.

H7e: The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the creation of political spillovers.

Collective ISC framework:

H7f: The perceived effectiveness of the collaboration is positively related to the creation of intellectual capital.

H7g: The perceived effectiveness of the collaboration is positively related to the creation of direct industrial spillovers.

H7h: The perceived effectiveness of the collaboration is positively related to the creation of indirect industrial spillovers.

H7i: The perceived effectiveness of the collaboration is positively related to the creation of political spillovers.

3.3.6 Summary

To summarize, this research of large-scale ISCs builds on the framework of Nahapiet and Ghoshal (1998). It investigates the effects of the social capital construct dimensions (structural, cognitive, and relational) on the selection of foreign scientific collaborators, the effectiveness of the collaboration, and the value creation from the international collaborative effort. Figure 8 illustrates the contribution of the research to the Nahapiet and Ghoshal (1998) framework. By taking a broad view of social capital in the context of large-scale ISCs, this research extends Nahapiet and Ghoshal's (1998) framework from intraorganizational to interorganizational relationships, in a multi-country setting, with an emphasis on polyadic relations, trust in aggregate social systems and more broadly defined value creation activities.

A novel framework, the Integrated Framework of Interorganizational Social Capital in ISCs, is operationalized in two forms to study the contribution of individual collaborator country, and the entire ISC collaboration. In total, 25 relationships between the 12 constructs of the individual-level country framework are hypothesized. The collective ISC framework comprises nine relations between the nine constructs of the framework. Tables 2 and 3 summarize the hypotheses of each framework.

Figure 8. Contributions of the research

Table 2. Hypothesized relationships – Individual-level country framework

	Hypotheses for the Individual-level country framework
H1a	The perceived quality of a country's S&T infrastructure is positively related to that country's image
H1b	The perceived quality of a country's S&T infrastructure is positively related to the perception of that country's scientists
H1c	The extent of network ties of a country within the global scientific community is positively related to that country's image
H1d	The extent of network ties of a country within the global scientific community is positively related to the perception of that country's scientists
H2a	The perceived quality of a country's S&T infrastructure is positively related to trusting relationships with that country's scientists
H2b	The extent of network ties of a country within the global scientific community is positively related to trusting relationships with that country's scientists
H2c	The extent of social interaction is positively related to trusting relationships with that country's scientists
H3a	The characteristics of a country are positively related to trusting relationships with that country's scientists
H3b	The characteristics of a country's scientists are positively related to trusting relationships with that country's scientists
H3c	The extent to which scientific collaborators from a country share the team's goals is positively related to trusting relationships with that country's scientists
H4a	The perceived quality of a country's S&T infrastructure is positively related to the attractiveness of that country as a scientific collaborator
H4b	The perceived quality of a country's S&T infrastructure is positively related to the contribution of that country to the perceived effectiveness of the collaboration
H4c	The extent of network ties of a country within the global scientific community is positively related to the attractiveness of that country as a scientific collaborator
H4d	The extent of social interaction is positively related to the attractiveness of that country as a scientific collaborator
H4e	The extent of social interaction is positively related to the perceived effectiveness of the collaboration
H5a	The characteristics of a country are positively related to the attractiveness of that country as a scientific collaborator
H5b	The characteristics of a country's scientists are positively related to the attractiveness of that country as a scientific collaborator
H5c	The extent to which scientific collaborators from a country share the team's goals is positively related to the contribution of that country to the perceived effectiveness of the collaboration
H6a	The level of trusting relationships with a country's scientists is positively related to the attractiveness of that country as a scientific collaborator
H6b	The level of trusting relationships with a country's scientists is positively related to the contribution of that country to the perceived effectiveness of the collaboration
H7a	The attractiveness of a country as a scientific collaborator is positively related to that country's contribution to the total value creation
H7b	The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the total value creation
H7c	The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the creation of intellectual capital
H7d	The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the creation of industrial spillovers
H7e	The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the creation of political spillovers

Table 3. Hypothesized relationships – Collective ISC

	Hypotheses for the Collective ISC
H4f	The perceived quality of resources and capabilities in the ISC is positively related to the perceived effectiveness of the collaboration
H4g	The perceived quality of network ties among collaborators of the ISC is positively related to the perceived effectiveness of the collaboration
H5d	The extent to which scientific collaborators share the team's goals is positively related to the perceived effectiveness of the collaboration
H5e	The perceived quality of the management of the ISC is positively related to the perceived effectiveness of the collaboration
H6c	The level of trust among collaborators of the ISC is positively related to the perceived effectiveness of the collaboration
H7f	The perceived effectiveness of the collaboration is positively related to with the creation of intellectual capital
H7g	The perceived effectiveness of the collaboration is positively related to the creation of direct industrial spillovers
H7h	The perceived effectiveness of the collaboration is positively related to the creation of indirect industrial spillovers
H7i	The perceived effectiveness of the collaboration is positively related to the creation of political spillovers

4 PHASE I RESEARCH AND RESULTS

The research employs a two-phase, sequential, mixed-methods approach to explore large-scale, publicly-funded international scientific collaborations. The specific focus is on ISC in scientific fields of strong interest to Canada, that involve Canadian and foreign government laboratories from selected developed and emerging economies. The research aims to explore the desired benefits driving the formation of large-scale ISCs, and to enhance the understanding of the socio-technical processes that impact on the selection of scientific partners, the perceived effectiveness of the collaboration, and on the value creation from large-scale ISCs. A mixed-method approach was selected given the exploratory nature of the research and the lack of a theoretical framework specifically underpinning ISCs. The initial qualitative phase allowed for development and exploration of the importance of the key constructs and their possible relationships. The follow-up quantitative phase, a survey instrument administered to selected Canadian and foreign scientists involved with ISCs with Canada allowed for direct testing of the relationships in the framework that was developed following the literature review and the first phase. Chapter 4 covers the design and results of the qualitative phase while the quantitative phase is covered in subsequent chapters.

4.1 Methodology

Objective 1 of this research is to explore what desired benefits drive the formation of large-scale ISCs among government research laboratories in Canada and abroad. This objective was achieved with phase I of the research, an exploration and generation of

themes from in-depth interviews with selected Canadian scientists and policy makers involved in ISCs within Canadian federal government research laboratories. In turn, these themes, along with the underpinning theoretical framework, form the basis of phase II of this research.

Specifically, the objectives of this qualitative phase of the research were to:

- validate factors extracted from the literature on ISCs in a Canadian context with key representatives from federal research laboratories,
- explore initial perceptions of a country image of Canada in ISCs,
- explore broad patterns of factors affecting success of ISCs,
- establish a foundation and direction for an international survey.

The literature review led to the development of an extensive list of themes related to ISCs. An interview questionnaire (see Appendix A) was designed to explore these themes as regrouped under the following six major categories:

- types of ISCs,
- perceived country attractiveness for ISCs,
- institutional “cachet” of Canadian government laboratories,
- attributes of scientists that would encourage ISCs,
- success factors for ISCs,
- desired benefits from ISCs.

A uniform protocol containing semi-structured questions was used to conduct interviews so that the main questions pertaining to theme categories mentioned above could be followed up by additional related questions of relevance. In this way, the interviews accommodated the flow of conversation and the respondents' experiences and areas of expertise (Seidman 1998). Interviews lasted 1.5 to 2 hours, were held in English or French, and were digitally recorded for later transcription. Textual analysis was used to regroup answers into categories of meanings, starting with broad categories and then going more closely into specific terms of meaning, based on Miles and Huberman (1994) and similar to the methodology used by Melin (2000). The approach is based on the Grounded Theory method (Glaser and Strauss 1967; Strauss and Corbin 1990).

In all, 21 interviews were conducted within Canadian federal government science-based department agencies. The respondents were selected using a judgmental sampling approach with the aim of including a range of scientific fields of interest to Canada, as well as a variety of types of ISCs. Of the 21 respondents, seven were from the life sciences, seven from the physical sciences, three from engineering and four from science and foreign policy areas. All participants were senior scientists, director generals of federal research institutes located across Canada, or senior policy makers. Respondents are involved in fields such as: agriculture, Polar Regions research, communication technologies, infectious diseases, marine biosciences, material engineering, energy, microstructural science, metrology, plant biotechnologies, genomics, construction, and nanotechnologies. They collaborate extensively with foreign scientists from developed and emerging countries including: the U.S., Japan, Australia, New Zealand, Israel,

China, India, South Korea, Taiwan, Russia, Brazil, Singapore, Thailand, and throughout Europe.

4.2 Interview Results

Since the interviews encompassed their personal involvement in international collaborations, participants were able to reveal details and opinions according to their many years of experience. Respondents were very willing to participate and interested by the study. Most interviews lasted longer than the allocated 1.5 to 2 hours. Therefore, there is good reason to believe that the interviews provide a fair and general picture of what the scientists and policy makers think about international scientific collaborations, and that the issues have significant relevance to their work and the goals of their unit. Inherent limitations include potential personal social acceptability bias. However, respondents were assured that responses would not be identified with any person or organization and that major themes were the focus. It is worth noting that these interviews were not conducted with a statistical analysis in mind, but rather as an exploration of key themes of importance to Canada in international collaborations, as experienced by the participants.

The results provide an overview of the answers of the respondents and are organized into the six categories mentioned above. Appendix B provides some illustrative comments received by the respondents.

4.2.1 Types of ISCs

ISCs range from big science collaborations to country-to-country, lab-to-lab, team-to-team, and scientist-to-scientist collaborations. The ‘International Polar Year 2007-2008’, a Polar Regions research initiative, is a big science collaboration. It involves some 60 countries, with Canada taking the lead, the International Council for Science (ICSU), and the World Meteorological Organization (WMO – a UN organization). The Government of Canada has provided new funding to promote Canada as an international leader in polar science. Nearly one-quarter of the Arctic region falls within Canada's borders. Other than those regarding the Polar Regions research project, all other interviews involved international scientific collaborations at the level of country-to-country, lab-to-lab, team-to-team, or scientist-to-scientist. Most organizations participate in several types of collaborations. Moreover, several collaborations involve a grouping of partners such as universities, several federal laboratories, and companies on the Canadian side, with corresponding foreign partners.

Formal international scientific collaborations that Canada is involved with are typically two to three years in duration, with the possibility of renewal. Informal collaborations can be of shorter or longer duration, depending on the purpose of the collaborations and specific circumstances.

4.2.2 Country Attractiveness of Canada for ISCs

Several questions for interviewees were aimed at exploring the underlying characteristics of Canada and its people that makes us a good country to partner with in ISCs. Because

of the status of the respondents and their exposure in the international area, they had a broad awareness of Canada's image in the world among the science and science policy communities. Several comments were made concerning the attractiveness of Canada as a partner because we are perceived as being a tolerant country. Canadians are perceived as open minded, easy to get along with, and exhibiting cultural flexibility and sensitivity. The honesty of Canada is well recognized. Canada is seen as friendly to foreigners, and people (including scientists) feel comfortable here. One respondent specified, however, that some regions of Canada were less receptive to foreigners than other regions. Other favourable factors include the general Canadian environment, the quality of life, and the cost of living. These factors are of importance for scientific exchanges, such as visiting scientists, professors, graduate students and post-doctoral graduates.

Respondents noted that because Canada is seen as a peaceful, politically neutral, and bilingual country, it is evaluated by foreign collaborators as an attractive partner. Several respondents commented that foreign countries perceive Canada positively compared to the U.S., because we are not a threat, not controlling, and we are willing to compromise. We are perceived as trustworthy compared to the U.S. and China. Politics does not appear to interfere with our science. It is easier to travel to Canada post 9/11 than to the U.S. We are not perceived as being as aggressive as the U.S., although this trait was considered a double-edged sword by some who experienced the U.S. minimizing or even ignoring Canadian scientific contributions. Others commented that Canada is a friendly window to North America and the U.S. Several specifically mentioned that Europeans, Australians and Chinese people especially like working with us.

Canada has had some breakthroughs in science that form good memories in people's mind. For instance, it is widely recognized that Canada developed the important oil seed grain, canola. Therefore, in the field of crop agriculture, Canada's historical leadership is looked on very highly. In other fields with smaller communities such as nanotechnologies, foreign scientists know the Canadian scientists, but not necessarily Canada. Overall though, there was broad agreement among respondents that foreign countries recognize the excellence of Canada's research in specific areas.

Areas in which Canada has strong technology clusters, such as the agriculture biotech in Saskatoon, appear to enhance Canada's image on the international scientific scene. Foreign countries admire our capacity to have federal research laboratories, universities, provincial organizations, and industry located in a geographical cluster to work on specific problems. This is perceived as giving us an advantage.

The questions on perceptions of foreign countries of our scientific capacity usually led to answers encompassing Canada's good infrastructure and capacity to do research, expertise and reputation, especially in specific scientific disciplines, research support systems, such as for university research with the Canadian Foundation for Innovation (CFI), and the good reputation of our federal laboratories. One respondent commented that Canada's scientific capacity is perceived at the same level as countries such as France and Germany, where investments in R&D are not exceptional but at a comparative level of other G8 countries. Others believe, however, that we are being perceived better than we actually are in infrastructure and research capacity.

Our education system received mixed assessments, although respondents acknowledged that it is not a topic discussed at length with foreign scientists. Most respondents indicated that our education system is highly regarded, with some world-class universities and overall strong education infrastructure. Foreign scientists have a lot of respect for our PhDs. Others, however, observed that tuition fees are lower than in other countries. Therefore, Canada has the image of being a cheaper and easier alternative for some students from Asian countries with highly competitive education systems.

On the question of factors supporting foreign countries wanting to collaborate with Canada, the capacity to form larger projects, the relationship with universities and governments, excellent networks, such as the Networks of Centres of Excellence, and being good at building partnerships were raised. In addition, federal programs for international collaborations, such as Genome Canada, and the international initiatives/seed funds with foreign countries, such as those set up at the National Research Council of Canada, are regarded as important factors supporting international collaborations.

On the question of key factors discouraging foreign countries from wanting to collaborate with Canada, by far the most important factor raised by most, if not all participants, is the very limited funding for ISCs. There are not many Canadian collaboration mechanisms to access funding for ISCs, and no central pot of money dedicated to ISCs. The implication is that we are perceived as not pulling our weight, and this in turn impacts negatively on our reputation and our visibility. For instance, several respondents

expressed frustration at being unable to effectively participate in the Framework Programmes of the EU due to the inability to find Canadian funding — at all, or in a timely fashion — to participate. Funds under the EU programs can only be accessed by European countries. Other countries can participate in collaboration with European countries but have to provide their own funding.

4.2.3 Institutional ‘Cachet’ of Canadian Government Laboratories

Canadian scientists interviewed believe that there is a strong perception of excellent intellectual capacity in Canadian federal laboratories. Our research infrastructure and facilities, the reputation of our teams and scientists, the breadth and excellence of research and research output, and our university-government-federal laboratories networks are positively commented on by foreign scientists working with the Canadian scientists interviewed. The way government laboratories work is held in high regard, i.e., our critical mass of inter-disciplinary expertise concentrated in one geographic location in specific fields working in an integrated fashion, unlike university departments that are perceived to be more compartmentalized. This gives foreign scientists a perception of huge resources being put to work. Our capacity to seek and build partnerships is valued. Other comments include our integration with the industrial reality, our generally good management of ISCs, the availability of fellowships and training, and our ability to provide a bridge to the U.S. However, several commented that a foreign government laboratory may not want to collaborate with a Canadian lab and vice versa on near-market research due to competitive position.

4.2.4 Collaborative Attributes of Canadian scientists

Canadian scientists are from all over the world. There is a cultural heterogeneity in the Canadian scientific community. Canadian scientists have a strong history of acceptance of the global nature of science; it is part of the Canadian culture. Therefore, the multi-cultural lab environment is a 'given' in Canada compared to Europe and Asian countries, and this is perceived favourably by ISC partners. When asked about attributes of Canadian scientists that make them good collaborators, a number of answers concerned our excellent scientific reputation, our collaborative approach, such as openness to sharing ideas and scientific data, trustworthiness, credibility and willingness to work in partnerships. Canadian scientists are perceived as collegial, open-minded, nice and polite, reliable, communicative, and willing to give-and-take. They also like to travel, have good values, and are not perceived as having a hidden agenda.

Interestingly, and likely due to our Canadian multi-cultural environment, dealing with scientists from different cultural backgrounds was not raised as a major obstacle to the success of ISCs. There is almost the sense that science is above cultural boundaries and barriers; science is its own world. This does not mean that challenges associated with different cultural backgrounds are not recognized. In fact, several respondents commented on various aspects of collaborations, such as the need to understand the operating context of the foreign scientists and differing intellectual property (IP) philosophies, which were rendered more challenging due to cultural diversity. However, these issues are not perceived as major hurdles, especially for informal, scientist-to-scientist collaborations where collaborators are likely to have known and worked with each other for extended periods of time. Cultural differences, especially with Asian

cultures, were raised but again, almost as a set of information to be integrated into the equation of international collaborations as opposed to a major hurdle. Language was not an issue either, English being the language of science. It was acknowledged, however, that there is a need to ensure that foreign collaborators, especially Asian scientists, comprehend the discussions.

Primary motives for scientists to engage in international collaborations were asked of respondents. As cited in the literature, most respondents raised complementarities of skills and access to expertise, teams, and facilities to advance their science as top drivers. Increased scope of the work and output to address problems of importance to Canada, building up something bigger than what can be done in Canada, and progressing faster were also important motives.

Others, however, believed that peer recognition is the major driver, with publications being a big motive for advancement of career and recognition. Some commented on the increased likelihood of accessing funding if Canadian scientists team up with foreign scientists. Others added travel as a secondary motive, something one respondent called 'scientific tourism'. One clarified that motives could be different depending on whether the scientist is junior or senior. Moreover, the scope and formality of the collaboration impact on motives. The notion of 'fun', i.e., good chemistry with the collaborators, was repeatedly mentioned.

Most believe that foreign scientists share similar motives. However, cultural differences could play a role in the relative importance among the various motives. Some raised the motive of getting research grants, especially in developing countries, since collaborating with other countries may increase the credibility of the funding requests. Another motive was collaborating with Canada as a bridge to the U.S. Opportunities to send students and post-doctoral scientists for training in Canada were also raised. Some respondents mentioned the situation of foreign scientists wanting to emigrate from their country, but this was considered the exception with the incidence decreasing over time.

4.2.5 Critical factors for Successful International Scientific Collaborations

A shared vision was by far the most cited critical success factor. Respondents mentioned common goals, real needs, willingness to collaborate, commitment to the collaboration, and mutually beneficial collaboration. By frequency of mention, other cited key factors were:

- complementarities of capacities and infrastructure, science excellence, and high level teams,
- good personality traits, chemistry among the collaborators, liking each other and wanting to work together,
- good communication; including face-to-face, regular contacts, working under the same roof,
- effective management of the collaboration; including the framework, strategies, processes,
- adequate funding; funding mechanisms, flow of money, timely access, etc.

Remarkably, the word 'trust' did not appear in the top factors. Probed on that aspect, respondents clearly believe that trust is absolutely fundamental and that it is embedded in the success factors mentioned above. Most were adamant that there is no successful collaboration without trust. They also pointed out that a match of interest and similar philosophies are required and that you have to live up to your commitments to build and maintain trust. Several mentioned the benefits of having built relationships and trust prior to entering into a collaboration by different mechanisms such as consultative committees and conferences. It takes time to build trust and mutual respect, and it is more challenging to establish trust among those with very different cultures. However, other respondents did not see building trust as a problem. They find scientists very trusting by nature and believe that given a common interest in a scientific area, they will 'click' quickly. One respondent indicated that trust almost guarantees a good relationship and that the absence of trust will most likely result in an unsuccessful collaboration.

On the question of intellectual property (IP), the general impression is that IP was not perceived as an issue for basic scientific collaborations. However, it can be an issue for collaborations closer to commercialization and when private industry partners are involved. It can be a lengthy process to negotiate agreements on pre-existing IP and the ownership and sharing of end results. In Canada, the Crown owns the IP of federal research laboratories. Therefore, the first impression of foreign countries is that the Canadian government wants to own everything. One respondent clarified that it is not necessarily the Canadian IP policy that is the issue. This respondent felt that the implementation of the IP policy in a timely fashion was the real issue often because of a

lack of clarity and consistency leading to misunderstanding of the rules internally and between the partners. Foreign countries have their own IP policies as well and hence, the importance of having good IP agreements in place up front was mentioned by several respondents. Some respondents raised the challenge of dealing with Asian countries, given their very different philosophy of IP. Overall, respondents believe that it is a matter of giving each partner a fair advantage.

Impacts of public funding of ISCs were investigated given that ISCs are largely supported by public funding in Canada. Overwhelmingly, respondents believe that without public funding, there would not be many ISCs. Scientists are perceived by foreign partners as more attractive if they have access to funding to collaborate. A common issue was the difficulties in finding money for international travel. Several respondents emphasized the importance of visibility at meetings and networking at international conferences. Although public funding of ISCs can produce negative impacts such as ‘marriages of convenience,’ all respondents believe that the positive impacts far outweigh the negative impacts.

4.2.6 Benefits

The nature of the benefits underlined in the literature was generally confirmed by the participants. There is broad agreement that benefits are multi-faceted and long term. One benefit from ISCs that stands out particularly is the enhanced visibility of Canada and the positive ramifications of such visibility. It makes Canada more attractive as foreigners develop a better understanding of the Canadian environment and culture. Some perceive ISCs as catalysts and precursors for the establishment of channels to pave the

way for industry. With blurring boundaries between scientific missions and trade, spillovers of ISCs to industry were highlighted: foreign countries looking to establish themselves in Canada, and ISCs helping to open foreign markets to Canadian firms. There are far-reaching effects of foreign scientists, post doctoral fellows and students training in Canada. The positive messages that they bring back to their country is 'gold' for Canada and our labs, as several participants mentioned. ISCs also lead to enhanced links between actors of the Canadian innovation system and increase opportunities for bigger collaborations. Without ISCs, Canada will be further isolated and will fall behind, especially with strong emergent countries like India and China.

4.3 Summary and conclusions

This exploratory phase of the study sought information on the perception of foreigners about ISCs with Canada through the lens of Canadian senior scientists from federal research laboratories and policy makers. Those interviewed expressed confidence in their ability to distinguish between their own perceptions and that of foreigners. In all, the respondents were able to articulate a broad image of ISCs, the challenges for a relatively small country like Canada, the impacts of ISCs, and trends. This certainly denotes the broad expertise, extensive experience, and high calibre of the respondents.

The overall image of Canada derived from these range of ISCs is that of a friendly and trustworthy country with a good research infrastructure, a strong reputation and expertise in specific scientific fields. Canada is therefore sought after as a collaborative scientific partner. However, due to its limited means and lack of focus, Canada is being

overshadowed by stronger countries. In addition, Canada appears badly equipped to face the new trends of broader scope, multi-partners, and very large-scale collaborative initiatives.

Critical success factors and the nature of benefits derived from participation in large-scale ISCs underlined in the literature were generally confirmed by the interviewees. The enhanced visibility of Canada and spillover effects from this enhanced visibility were recognized as important.

The objectives for this first phase of research were met: First of all, the study validated factors extracted from the literature on ISCs in a Canadian context. For instance, the results of the interviews on questions related to motives, mechanisms and benefits of ISCs were comparable to those of Melin (2000) who researched specific micro level aspects of ISCs at the university level in Sweden. However, further research is warranted concerning university settings and that of federal research laboratories as scientific partners in ISCs given the different dynamics at play. This type of research would help shed light on factors impacting on ISCs given the trends towards multi-institutions.

Secondly, the results support the notion that science is a socio-cognitive practice (Stern, 1996 in Melin, 2000). Although cognitive and technical reasons dominated many of the respondents' answers, social factors were raised as well, supporting the belief from Stern (1996 in Melin, 2000) and others that science and knowledge must incorporate its social as well as its cognitive forms. This study demonstrates the broad dynamics of ISCs and

the need to integrate the social aspects of collaboration rationales in the exploration of micro level aspects of ISCs. This in turn confirms that theories underpinning the international strategic alliance literature such as the social exchange theory, social capital, and social networks, are relevant theoretical approaches for the study of ISCs.

Thirdly, drawing from the literature on country image, the study sketched out a profile of the country image of Canada in ISCs. In doing so, important aspects of country image, such as attractiveness as a scientific collaborator and potential spillover effects to industry, were confirmed. Wagner (2005a) believes that with the globalization of research, the ability of any actor to join distributed collaborative projects depends largely on their attractiveness as a partner. This is of importance given that although most ISCs are informal and scientist-to-scientist, the growing trend is toward larger-scale collaborations involving several countries. In this context, the main concern for many governments is whether their local research environments appear prominently on the international map of scientific exchanges (Mahroum 2005).

Finally, the results of Phase I show that the ability to develop trusting relationships within global scientific partners continues to increase in importance and that the role of national culture in the formation and maintenance of trust is not negligible. In this sense, a shift is noted in research attention from trust in dyadic relations to trust in aggregate social systems (McEvily, Perrone *et al.* 2003).

Due to the exploratory nature of this research, a broad range of Canadian respondents, scientific fields, types of ISCs, and collaborating foreign countries were sought.

However, differences in the background of respondents, the scientific discipline, the nature of the collaboration and the foreign collaborators became apparent during the interviews and the relationship of these differences to responses. This suggests that the design of the quantitative phase of this research needs to include a broad range of large-scale ISCs in several scientific fields and from several countries.

5 PHASE II RESEARCH

The literature review of ISCs highlighted the limited research and theoretical frameworks for the study of ISCs. Several potential avenues of investigation were also covered. The results from Phase I allowed an initial general support and prioritisation of research focus within the research framework and suggested a narrower set of key constructs. It also validated the novel approach of integrating a resource-based view and a country image perspective within a social capital framework to the study of ISCs. In addition, findings from the interviews provided support to the appropriateness of incorporating constructs from the strategic alliance and country-image literature in the research framework.

Therefore, the objective of Phase II was to conduct an exploratory quantitative survey to create a broader set of evidence regarding the relationships between the structural, cognitive and relational dimensions outlined in the research framework with the attractiveness of scientific collaborators, the effectiveness of the collaboration, and the value creation from large-scale ISCs.

The subsequent sections cover the development of construct measures in the research frameworks, the survey design, and the pre-test of the methodology for the survey.

5.1 Construct Measurement

Measures, as indicators for the constructs of the research frameworks, have been selected based upon a thorough review of the strategic alliance literature, the national innovation

system literature, the country-image literature and the social capital literature. Existing construct measures strongly supported in past research have been selected wherever possible and appropriate. Although the cornerstone relationships of the social capital perspective on resource exchange and combination leading to value creation of the framework are well established in past research, the addition of constructs from the strategic alliance and the country image literature to the framework is novel. Therefore, while several other construct relationships are known within each respective field, only those constructs that reflect direct relevance to the study of large-scale ISCs were considered. Measures identified for each construct of the research frameworks were adjusted during on-going refinements to the framework based on the interview results of Phase I and during the questionnaire development phase.

The following sections list the constructs and the measures developed.

Structural Dimension – S&T Infrastructure

The structural dimension influences value creation primarily through the ways in which its various facets affect access to parties for exchanging knowledge and participating in knowing activities (Nahapiet and Ghoshal 1998). Elements of the national system of innovation literature was considered most suitable for the S&T infrastructure dimension of this construct because it is a system of interconnected institutions to create, store and transfer the knowledge, skills, and artifacts which define new technologies (Metcalf 1995). From this perspective, the innovative performance of an economy depends not only on how the individual institutions (e.g. firms, research institutes, universities)

perform in isolation but also on how they interact with each other as elements of a collective system of knowledge creation and use, and on their interplay with social institutions. However, empirical studies including measures of scientific capabilities, technological performance and their relatedness on the level of national innovation systems, are scarce (Van Looy 2006). Therefore, the measures of this construct are related to scientific resources, capabilities and linkages, drawing from the work of Van Looy (2006) who examined the relationship between national scientific capabilities, the science intensity of technology and technological performance within six emergent industrial fields, and Soltani and Birang (2005) who explored the impacts of the main elements in national innovation systems on the attractiveness in knowledge economy. Thus, for the individual-level country framework, the structural dimension – S&T infrastructure is represented by the following measures:

1. scientific capabilities,
2. level of scientific productivity,
3. level of funding of S&T,
4. quality and availability of highly qualified personnel in S&T,
5. quality of linkages between government laboratories, universities, and private sector,
6. quality of the regulatory context, including S&T policies and IP regime,
7. overall quality of the national innovation system (e.g., government laboratories, universities, private sector).

For the collective ISC framework, the structural dimension – resources and capabilities construct is represented by the following measures:

1. quality of equipment and facilities,
2. complementarity of resources,
3. level of funding,

4. scientific capabilities,
5. quality of collaborators,
6. use of internet-based tools.

Structural Dimension – Network Ties

The structural dimension of social capital refers to the overall pattern of connection between actors (Nahapiet and Ghoshal 1998). Further, Nahapiet and Ghoshal (1998) point out that network ties provide access to resources, constitute a valuable source of information benefits, and reduce the amount of time required to gather information.

The following three measures of the network ties construct are drawn from the work of Nahapiet and Ghoshal (1998), Tsai and Ghoshal (1998), and Hagedoorn, Cloudt *et al.* (2005) for the individual-level country framework:

1. quality of scientific networks,
2. embeddedness (ties to others) within the global scientific community,
3. number of world-renowned clusters.

The collective ISC framework examines network ties among collaborators with the following five measures:

1. quality of network ties among collaborators,
2. level of interaction,
3. quality of communication,
4. level of flexibility,
5. level of tolerance.

Structural Dimension – Social Interaction

Social interaction is viewed as a manifestation of the structural dimension of social capital (Chen, Chang *et al.* 2006). Team members having more social interaction with one another are more likely to generate new ideas leading to creation of intellectual capital.

The effect of network tie strength (Granovetter 1973) has so far mostly been analyzed in the context of inter-personal and intra-organizational relationships. Few studies have concentrated on the effect of tie strength in an interorganizational network setting. Measurement of tie strength in the literature has often been reduced to a straightforward categorical measurement like the form of interfirm partnerships: joint venture, equity alliances and R&D partnerships being considered strong ties, and marketing and licensing agreements being considered weak ties. This, however, does not capture the richness of the phenomenon. Recently, Hagedoorn, Cloudt *et al.* (2005) have developed a broader set of measures to explore the multidimensions of network ties of R&D network ties in high-tech industries. These measures are being used in this research, in addition to measures from the work of Chen, Chang *et al.* (2006). The following three measures of the social interaction construct of the individual-level country framework are:

1. length of relationship,
2. level of social interaction (e.g., frequency of interaction, intensity of relationship),
3. network tie strength.

Cognitive Dimension – Country Characteristics

The cognitive dimension of social capital represents the resources providing shared representations, interpretations, systems of meaning, and shared goals between network members (Nahapiet and Ghoshal 1998). Perceived attributes of countries are important as selection criteria of potential scientific collaborators. Drawing and adapting from the extensive literature on country image (Heslop and Papadopoulos 1993; Papadopoulos and Heslop 2000; Papadopoulos and Heslop 2002; Heslop, Papadopoulos *et al.* 2004; Papadopoulos 2004; Laroche, Papadopoulos *et al.* 2005), the following ten cognitive and affective attributes are used as measures for the country characteristic construct of the individual-level country framework:

1. friendliness,
2. trustworthiness,
3. likeability,
4. honesty,
5. credibility,
6. concern for others,
7. level of education,
8. innovative/entrepreneurial culture,
9. scientific reputation (e.g., overall achievements in science),
10. openness to international trade.

Cognitive Dimension – Scientist characteristics

Earlier studies have shown the importance of careful selection of partners to ensure a high level of compatibility (Madhok 1995a,b; Hara, Solomon *et al.* 2003). Reputational information plays an important role in the choice of interorganizational partners (Andersen and Sorensen 1999). Cross-cultural researchers have strongly emphasized

intercultural competence and cross-cultural communication as a prerequisite for successful performance of international business alliances (Kuada 2002). Measures for this construct of the individual-level country framework were derived from several streams of literature (Madhok 1995a,b, Andersen and Sorensen 1999, Kuada 2002, Hara, Solomon *et al.* 2003) and are:

1. reputation,
2. competencies (technological, interpersonal, intercultural),
3. connected within domestic and global scientific networks,
4. willingness to collaborate and to trust,
5. trustworthiness,
6. flexibility and tolerance,
7. international experience in ISCs,
8. management skills.

Cognitive Dimension – Shared Goals

An essential part of social exchange and combination processes requires at least some sharing of context between the parties to such exchanges (Nahapiet and Ghoshal 1998). Shared goals represent the degree to which network members share a common understanding and approach to the achievement of network tasks and outcomes (Inkpen and Tsang 2005). When a shared goal is present in the network, team members have similar perceptions about how they should interact with one another (Chen, Chang *et al.* 2006). Most models building on the framework of Nahapiet and Ghoshal (1998) contain this construct of shared vision/shared goals/goal congruence. Past research has shown that a shared vision may hold together a loosely coupled system. Tsai and Ghoshal (1998) refers to it as: “a bonding mechanism that helps different parts of an organization

to integrate or to combine resources” (Tsai and Ghoshal 1998, p. 467). Therefore, deriving from past social capital studies, the following three measures for both research frameworks are selected:

1. shared vision,
2. shared common goals and objectives,
3. agreement with task priorities.

For the collective ISC framework, the following three measures are selected for the management of collaboration construct:

1. management of data,
2. management of IP issues,
3. Overall management and coordination.

Relational Dimension – Trusting Relationships

Much of the evidence for the relationship between social capital and intellectual capital highlights the significance of the relational dimension of social capital (Nahapiet and Ghoshal 1998). A large body of research indicates that trust is a prerequisite for successful collaborations (Christiansen and Vendeke 2003). Tsai and Ghoshal (1998) pointed out that “as trusting relationships develop inside a network, actors build up reputations of trustworthiness that may become important information for other actors in the network” (Tsai and Ghoshal 1998, p. 467). In the context of the study, three dimensions of trust for trusting relationships are investigated: interpersonal, interorganizational and institutional trust. Interpersonal trust includes cognitive and affective trust. Cognitive trust allows people to count on others to provide promised contributions to a project according to agreed upon plans and schedules, while affective trust refers to confidence and openness in sharing ideas, feelings and concerns (Rocco,

Finholt *et al.* 2001). Interorganizational trust refers to trust by members of one organization toward another organization (Zaheer, Lofstrom *et al.* 2002). Zaheer, McEvily *et al.* (1998) demonstrated that interpersonal and interorganizational trust are related but distinct constructs and that trust in interorganizational exchange relations clearly matters. Institutional trust relates to trust people have in institutions or organizations in a given society (Dakhli and de Clercq 2004). In the context of the individual-level country framework, the work of McAllister (1995), Zaheer, McEvily *et al.* (1998), Rocco, Finholt *et al.* (2001), Zaheer, Lofstrom *et al.* (2002), and Dakhli and de Clercq (2004) and others is used for the following measures of trust :

1. interpersonal trust (cognitive and affective),
2. interorganizational trust,
3. institutional trust.

The collective ISC framework examines the level of trust among collaborators.

Resource Exchange and Combination – Partner Attractiveness and Collaboration Effectiveness

Moran and Ghoshal (1996) have argued that all new resources, including knowledge, are created through two generic processes: combination and exchange. Where resources are held by different parties, exchange is a prerequisite for resource combination (Nahapiet and Ghoshal 1998). A key contribution of the study is that the above constructs and measures derived from the strategic alliance literature and the country image literature augment the social capital framework of Nahapiet and Ghoshal (1998) and provide a broader understanding of the phenomena of large-scale ISCs, since it is believed that these constructs and measures all play a key role in the attractiveness and hence the

selection of large-scale ISC collaborators. Therefore, for the individual-level country framework, measures for partner attractiveness are:

1. scientific capabilities,
2. resources (equipment and facilities, funding),
3. position within domestic and global scientific networks,
4. quality of IP protection,
5. quality of data sharing.

Measures for collaboration effectiveness of both research frameworks are:

1. quality of the collaboration,
2. efficiency of the collaboration,
3. productivity of the collaboration,
4. success of the collaboration.

Value Creation – Intellectual Capital

Studies building on the social capital framework of Nahapiet and Ghoshal (1998) have analyzed value creation as intellectual capital, product innovations (Tsai and Ghoshal 1998), knowledge acquisition and exploitation in technology-based firms (Yli-Renko, Autio *et al.* 2001), innovation at the country level (Dakhli and de Clercq 2004), industrial knowledge spillovers from big-science centers (Autio, Hameri *et al.* 2004), knowledge transfer among network types (Inkpen and Tsang 2005), and creativity in project teams (Chen, Chang *et al.* 2006). Others, such as Goddard and Isabelle (2006) have examined the outcomes of research collaboration of French public laboratories with industry. None, however, have explicitly researched value creation from large-scale ISCs.

Intellectual capital derived from large-scale ISCs is broad and can include the following elements of scientific output: invention, innovation, new products/processes/services, patents, scientific publications, and knowledge. For the purpose of the study, the measures for both research frameworks are the perceived value of:

1. knowledge transfer,
2. scientific output (e.g., scientific discoveries, publications, patents).

Value Creation – Industrial Spillovers

A key aspect of the study is to research benefits to industry from large-scale ISCs. With the exception of Autio, Hameri *et al.* (2004) who have developed a framework and propositions around industrial knowledge spillovers to suppliers of the CERN big-science center, no other studies have specifically exploited this topic. The focus of their research was on interorganizational learning. Although the focus of this study is broader and includes industry as collaborators and recipients of large-scale ISCs, some of their propositions can be adapted in this study. The measures of this construct of the collective ISC framework are:

1. technological learning/knowledge transfer,
2. access to resources and expertise,
3. network extension: boundary-crossing links (access to networks),
4. increased competitiveness,
5. access to new international markets,
6. effect of prestige of government laboratories,
7. effect of scientific country image on industry.

Value Creation – Political Spillovers

Although researched to a lesser extent than intellectual outcomes, political spillovers are derived from large-scale ISCs. Building from the work of Wagner (2002) and Wagner and Staheli (2002), the study examines the impact of ISCs on the following measures.

Individual-level country framework:

1. reputation and credibility of country,
2. ability to access knowledge from other countries,
3. ability to access other ISCs with other countries.

Collective ISC framework:

1. science policy and priorities,
2. governance of international science issues,
3. S&T capacity building in developing countries,
4. leverage of national public research funding,
5. foreign policy,
6. international relations,
7. broader public (e.g., awareness, interest).

Tables 4 and 5 below summarize constructs and measures of the individual-level country and collective ISC research frameworks.

Table 4. Summary of measures - Individual-level country framework

Dimension	Construct	Measures	References
Structural	S&T Infrastructure	Scientific capabilities	OECD (2003b); Soltani and Birang (2005); Van Looy <i>et al.</i> (2006)
		Level of scientific productivity	
		Level of funding of S&T	
		Quality and availability of highly qualified personnel in S&T	
		Quality of linkages between government laboratories, universities, and private sector	

		Quality of the regulatory context			
		Overall quality of NIS			
	Network Ties	Quality of scientific networks	Granovetter (1973); Nahapiet and Ghoshal (1998); Tsai and Ghoshal (1998); Hagedoorn, Cloudt <i>et al.</i> (2005); McEvily and Zaheer (1999); Chen, Chang <i>et al.</i> (2006)		
		Embeddedness within the global scientific community			
		Number of world-renowned clusters			
	Social Interaction	Length of relationship			
		Level of social interaction			
		Network tie strength			
	Cognitive	Country Characteristics		Friendliness	Van Looy <i>et al.</i> (2006); Papadopoulos and Heslop (2000, 2002); Heslop, Papadopoulos <i>et al.</i> (2004);
				Trustworthiness	
Likeability					
Honesty					
Credibility					
Concern for others					
Level of education					
Innovative/entrepreneurial culture					
Achievements in science					
Openness to international trade					
Scientist Characteristics		Reputation	Madhok (1995); Hara, Solomon <i>et al.</i> (2003); Andersen and Sorensen (1999); Kuada (2002), Tsai and Ghoshal (1998); Christiansen and Vendele (2003)		
		Technological competencies			
		Connected within scientific networks			
		Interpersonal relationship skills			
		Ability to deal with collaborators from other cultures			
		Willingness to collaborate and trust			
		Trustworthiness			
		Flexibility and tolerance			
		International experience in ISCs			
		Management skills			
Shared Goals	Shared vision	Nahapiet and Ghoshal (1998); Rickards <i>et al.</i> (2001); Inkpen and Tsang (2005); Chen, Chang <i>et al.</i> (2006); Rocco <i>et al.</i> (2001)			
	Shared common goals and objectives				
	Agreement with task priorities				
Relational	Trusting Relationships	Interpersonal trust	McAllister (1995); Rocco, Finholt <i>et al.</i> (2001); Zaheer, Lofstrom <i>et al.</i> (2002); Dakhli and de Clercq (2004); Zaheer <i>et al.</i> (1998)		
		Interorganizational trust			
		Institutional trust			
Resource Exchange and Combination	Partner Attractiveness	Partner attractiveness (capabilities, resources, position within networks, IP protection, quality of data sharing)	Andersen and Sorensen (1999); Christiansen and Vendele (2003)		

	Collaboration Effectiveness	Quality of the collaboration	Christiansen and Vendele (2003)
		Efficiency of the collaboration	
		Productivity of the collaboration	
		Success of the collaboration	
Value Creation	Intellectual Capital	Knowledge transfer	Goddard and Isabelle (2006)
		Scientific output	
	Industrial Spillovers	Value of industry benefits	Autio et al. (2004); Kaufmann and Tödtling (2001); Chen, Chang <i>et al</i> (2006)
	Political Spillovers	Reputation and credibility of country	Wagner (2002); Wagner and Staheli (2002)
		Ability to access knowledge from other nations	
		Ability to access other ISCs with other countries	

Table 5. Summary of measures – Collective ISC framework

Dimension	Construct	Measures	References
Structural	Resources & capabilities	Quality of equipment and facilities	OECD (2003b); Soltani and Birang (2005); Van Looy <i>et al.</i> (2006)
		Complementarity of resources	
		Level of funding	
		Scientific capabilities	
		Quality of collaborators	
		Use of internet-based tools	
	Network Ties	Quality of network ties among collaborators	Granovetter (1973); Nahapiet and Ghoshal (1998); Tsai and Ghoshal (1998); Hagedoorn, Cloudt <i>et al.</i> (2005); McEvily and Zaheer (1999); Chen, Chang <i>et al.</i> (2006)
		Level of interaction	
		Quality of communication	
		Level of flexibility	
		Level of tolerance	
Cognitive	Shared Goals	Shared vision	Nahapiet and Ghoshal (1998); Rickards <i>et al.</i> (2001); Inkpen and Tsang (2005); Chen, Chang <i>et al.</i> (2006); Rocco <i>et al</i> (2001)
		Shared common goals and objectives	
		Agreement with task priorities	
	Management of	Management of data	Madhok (1995);

	collaboration	Management of IP issues	Hara, Solomon <i>et al.</i> (2003); Andersen and Sorensen (1999); Kuada (2002)
		Overall management and coordination	
Relational	Trust	Level of trust among collaborators	McAllister (1995); Rocco, Finholt <i>et al.</i> (2001); Zaheer, Lofstrom <i>et al.</i> (2002); Dakhli and de Clercq (2004); Zaheer <i>et al.</i> (1998)
Resource Exchange and Combination	Collaboration Effectiveness	Quality of the collaboration	Christiansen and Vendele (2003)
		Efficiency of the collaboration	
		Productivity of the collaboration	
		Success of the collaboration	
Value Creation	Intellectual capital	Knowledge transfer	Goddard and Isabelle (2006)
		Scientific discoveries	
		Publications	
		Patents	
	Industrial spillovers	Technological learning	Autio <i>et al.</i> (2004); Kaufmann and Tödtling (2001); Chen, Chang <i>et al.</i> (2006)
		Access to resources and expertise	
		Access to networks	
		Increased competitiveness	
		Access to new international markets	
		Prestige of public research labs	
	Political spillovers	Improved scientific country image	Wagner (2002); Wagner and Staheli (2002)
		Science policy and priorities	
		Governance of international science issues	
		S&T capacity building in developing countries	
		Leverage of national public research funding	
		Foreign policy	
		International relations	
		Broader public	

5.2 Survey Design

This research is exploratory and descriptive, using an ex post facto design (Davis 2000). Findings from Phase I fieldwork highlighted the need to include a broad range of scientific fields and countries. The type of ISCs, i.e., formal large-scale collaboration

involving Canada and one or more countries, has already been established for the purpose of the study. Therefore, this section addresses the final selection of scientific fields, countries, and sampling methodology.

5.2.1 Scientific Fields

The final selection of fields and number of fields was based on an analysis of formal, large-scale ISCs which are of strategic importance and relevance to Canada and globally, and that involves a Canadian or foreign government laboratory. Other considerations were accessibility for sampling and a good balance between centralized versus distributed ISCs based on Wagner's (2005a) categorization of ISCs.

In light of these criteria, the following eight scientific areas were sampled:

- space research (astrophysics, astronomy, aeronautics, astro-informatics, planetary atmospheric research),
- earth research (air, land, soil, oceanic science, marine biology, marine science, entomology, behavioural ecology, climate, atmospheric, Polar Regions),
- biotechnologies,
- agricultural and animal science,
- nanosciences and nanotechnologies,
- health research,
- advanced engineering, materials and manufacturing,
- physics (physical science, laser science, molecular physics, particle physics, molecular photonics, fundamental subatomic physics, mathematical physics).

These scientific fields are high on the priority list of Canada and other scientifically advanced countries. For instance, the European framework program (FP7) has targeted the following nine thematic areas: health; food; agriculture and biotechnology; ICT; nanosciences; nanotechnologies; materials and new production technologies; energy, environment; transport, security and space (http://cordis.europa.eu/fp7/home_en.html).

5.2.2 Country Selection

The country of application and primary interest is Canada. This research is not conceptualized or developed as a country-specific study. However, to satisfy the theoretical objectives of the study and to draw implications from a policy perspective for Canada, the study has been conceptualized to involve empirical analysis of a number of countries with whom Canada actively participates in large-scale ISCs, regrouped under home countries and other countries. The selection of other countries for empirical analysis has been based on the following criteria:

- scientifically advanced countries,
- actively involved with Canada on large-scale ISCs in the selected scientific fields mentioned above,
- accessibility for sampling.

The countries targeted for this study include those with whom Canada maintains active S&T umbrella agreements: Germany, France, Japan, and the European Union and China, as well as the U.S. and countries actively involved with Canada, such as the U.K., Nordic Countries, and Australia.

5.2.3 Sampling and Fieldwork

The sample is a judgmental (nonprobability/non-random sample), convenience sample of senior scientists working at Canadian or foreign government laboratories or universities, and involved in large-scale ISCs. Care was taken to ensure that respondents were part of ISCs that involved a Canadian or foreign government laboratory. The unit of analysis is individual scientist respondent. Stratification of the population before selection of the sample was based on status of scientists (principal investigator and senior scientist), selected scientific fields, and collaborating countries.

5.3 Pre-test

A questionnaire was developed for this research, and pilot testing of the questionnaire's functionality was conducted, using a convenience sample of twelve Canadian scientists of similar stature and qualifications as the population. Seven provided detailed written comments of the MS Word version of the questionnaire, and five provided verbal comments that helped refine the final on-line version.

Because of the validation of the reference of the research framework constructs during the in-depth interviews of Phase I, only minor modifications were required to the content of the questionnaire. Modifications were made to clarify the instructions and reword some terms to ensure good understanding of the terminology used in the survey. This was especially important given the international scope of the survey and its form of administration. One modification involved clarifying the definition of 'formal, large-scale' ISC. It was originally defined as 'those under a formal agreement such as a Treaty

of S&T, an S&T Agreement or International Arrangement, a Memorandum of Understanding among countries and/or government laboratories, or any other formal written agreement'. However, it was pointed out that in some fields such as agriculture and animal science, ISCs do not necessarily fall under a formal written agreement, even though they are long term and funded research projects. Therefore, clarifications were provided around the nature of such ISCs for the purpose of the study as being 'specific research projects (as opposed to informal exchanges of information and personnel), typically involving resources (funding, people) of some duration and, sometimes but not always, under some form of agreement among collaborating parties, such as a research collaboration agreement or Memorandum of Understanding.'

The questionnaire was distributed using the web-based research tool Zoomerang. It was comprised of a cover page and three questionnaire sections. The questionnaire is presented in Appendix C. Section A included questions on the constructs at the individual country collaborator level, that is: section A1 Canada (all respondents); section A2 Home Country if different from Canada (respondents not working in Canada); and section A3, another country significantly involved in the ISC (all respondents). Section B is concerned with measures related to the entire collaboration. Section C contained general information on the respondent and the ISC they selected as the focus in responding to the questionnaire.

5.4 Full-Scale Survey

Data were collected through a web-based self-administered questionnaire. Based on the results of the pilot study, the revised questionnaire was set up in Zoomerang and launched Feb. 19, 2007. Data collection ended June 26, 2007.

There is no Canadian directory, repository or other mechanisms listing ISCs. Therefore, substantial effort was required to gather information concerning ISCs and to ensure that selected ISCs met the criteria for the intent of the study, that is formal, large-scale and involving a Canadian or foreign government laboratory. The general approach consisted of identifying ISCs involving Canada in the selected scientific fields and then obtaining the name/email of the Canadian and foreign Principal Investigators (PI) and/or senior scientists. This was accomplished by contacting senior individuals within the NRC's various institutes and NRC International Relations Office, and within other science-based department agencies. In particular, Agriculture and Agri-Food Canada took a keen interest in the research and ensured a good participation from their researchers and their foreign counterparts.

Contacts were also established with individuals interviewed during Phase I, with members of the Department of Foreign Affairs and International Trade's Interdepartmental Network on International S&T (DFAIT - INIST) and other networks such as Federal Partners in Technology Transfer (FPTT), the Canadian Network of Centres of Excellence (CNE), the Canadian Institute for Health Research (CIHR), the Canadian Foundation for Innovation (CFI), and the International Council for Science

(ICSU). Other sources include European programs for international scientific collaboration, government lists of large-scale ISCs extracted from websites and reports, web searches, special reports and professional contacts. Several of DFAIT's S&T Counsellors abroad were extremely helpful in providing lists of ISCs involving a Canadian or foreign government laboratory, as well as contacts. In particular, the counsellors in Germany, Norway, Denmark, Finland, and Australia provided helpful assistance. Key individuals within the course of the researcher's international work functions at NRC were contacted. Email addresses of PIs and senior scientists were searched.

A cover letter was emailed to the PIs explaining the purpose of the study and providing the link to the web site. PIs were asked to respond to the survey as well as to forward the questionnaire to their collaborators if their names were not already identified. Both French and English versions of the questionnaire were developed. Ninety percent of the respondents filled in the English questionnaire.

5.5 Questionnaire Response Rate

In all, approximately 350 ISCs were identified and invitation emails to participate in the survey were sent to a total of 655 Canadian and foreign scientists. A number of steps were taken to ensure a good response rate to the survey. The survey was designed to make it easy to complete. This included laying out the survey clearly, making the questions easy to read and well spaced, and making responses easy to complete by simply clicking the appropriate response. Email addresses were searched when invitations

‘bounced’, and reminders were sent. Zoomerang registered 518 ‘visits’ to the survey site; 77 respondents partially completed the survey and 184 fully completed the survey for a total of 261 partially and fully completed questionnaire. The overall response rate was 39.8% (261/655) for partial and full responses, and 28% (184/655) response rate for the fully completed surveys. This response rate can be considered quite acceptable given that a typical response rate for web-based surveys is lower than 20. The 77 partially completed questionnaires were eliminated from further analysis. Of the 184 fully completed questionnaires, five questionnaires were further eliminated upon analysis as they were too incomplete, and two were rejected because they were improperly completed (same score for all questions of the questionnaire). Therefore, the usable number of questionnaires for this study is 177 and a response rate of 27% (177/655). The goal of 100 usable surveys was well exceeded.

Possible reasons for not completing the survey include the ISC not fitting the focus of the study, lack of time to complete the questionnaire, and language barriers. A possible indicator of the language issue is the low response rate (approx. 14%) proportionally of Asian scientists compared to the number of surveys sent out to scientists from Asian countries.

6 PHASE II RESULTS

6.1 Overview of Respondents

The vast majority of respondents (88%) were senior researchers, as they were the target of the survey. Specifically, of the 177 usable questionnaires, 92 (52%) respondents were principal investigators, 63 (36%) were senior scientists, while 10 (6%) were managers. Of the remainder, 9 (5%) were junior members and 3 (2%) respondents did not answer this question. Participants were asked to specify the type of organization they work for. Of 170 answers, 91 (53.5%) respondents worked at a government laboratory, while 76 (44.7%) worked at a university. Likely, this finding reflects an increasing trend of government and academia to jointly collaborate in ISCs. As previously mentioned, care was taken to select respondents from ISCs involving a Canadian or foreign government laboratory. Out of 175 respondents who indicated their country of work, 96 (54.9%) scientists work in Canada, and 79 (45.1%) work outside of Canada. Out of the 96 scientists working in Canada, five claimed Canada not to be their home country. Fifty-five respondents (31%) reported that an industrial firm was directly involved in the ISC.

The questionnaire was composed of the three sections described in the previous chapter, and used a 7-point Likert scales for scale-based questions. Although respondents were quite diligent in answering questions in the 177 usable questionnaires, some sections were nevertheless judged as incomplete. Using a cut-off of 85% completion of the number of questions per section, answers to incomplete sections were deleted from the dataset for further analyses. Table 6 displays the maximum sample sizes.

Table 6. Maximum sample sizes per questionnaire section

Questionnaire section	N
Section A: selected country collaborators	
Canada	151
Home Country	72 ^a
Other Country	101
Section B: Entire ISC	157
Section C: General Information	175

^a: Canadian scientists did not answer this section.

6.2 Geographical Regions

Table 7 shows the breakdown of respondents by geographical regions. Although an attempt was made during sampling to ensure an adequate representation of scientists from several geographical regions of scientifically advanced countries, sampling was of a convenience nature and access to and answers from respondents could not easily be controlled. For instance, the Department of Foreign Affairs and International trade were particularly helpful in encouraging response from the Nordic countries and Australia which helps explain the higher response rate from these regions. However, results from other parts of the world (including the U.S. and Asia) were lower.

Table 7. Geographical regions of respondents

Geographical regions of respondents	Frequency	Percent
Canada	96	54.2
Europe		
Nordic	28	15.8
Other	14	7.9
US	6	3.4
Asia	9	5.1
Australia	22	12.4
Total	175	98.9

Overall, Canadian and foreign scientists in this research were collaborating with the US, France, Taiwan, the UK, Germany, Spain, China, and Japan. Table 8 illustrates the breakdown of collaborators across geographical regions.

Table 8. Geographical regions of collaborators

Geographical regions of collaborators	Frequency	Percent	Valid Percent
Europe – Non Nordic	36	20.3	33.3
Nordic Europe	11	6.2	10.2
US	19	10.7	17.6
Asia	33	18.6	30.6
Australia	6	3.4	5.6
Others	3	1.7	2.8
Sub total	108	61.0	100.0
Missing	69 ^a	39.0	
Total	177	100.0	

^a= Excludes Canada

6.3 Scientific Fields

The eight scientific fields selected in this study were fairly well represented in the dataset as illustrated in Table 9.

Table 9. Distribution of scientific fields

Scientific Fields	Frequency	Percent	Examples of ISCs
Space Research	20	11.7	Mars exploration
Earth Research	29	17.0	International Polar Year
Biotechnologies	23	13.5	Marine biotechnologies
Nanosciences and nanotechnologies	12	7.0	Engineered nanomaterials
Health Research	18	10.5	Food and biomaterials
Advanced engineering and manufacturing	29	17.0	Materials science
Agricultural and animal science	15	8.8	Brassica genomics
Physics	13	7.6	Ginsparg-Wilson fermion
Others	12	7.0	Energy, ICT
Total	171	100.0	

6.4 Duration of ISCs

Participants were asked to specify the duration of the ISC they selected as the focus in completing the questionnaire. Of the 150 who responded to the question, the total duration of ISCs varied greatly with a mean of 4.86 years, a median of 3.5 years and a standard deviation of 4.5. As can be expected, fields such as space research and physics exhibited higher average duration, respectively 7.4 and 8.4 years, than other fields in the survey. Five respondents indicated a duration of over 20 years.

6.5 Data Analysis

The aim of this section is to provide relevant statistical analyses of the data in order to effectively compare the results with key findings from the literature review section, as well as with insights gathered from the in-depth interviews. Then, the analysis of the form of the relationships within both research frameworks, taking into account the main and mediating effects, are presented and discussed. The ultimate goal is to derive implications and directions for policy makers, as discussed in chapter 7.

6.5.1 Overview of Survey Responses

A frequency distribution of all key constructs and individual variables was conducted. The answers were widely distributed over the response range on the 7-point Likert scale. Means and standard deviations of the variables for the individual-level country framework and the collective ISC framework are displayed in Appendix E. Assumptions of parametric data were checked using histograms and values of skewness and kurtosis. The values of skewness and kurtosis should be zero in a normal distribution. The further the value is from zero, the more likely it is that the data are not normally distributed

(Field, 2005). Measures were within acceptable limits for all but a small number of measures.

6.5.1.1 Reliability tests of the variable measures – Cronbach's alpha values

The reliability of the variable measures of each construct was assessed. Reliability refers to the consistency and stability of a score from a measurement scale (Davis 2000). Cronbach's alpha coefficient is the most widely used method of reliability assessment in business research and is therefore used in this research. An alpha of 0.70 is usually considered reliable, coefficients as low as 0.50 are, however, accepted for constructs with few measures and for exploratory research (Nunnally 1978). All of the values for Cronbach's alpha of the variable measures exceed the threshold of 0.70 as indicated in the tables 10 and 11 below. The constructs of the two frameworks were judged as having acceptable reliability.

6.5.1.2 Exploratory factor analysis

The measures in this research were derived from previous research (see Tables 4 and 5). The evidence gathered in these previous studies provides significant support for the usefulness of the measures. However, since the measures came from more than one previous study, there was a risk that the scales and measures derived by two different authors may be measuring the same underlying construct. To test for this, an exploratory factor analysis (EFA) was conducted for both research frameworks, using the constructs and measures of each framework. The analysis was performed using principal component analysis with varimax rotation, using a cut-off of eigenvalues greater than 1.0, and factor loading above 0.4 (Stevens 2002).

Results of the EFA for individual measures of each research frameworks are shown in Appendix E. The loadings were all within acceptable limits with the measures of each constructs loading on one factor as predicted on the research frameworks. However, after careful review of the results of the EFA for the network ties construct and the industrial spillovers construct, two slight modifications were brought to the original research frameworks. The first modification involved separating the measures under ‘network ties’ of the structural dimension of the individual-level country framework into two distinct constructs: ‘network ties’ and ‘social interaction’ (reflected in figure 6) as per Chen, Chang *et al.* (2006), given that in this research, the measures of network ties were at the country level while the measures of social interaction were at the ISC level. The second modification separated the measures of ‘industrial spillovers’ of the collective ISC research framework into direct industrial spillovers (that is spillovers to firms directly involved in the ISC) and indirect industrial spillovers (that is spillovers for the industry in general).

Cronbach’s alpha and principal components factor analysis confirmed that the measures of the key constructs appear to be measuring each of the constructs as a single-dimension construct. Therefore, these results provide further support for the validity of the measures and for combining the measures into measures of the constructs as per the two research frameworks. Consequently, the measures of each construct were combined to develop an overall score for each of the main constructs. Tables 10 and 11 below summarize for each research framework the number of measures of each key construct, the means and standard deviations of each key construct for each reference country, as

well as the range of factor loadings of measures composing each key construct from EFA and reliability results using Cronbach's alpha.

Table 10. Key constructs – Individual-level country framework

Key construct (Number of measures)	Mean (std dev)			Factor loadings (range) of component measures			Cronbach's Alpha		
	Canada N=151	Home N=72	Other Country N=101	Canada	Home	Other Country	Canada	Home	Other Country
S&T Infrastructure (10)	4.76 (1.00)	4.74 (.98)	5.23 (.88)	.697- .902	.507- .911	.679- .888	.930	.912	.938
Network ties (3)	4.74 (1.10)	4.95 (1.04)	5.15 (1.14)	.853- .879	.812- .890	.847- .884	.845	.804	.847
Social interaction (4)	4.61 (1.31)	5.66 (1.37)	4.73 (1.26)	.594- .912	.770- .897	.642- .890	.809	.870	.810
Country characteristics (10)	5.63 (.73)	5.52 (.80)	5.44 (.75)	.629- .907	.483- .859	.446- .908	.919	.878	.884
Scientist characteristics (13)	5.47 (.85)	5.34 (.91)	5.40 (.85)	.644- .860	.705- .867	.529- .855	.942	.949	.941
Shared goals (3)	5.42 (1.08)	5.66 (1.03)	5.50 (1.07)	.932- .961	.911- .967	.942- .961	.944	.944	.947
Trusting relationships (5)	5.55 (.88)	5.55 (.91)	5.31 (.98)	.658- .895	.555- .920	.721- .902	.857	.842	.891
Partner attractiveness (10)	5.16 (.94)	5.07 (1.10)	5.41 (.89)	.657- .827	.667- .885	.613- .828	.942	.919	.909
Collaboration effectiveness (4)	5.53 (1.01)	5.58 (.97)	5.55 (1.09)	.907- .937	.909- .930	.931- .955	.937	.940	.958
Total value creation (6)	5.31 (.91)	5.27 (.99)	5.24 (.98)	.675- .847	.714- .901	.721- .874	.885	.906	.889
Intellectual capital (2)	5.52 (.95)	5.54 (1.01)	5.50 (1.03)	.933	.933	.939	.862	.852	.869
Industrial capital (1)	4.70 (1.35)	4.73 (1.53)	4.78 (1.44)	---	---	---	---	---	---
Political spillovers (3)	5.36 (1.02)	5.26 (1.09)	5.21 (1.10)	.834- .901	.912- .925	.897- .942	.845	.909	.911

At the individual-level country, Cronbach' alpha values are fairly consistent across the reference countries (Table 10). The same can be said of the factor loadings. It appears that scientists were quite able to consistently take into consideration the broader view of a country and its people in their ISCs. This would tend to lend credibility to the addition of themes from the country image literature to the three dimensions of Nahapiet and Ghoshal's (1998) social capital framework. Means of the political spillovers construct are higher than industrial spillovers. However, only 31% reported a direct involvement of an industrial firm with the ISC. It may also be that scientists are cognizant of the importance of such political benefits as credibility and reputation of country, and ability to access knowledge and other ISCs with other countries.

Table 11. Key constructs – Collective ISC framework

Key construct	Number of Measures	N	Mean (std dev)	Factor loadings (range)	Cronbach's alpha
Resources and capabilities	6	157	5.23 (.90)	.410 - .904	.826
Network ties	5	156	5.29 (.97)	.790 - .909	.911
Shared goals	3	154	5.47 (1.05)	.939 - .962	.949
Management of collaboration	3	155	5.10 (1.12)	.860 - .927	.892
Trust	1	155	5.65 (1.08)	---	---
Collaboration effectiveness	4	156	5.55 (1.07)	.930 - .947	.957
Intellectual capital	6	156	5.09 (.98)	.522 - .857	.818
Direct industrial spillovers	9	56	4.98 (1.09)	.702 - .847	.921
Indirect industrial spillovers	9	120	5.08 (1.16)	.749 - .874	.950
Political spillovers	7	146	4.17 (1.52)	.757 - .895	.940

The sample size for direct industrial spillovers was lower than for indirect industrial spillovers (Table 11) as respondents were to answer questions related to that construct only if industrial firms were directly involved in the ISC. The lowest factor loading for resources and capabilities was caused by the measure around the use of internet-based tools (excluding email) to collaborate, with a mean of 4.24 and a standard deviation of 1.58. Despite the recent literature on cyberinfrastructure, it appears that the use of internet-based tools or computer-mediated communication to collaborate still does not rate very highly. Space research, physics and biotechnologies exhibited higher averages on this measure (not shown) as can be expected given the manipulation of large datasets in these scientific fields. An overview of results for individual measures of each of the key constructs for both research frameworks can be found in Appendix E.

6.5.2 Desired Characteristics of Scientific Collaborators

Objective 2, to research the desired characteristics of international partners in ISCs and the attractiveness of Canada as a scientific partner, was achieved by asking respondents to rate two or three countries involved in an ISC – Canada, their own country if different from Canada, and another country significantly involved in the ISC (Sections A1, A2 and A3 respectively of the questionnaire in Appendix C). Means and standard deviations of the characteristics of Canada, Home Country and Other Country were described above. The individual-level country framework did not contain hypotheses related to inter-country differences. However, MANOVA analysis was used to explore differences among the ratings of the measures and the constructs for the three groups.

6.5.2.1 Exploration of all measures

Exploration of the data was first done through a MANOVA analysis using all 66 measures together from all respondents. Table 12 displays means and standard deviations of the measures showing statistically significant differences, as well as F-ratios and significance, with equal variances assumed and using Bonferroni and Tukey as *post hoc* tests to explore differences between means. All overall multivariate F-test statistic reported are Wilks' Lambda tests. Results for all measures are shown in Appendix F.

Table 12. Means of measures and test of inter-country differences

Constructs	Measures	Mean (Standard deviation) of measures			F	Sig.
		Canada N=65	Home Country N=38	Other Country N=65		
S&T infrastructure	Level of funding of S&T (country level)	4.20 ^a (1.39)	4.26 ^a (1.13)	<u>5.15^b</u> (1.41)	9.57	.000
	Availability of HQP* in S&T	5.08 ^{a,b} (1.23)	4.87 ^a (1.21)	<u>5.54^b</u> (.95)	4.97	.008
	Quality of linkages among public research organizations	4.29 ^a (1.26)	<u>5.00^b</u> (1.23)	4.97 ^b (1.15)	9.45	.002
	Supportive S&T Policies	4.00 ^a (1.24)	4.32 ^a (1.36)	<u>5.09^b</u> (1.34)	11.82	.000
	Quality of Regulatory policies	3.97 ^a (1.21)	4.39 ^{a,b} (1.24)	<u>4.65^b</u> (1.14)	5.33	.006
Network Ties	Ties within global scientific community	4.80 ^a (1.25)	<u>5.50^b</u> (1.23)	5.32 ^{a,b} (1.30)	4.54	.012
	Number of world-renowned research clusters	4.35 ^a (1.08)	4.50 ^a (1.33)	<u>5.11^b</u> (1.45)	6.02	.003
Social interaction	Length of relationship	4.97 ^a (1.95)	<u>5.95^b</u> (1.72)	5.05 ^a (1.87)	3.73	.026
	Frequency of interaction	4.55 ^a (1.44)	<u>5.74^b</u> (1.62)	4.65 ^a (1.46)	8.62	.000
	Intensity of relationship	4.60 ^a (1.48)	<u>5.68^b</u> (1.34)	4.82 ^a (1.45)	7.18	.001
	Strength of ties with scientific networks	4.08 ^a (1.53)	<u>5.37^b</u> (1.60)	4.40 ^a (1.46)	8.86	.000
Country Characteristics	Concern for others	<u>5.60^b</u> (.92)	5.50 ^b (1.06)	4.85 ^a (1.18)	9.31	.000
Partner Attractiveness	Level of funding (ISC level)	3.94 ^a (1.54)	4.39 ^{a,b} (1.52)	<u>5.06^b</u> (1.47)	9.10	.000

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$.

Underlined values represent highest means. MANOVA F-test 2.340 at $\alpha < .000$

* Highly Qualified Personnel

Overall F was significant, indicating that there are differences across countries reviewed. Of the 66 measures, 13 were significantly different among the three groups. Specifically, statistical differences were observed for five of the ten measures composing the S&T infrastructure construct, two of the three measures of the network ties construct and all measures of the social interaction construct. These three constructs were part of the structural dimension of social capital of the framework. Only one measure of the country characteristics – concern for others, was found to have a significant difference among the groups, and only one of the eight measures of the partner attractiveness construct. With the exception of concern for others, Canada's ratings on the measures were lower than for Home Country and Other Country. No significant differences among the groups were observed for the measures of the other constructs of the framework, namely scientist characteristics, shared goals, trusting relationships, collaboration effectiveness and measures of value creation from the ISC. Hence, it would appear that the constructs of the structural dimension of the framework – S&T infrastructure, network ties and social interaction, are the ones where respondents found most differences among the groups.

6.5.2.2 MANOVA analysis of the constructs for all respondents

Given that factor analysis and Cronbach's alpha confirmed all construct measures, the means were calculated of the measures to determine an overall computed value of each key construct of the individual-level country research framework. Specific constructs displaying significant inter-country differences were then investigated through MANOVA analyses to compare with results of the previous MANOVA analysis of all measures. The F-test of the 13 constructs is 3.51 at $\alpha = .000$ and therefore reveals

significant differences among the groups. Table 13 displays the results for the computed values of these 13 key constructs.

Table 13. Means of key constructs and test of inter-country differences

Constructs	Mean (Standard deviation) of Constructs			F	Sig.
	Canada N=103	Home Country N=53	Other Country N=95		
Structural dimension					
S&T Infrastructure	4.86 ^{a,b} (1.03)	4.64 ^a (1.01)	<u>5.23^b</u> (.90)	6.87	.001
Network Ties	4.78 ^a (1.15)	4.92 ^a (1.10)	<u>5.16^a</u> (1.17)	2.66	.072
Social Interaction	4.60 ^a (1.35)	<u>5.64^b</u> (1.43)	4.75 ^a (1.28)	11.07	.000
Cognitive Dimension					
Country Characteristics	<u>5.68^a</u> (.77)	5.49 ^a (.82)	5.46 ^a (.76)	2.18	.115
Scientist Characteristics	<u>5.49^a</u> (.91)	5.28 ^a (.90)	5.40 ^a (.87)	.95	.389
Shared Goals	5.37 ^a (1.11)	<u>5.60^a</u> (1.08)	5.54 ^a (1.06)	.98	.377
Relational Dimension					
Trusting Relationships	<u>5.53^a</u> (.95)	5.47 ^a (.96)	5.33 ^a (.97)	1.14	.321
Resource Exchange and Combination					
Partner Attractiveness	5.23 ^{a,b} (.99)	4.99 ^a (1.15)	<u>5.41^b</u> (.91)	3.10	.047
Collaboration Effectiveness	5.54 ^a (1.05)	5.50 ^a (1.02)	<u>5.56^a</u> (1.11)	0.50	.951
Value Creation					
Intellectual Capital	<u>5.50^a</u> (1.00)	5.42 ^a (1.02)	5.50 ^a (1.04)	.12	.884
Industrial Spillovers	4.78 ^a (1.31)	4.70 ^a (1.34)	<u>4.78^a</u> (1.44)	.07	.931
Political Spillovers	<u>5.37^a</u> (1.07)	5.21 ^a (1.14)	5.19 ^a (1.13)	.71	.491
Total Value Creation	<u>5.32^a</u> (.97)	5.19 ^a (1.03)	5.23 ^a (1.00)	.35	.706

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$. Underlined values represent highest means. MANOVA F-test 3.51 at $\alpha < .001$.

Results in Table 13 show beliefs about the countries differed on all the constructs of the structural dimension and for one of the constructs of the resource exchange and combination dimension. Specifically, there were statistically significant differences among the S&T Infrastructure, social interaction and partner attractiveness constructs,

with network ties approaching significance at $\alpha < .10$. The S&T infrastructure of Other Country rated significantly higher by the respondents than the S&T infrastructure of Canada and of Home Country. This finding, in particular, points to the effectiveness of integrating constructs from the national innovation systems literature (OECD 2003b, Soltani and Birand 2005, Van Looy *et al.* 2006.) in the research framework to study inter-country differences.

Comparing MANOVA analyses of the measures (Table 12) and constructs levels (Table 13), the results are generally congruent. Analyses at both measure and construct levels found constructs of the structural dimension and partner attractiveness showing significant differences in ratings among the groups. However, at the construct level, ratings of country characteristics were not significantly different among the groups due to measure smoothing.

To further investigate specific constructs displaying significant inter-country differences, individual level ANOVA analyses were performed on the measures of each of these significantly different constructs. Table 14 below indicates the means of these measures for the S&T infrastructure construct.

Table 14. Means of S&T infrastructure measures and test of inter-country differences

Measures	Mean (Standard deviation) of Measures			F	Sig.
	Canada (N=113)	Home Country (N=62)	Other Country (N=73)		
Scientific Capabilities	5.50 ^a (1.06)	5.40 ^a (1.20)	<u>5.70^a</u> (.98)	1.36	.259
Scientific Productivity	5.24 ^{a,b} (1.09)	5.16 ^a (1.19)	<u>5.60^b</u> (1.05)	3.34	.037
Funding of S&T	4.04 ^a (1.36)	4.16 ^a (1.22)	<u>5.19^b</u> (1.34)	18.26	.000
Availability of HQP in S&T	4.91 ^a (1.29)	4.89 ^a (1.24)	<u>5.49^b</u> (.99)	6.30	.002
Quality of HR in S&T	5.16 ^{a,b} (1.08)	4.89 ^a (1.29)	<u>5.33^b</u> (1.01)	2.63	.074
Quality of linkages among public research organizations	4.15 ^a (1.23)	4.95 ^a (1.21)	<u>5.01^b</u> (1.12)	15.12	.000
S&T Policies	3.90 ^a (1.32)	4.15 ^a (1.33)	<u>5.14^b</u> (1.32)	20.20	.000
Regulatory Policies	3.90 ^a (1.30)	4.39 ^b (1.26)	<u>4.67^b</u> (1.12)	9.07	.000
IP Policies and Practices	4.27 ^a (1.19)	4.55 ^{a,b} (1.33)	<u>4.77^b</u> (1.31)	3.49	.032
Overall Quality of S&T system	4.76 ^{a,b} (1.15)	4.66 ^a (1.19)	<u>5.19^b</u> (1.21)	4.18	.016

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$. Underlined values represent highest means. MANOVA F-test 5.44 at $\alpha < .001$.

The Other Country was rated significantly higher on all of the measures of the S&T infrastructure construct compared to Canada and Home Country. Quoting from a Phase I participant, 'ISCs are about collaborating with the best'. It appears that respondents felt the Other Country was better on these dimensions. Of the ten measures composing the S&T infrastructure construct, only scientific capabilities were not significantly different among the three groups. For Canada, this finding confirms the conclusions of several Canadian and foreign reports of the excellent Canadian scientific reputation. These findings were also confirmed by the Canadian scientists interviewed in Phase I. Canada was not seen as significantly different from the Other Country rated on scientific productivity, and likewise for the quality of HR in S&T and the overall quality of S&T

system. However, on funding of S&T, quality of linkages among public research organizations and measures around S&T and regulatory environment – S&T policies, regulatory policies and IP policies and practices, Canada was given the lowest ratings in comparison with the other countries assessed.

Since inter-country differences on network ties approached significance ($\alpha < .10$), ANOVA analyses of each individual measure of network ties were conducted. Results are shown in Table 15.

Table 15. Means of network ties measures and test of inter-country differences

Measures	Mean (Standard deviation) of measures			F	Sig
	Canada (N=142)	Home Country (N=69)	Other Country (N=92)		
Quality of scientific networks	4.75 ^a (1.27)	<u>5.06^a</u> (1.15)	5.05 ^a (1.30)	2.31	.101
Ties within global scientific community	4.99 ^a (1.25)	5.26 ^a (1.22)	<u>5.40^a</u> (1.24)	3.36	.036
Number of world-renowned research clusters	4.52 ^a (1.21)	4.52 ^a (1.35)	<u>5.17^b</u> (1.42)	8.00	.000

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$. Underlined values represent highest means. MANOVA F-test 3.98 at $\alpha < .001$.

No statistically significant differences were observed for quality of scientific networks. The measure of ties within the global scientific community was significant but no inter-country mean differences were found in *post hoc* testing. As for the number of world-renowned research clusters, there were significant inter-country differences, and the ratings were higher for Other Country. The cluster phenomenon is relatively recent in Canada compared to the U.S. and requires a large public sector investment in relevant science and technology for creation and sustainability (Isabelle 2007). This finding suggests the relevance of world-renowned research clusters for the network ties construct.

Table 16 shows the results of the ANOVA analyses on individual measures composing the social interaction construct. In the questionnaire, respondents were asked, specific to the ISC, to provide information on the nature of their relationship with scientific collaborators from the country (Canada, their Home Country, Other Country – three separate questions). In the case of Canada and their Home Country, they were instructed to skip the question if they were not collaborating with other Canadian scientists in the case of Canadian respondents, and if they were not collaborating with other scientists from their Home Country in the case of foreign scientists.

Table 16. Means of social interaction measures and test of inter-country differences

Measures	Mean (Standard deviation) of measures			F	Sig
	Canada N=115	Home Country N=59	Other Country N=99		
Length of relationship (in years)	5.01 ^a (1.96)	<u>6.05^b</u> (1.62)	5.01 ^a (1.93)	7.09	.001
Frequency of interaction	4.57 ^a (1.55)	<u>5.92^b</u> (1.43)	4.69 ^a (1.47)	17.39	.000
Intensity of relationships	4.69 ^a (1.50)	<u>5.63^b</u> (1.34)	4.86 ^a (1.41)	8.72	.000
Strength of ties with scientific networks	4.18 ^a (1.57)	<u>5.32^b</u> (1.61)	4.41 ^a (1.46)	11.00	.000

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$. Underlined values represent highest means. MANOVA F-test 4.834 at $\alpha < .001$.

All measures composing the social interaction construct were statistically significant. Ratings of Home Country, i.e., foreign scientists rating their interaction with other scientists from their home country, were significantly higher. However, they also rated highly the quality of linkages among public research organizations, quality of scientific networks of their home country, and position within domestic scientific networks. Together, these ratings may point to strongly coordinated national innovation systems (NIS) likely favouring a high level of interaction.

Finally, ANOVA analyses were conducted on individual measures of the partner attractiveness construct, shown in Table 17. The respondents were asked to rate the attractiveness of the country as a scientific collaborator on several measures.

Table 17. Means of partner attractiveness measures and test of inter-country differences

Measures	Mean (Standard deviation) of measures			F	Sig
	Canada N=115	Home Country N=59	Other Country N=99		
Scientific capabilities	5.71 ^a (1.03)	5.57 ^a (1.25)	<u>5.79^a</u> (.96)	.72	.486
Equipment and facilities	5.44 ^a (1.12)	5.37 ^a (1.28)	<u>5.51^a</u> (1.26)	.23	.795
Complementarity of resources	5.37 ^a (1.03)	5.27 ^a (1.18)	<u>5.41^a</u> (1.22)	.29	.746
Position within domestic scientific networks	4.94 ^a (1.08)	<u>5.32^a</u> (1.18)	5.23 ^a (1.16)	2.66	.072
Position within global scientific networks	4.96 ^a 1.27	<u>5.22^a</u> 1.29	5.13 ^a 1.29	.95	.390
Level of funding	4.02 ^a (1.49)	4.15 ^a (1.66)	<u>5.01^b</u> (1.48)	10.46	.000
Quality of IP protection	<u>4.84^a</u> (1.28)	4.78 ^a (1.31)	4.59 ^a (1.23)	.96	.385
Quality of data sharing	5.17 ^a (1.09)	<u>5.23^a</u> (1.44)	5.11 ^a (1.34)	.17	.843
Interest in working with country and its scientists again	6.14 ^c (1.16)	---	5.98 (1.16)	--	--
Likelihood of selecting country for future collaborations	5.93 ^c (1.36)	---	5.90 (1.19)	--	--

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$. Underlined values represent highest means. MANOVA F-test 3.70 at $\alpha < .001$.

^c N = 70

From the results in Table 17, it might be concluded that only money matters as level of funding is the only statistically different measure. Canada displayed the lowest rating but not significantly lower than the rating of Home Country. This lower funding support in Canada was substantiated by comments from the interviewees who believed that Canada does not have the money to “play the game”. The measure of position within domestic scientific networks approached significance at $\alpha < .10$. On the question of interest in

working with Canada and its scientists again, the rating of foreign scientists was a very high 6.14, but this was not significantly different from the rating of Other Country. In addition, ratings on the question of likelihood of selecting the country for future collaboration were nearly identical at 5.93 and 5.90 for Canada and Other Country respectively.

Consistent with results above, several ratings of measures around scientific capability and resources (equipment and facilities, resources, funding) for Other Country were consistently higher than for Canada and Home Country. Likewise, ratings of measures around network ties (domestic and global scientific networks) were higher for Home Country. Although Canada's quality of IP policies and practices was rated relatively lower (Table 14), the quality of Canada's IP protection was considered higher than Home and Other Country. Of note, there was no significant difference in the ratings of IP protection among the groups. This was likely due to the fact that countries involved in the sampling are scientifically advanced countries with a long-standing tradition of adequate IP protection.

As the collaboration effectiveness and value creation constructs did not display inter-country differences, ANOVA analyses of the measures of these constructs were not performed.

6.5.2.3 Perceptions of Canadian and foreign scientists

This section examines how Canadian scientists see themselves and others, and likewise how foreign scientists perceive Canada and its scientists versus the Other Country. These

analyses were conducted by first, including only scientists working in Canada (Table 18) and then in a second analysis, by excluding them (Table 19) to see how others view Canada.

Table 18. Canadian scientists' views of Canada and Other Country

Constructs	Mean (Std dev) of constructs		F	Sig
	Canada N=43	Other Country N=75		
Structural dimension				
S&T Infrastructure	4.37 (.95)	<u>5.13</u> (.88)	19.46	.000
Network Ties	4.37 (.98)	<u>4.99</u> (1.11)	9.26	.003
Social Interaction	<u>4.66</u> (1.20)	4.61 (1.25)	.040	.842
Cognitive Dimension				
Country Characteristics	5.42 (.77)	<u>5.43</u> (.73)	.005	.943
Scientist Characteristics	5.24 (.59)	<u>5.35</u> (.86)	.55	.461
Shared Goals	5.09 (.92)	<u>5.48</u> (1.07)	3.87	.052
Relational Dimension				
Trusting Relationships	5.21 (.86)	<u>5.30</u> (.97)	.26	.615
Resource Exchange and Combination				
Partner Attractiveness	4.81 (.75)	<u>5.33</u> (.90)	10.35	.002
Collaboration Effectiveness	5.45 (.80)	<u>5.48</u> (1.16)	.02	.884
Value Creation				
Intellectual Capital	5.37 (.83)	<u>5.43</u> (1.08)	.10	.749
Industrial Spillovers	4.51 (1.18)	<u>4.60</u> (1.47)	.11	.737
Political Spillovers	<u>5.43</u> (.76)	5.07 (1.15)	.33	.071
Total Value Creation	<u>5.26</u> (.73)	5.11 (1.02)	.70	.406

Sig at $\alpha < .05$. MANOVA F-test 4.01 at.

Only three constructs displayed significant statistical differences: S&T infrastructure, network ties and partner attractiveness. This is similar to the general combined findings. T-tests were conducted on individual measures of the significant constructs (not shown).

For the S&T infrastructure constructs (N=80), all the measures were found to be significantly different between countries rated except for scientific capabilities, scientific productivity and quality of HR in S&T. All average means were higher for Other Country. Highest differences were for funding of S&T (3.66 vs. 5.21) and for S&T policies (3.47 vs. 5.16), followed by quality of linkages among public research organizations (3.83 vs. 4.89). T-tests on the measures of network ties (N=79) showed similar results. All measures were significant with average means higher for Other Country especially for world-renowned research clusters (4.27 vs. 4.93). For the partner attractiveness construct, position within domestic network showed a significant difference (4.74 vs. 5.12), and, there was, as expected, a large significant difference for the level of funding (3.58 vs. 5.17). The data suggest that Canadian scientists are acutely aware of the shortcomings of their innovation system. In particular, they feel that they are underresourced compared to other countries, and that Canada lacks good national and international linkages.

Next, MANOVAs were computed on the constructs for the foreign scientists only to get a picture of how they see Canada vs. other collaborators.

Table 19. Foreign scientists' views of Canada, Home Country and Other Country

Constructs	Mean (Standard deviation) of Constructs			F	Sig
	Canada N=60	Home Country N=53	Other Country N=20		
Structural dimension					
S&T Infrastructure	5.22 ^b (.95)	4.64 ^a (.13)	5.60 ^b (.90)	9.01	.000
Network Ties	5.08 ^a (1.19)	4.92 ^a (.16)	5.78 ^b (1.21)	4.00	.021
Social Interaction	4.57 ^a (1.46)	5.64 ^b (.20)	5.29 ^b (1.29)	8.16	.000
Cognitive Dimension					
Country Characteristics	5.86 ^a (.72)	5.49 ^a (.11)	5.57 ^a (.89)	3.31	.040
Scientist Characteristics	5.66 ^a (1.06)	5.28 ^a (.14)	5.60 ^a (.93)	2.29	.105
Shared Goals	5.57 ^a (1.20)	5.60 ^a (.16)	5.77 ^a (1.04)	.24	.787
Relational Dimension					
Trusting Relationships	5.77 ^a (.94)	5.47 ^a (.13)	5.44 ^a (.99)	1.69	.189
Resource Exchange and Combination					
Partner Attractiveness	5.54 ^{a,b} (1.03)	4.99 ^a (.15)	5.73 ^b (.89)	5.25	.006
Collaboration Effectiveness	5.61 ^a (1.20)	5.50 ^a (.15)	5.86 ^a (.90)	.81	.449
Value Creation					
Intellectual Capital	5.60 ^a (1.10)	5.43 ^a (.14)	5.75 ^a (.87)	.83	.438
Industrial Spillovers	4.97 ^{a,b} (1.38)	4.70 ^a (.18)	5.45 ^b (1.10)	2.38	.097
Political Spillovers	5.33 ^a (1.26)	5.21 ^a (.16)	5.67 ^a (.90)	1.13	.327
Total Value Creation	5.36 ^a (1.11)	5.20 ^a (.14)	5.66 ^a (.79)	1.48	.232

Sig at $\alpha < .05$. MANVOA F-test 3.552 at $\alpha < .001$

Key differences in the results between the views of Canadian and foreign scientists were found for several country characteristics. As for Canadian scientists, S&T infrastructure, network ties and partner attractiveness showed significant differences. ANOVA analysis of the ten individual measures (not shown) composing the S&T infrastructure construct

showed them all with significant inter-country differences, except for quality of linkages among public research organizations, regulatory policies, and IP policies and practices. Average means of all S&T infrastructure measures were higher for Other Country, especially for scientific capabilities and scientific productivity (6.21 and 6.14 respectively). With regards to measures of network ties, ties within global scientific community (5.29 for Canada, 5.26 for Home Country vs. 6.11 for Other Country) and world-renowned research clusters (4.79 for Canada, 4.52 for Home Country vs. 6.00 for Other Country) showed a highly significant difference. As for social interaction, all four measures showed significant differences with lowest ratings for Canada.

Further analysis of the measures of the country characteristic construct showed that six of the ten measures had significant differences. In particular, friendliness had the highest level of significance among the three groups (Canada 6.22, Home Country 5.65, Other Country 5.53), followed by concern for others (Canada 5.87, Home Country 5.48, Other Country 4.79), trustworthiness (Canada 6.11, Home Country 5.93, Other Country 5.42), and likeability (Canada 6.02, Home Country 5.67, Other Country 5.42). Canada was at par with Other Country for level of education, and overall achievements in science. Canada ranked highest among the three groups for honesty (6.06) and credibility (6.05), but *post hoc* testing showed no significant inter-country differences. In all, Canada rated very well on the cognitive and relational dimensions. By and large, these findings align with those of Papadopoulos and Heslop (1992, 2000) indicating Canada has a strong country image. Ratings for the resource exchange and combination construct and value creation were all lower for Canada, but not statistically significant. Quoting from

Mandel-Campbell (2007) “We (Canadians) are nice. But business and nice don’t work.” (p. 72) and “Canadians need to develop a bit of an ego. They suffer from a lack of presence.” (p. 280). A MANOVA analysis of the measures of partner attractiveness did not reveal significant difference. Interestingly, level of funding did not show up as being significantly different. This is likely because foreign scientists are not as aware of the funding shortcomings seen by Canadian scientists.

A comparison was made between the ratings of Canadian scientists on the measures of Canada (Table 18) and the ratings of foreign scientists on the same measures (Table 19). A similar pattern as in earlier findings was observed in that Canadian scientists are harsher on their rating of Canada than foreign scientists on all 13 constructs relative to Canada. In particular S&T infrastructure and partner attractiveness were rated significantly lower by Canadian scientists. Several explanations can be advanced including the humble, low key nature of Canadians (Mandel-Campbell, 2007) and the harsh reality that indeed Canada’s S&T infrastructure and attractiveness as a scientific collaborator may not be at par with others, yet foreign scientists may not readily recognize this reality. Several Canadian scientists interviewed during Phase I of the research noted that Canadian scientist collaborators are being perceived better than they actually are in infrastructure and research capacity. A similar comparison was made between scientists working in Canada and scientists working in another country for all measures relative to Canada using independent t-tests. Table 20 displays the significant measures. Appendix G shows results for all measures.

Table 20. Significant differences between scientists working in Canada versus working in another country for measures relative to Canada

Measures Canada	Mean/ (Standard deviation) of measures		t	Sig.
	Working in Canada N=80	Working in Another Country N=71		
Canada's S&T system - Scientific capabilities	5.39 / (1.04)	5.85 / (1.02)	2.7	.007
Level of funding of S&T	3.66 / (1.11)	4.88 / (1.35)	5.99	.000
Availability of highly qualified personnel in S&T	4.68 / (1.28)	5.61 / (1.10)	4.69	.000
Quality of linkages among public research organizations	3.83 / (1.11)	4.86 / (1.18)	5.42	.000
Quality of scientific networks	4.35 / (1.13)	5.12 / (1.33)	3.76	.000
Ties to others in the global scientific community	4.73 / (1.16)	5.27 / (1.31)	2.66	.009
Number of world-renowned research clusters	4.27 / (1.07)	4.79 / (1.29)	2.70	.008
Supportive S&T Policies	3.47 / (1.23)	4.82 / (1.13)	6.60	.000
Quality of regulatory policies	3.51 / (1.30)	4.57 / (1.17)	4.76	.000
Quality of IP policies and practices	4.05 / (1.25)	4.69 / (1.11)	2.95	.004
Overall quality of Canada's S&T System	4.46 / (1.02)	5.33 / (1.15)	4.92	.000
Canada and its people - Friendliness	5.77 / (.92)	6.25 / (.75)	3.49	.001
Trustworthiness	5.75 / (.72)	6.13 / (.86)	2.93	.004
Likeability	5.68 / (.84)	6.01 / (.84)	2.41	.017
Honesty	5.75 / (.88)	6.08 / (.82)	2.41	.017
Credibility	5.68 / (.90)	6.07 / (.80)	2.77	.006
Concern for others	5.53 / (.93)	5.87 / (.95)	2.18	.031
Level of education	5.46 / (.96)	5.81 / (.91)	2.34	.021
Innovative/entrepreneurial culture	4.44 / (1.05)	5.25 / (1.12)	4.41	.000
Openness to international trade	5.12 / (1.11)	5.48 / (1.09)	2.00	.048
Connected within domestic scientific networks	4.83 / (.99)	5.47 / (1.19)	3.56	.001
Trustworthiness	5.63 / (.69)	6.06 / (1.03)	2.98	.003
Flexibility	5.16 / (.88)	5.54 / (1.36)	2.05	.042
International experience in ISCs	5.05 / (.98)	5.49 / (1.33)	2.24	.027
Position within domestic scientific networks	4.74 / (.95)	5.26 / (1.22)	2.85	.005
Position within global scientific networks	4.78 / (1.16)	5.31 / (1.40)	2.53	.012
Level of funding	3.58 / (1.15)	4.57 / (1.59)	4.35	.000
Quality of IP protection	4.50 / (1.15)	5.21 / (1.35)	3.23	.002
It is easy to share ideas and feelings with these collaborators	5.45 / (.98)	5.92 / (1.08)	2.78	.006
Organizations the collaborators belong to are trustworthy	5.48 / (.93)	5.89 / (1.06)	2.54	.012
Canadian Institutions are trustworthy	5.46 / (.91)	5.90 / (1.04)	2.75	.007
Canada is competently governed	4.70 / (1.34)	5.27 / (1.34)	2.57	.011

Sig at $\alpha < .05$.

Again, a key observation is that consistently, scientists working in another country think more highly of Canada and its people than Canadians scientists do, especially for measures related to the nature of Canadians. For instance, foreign scientists think we are more trustworthy than we think we are.

6.5.2.4 Collective ISC framework

The overall MANOVA F-test of the constructs of the collective ISC framework was not significant, meaning that at the aggregate level, there were no significant differences between Canadian and foreign scientists on the collective ISC framework. It is very likely that MANOVA was not significant due to sample size being too small with listwise deletion of missing cases used in this test. However, the number of missing values was not high for any of the included cases. Therefore, a cautious look at the individual level t-tests, using analysis-by-analysis deletion of missing cases, was taken so as not to lose important insights. T-tests at the measure level were run for the collective ISC (section B of the questionnaire). Respondents were asked their rating on specific measures (53 questions) based on the collective ISC research framework. Of all these 53 measures, only the following five showed significant differences in rating among scientists working in Canada versus scientists working in another country, as evidenced in Table 21. Appendix G shows results for all measures.

Table 21. Significant measures of the collective ISC framework among scientists working in Canada and scientists working in another country.

Measures Other Country	Mean (Std dev) of measures		t	Sig.
	Working in Canada N=88	Working in another country N=65		
Quality of network ties	5.14 (1.04)	5.54 (1.26)	2.13	.035
Level of interaction among collaborators	4.97 (1.11)	5.57 (1.13)	3.30	.001
Quality of communication among members	5.05 (1.12)	5.52 (1.17)	2.55	.012
Management of IP issues	4.55 (1.20)	5.04 (1.39)	2.14	.034
Improved scientific country image (benefits to firms directly involved in ISC)	4.89 (1.34)	5.61 (.94)	2.16	.036

Yet again, ratings of Canadian scientists were consistently lower even at the collective ISC level. Using a cautious sig at $\alpha < .01$, the significant differences centered on the social interaction aspects of the ISC. Foreign scientists rated the benefits to firms from an improved scientific country image substantially higher than Canadian scientists.

6.5.2.5 Comparison of centralized vs. distributed ISCs

In an attempt to compare results with the organization of collaborative research of Wagner, Staheli *et al.* (2002) (Figure 1), scientific fields were grouped by centralized versus distributed collaborative research and findings compared. Space research, earth research and physics were regrouped under centralized ISCs, while distributed ISCs covered the remainder fields; biotechnologies, nanosciences, health research, advanced engineering & manufacturing, agricultural & animal science. This selection, although based on prior research and the general nature of the ISCs in these scientific fields, was somewhat arbitrary and, therefore, this analysis is considered very exploratory. Under this classification, 61 ISCs (38%) were of the centralized collaborative research type,

while 99 ISCs (62%) were considered distributed collaborative research type. As expressed by Wagner, Staheli *et al.* (2002), this is typical of the increase toward the distributed type of ISCs. Comparing measures of the collective ISCs between centralized and distributed ISCs, Table 22 displays measures significantly different between the two types. Again, overall, MANOVA results at the construct level were not significant probably due to the sample size being quite small (N=14 centralized and 33 distributed) with listwise deletion of missing cases. Therefore, an examination of the measures was carefully explored with t-tests, using analysis-by-analysis deletion of missing cases. Significant results are shown in Table 22.

Table 22. Significant measures between Centralized versus Distributed ISCs

Measure	Centralized ISC N=54	Distributed ISC N=95	t	Sig.
Quality of equipment and facilities	5.80	5.42	2.23	.028
Scientific discoveries	5.77	5.40	1.97	.051
Patents	2.45	3.28	2.43	.017
S&T Capacity building in developing countries	3.31	4.24	2.62	.010
Leverage of national public research funding	3.86	4.51	2.24	.027
Foreign Policy	2.74	3.80	3.10	.002
International Relations	3.79	4.44	1.98	.050

Sig at $\alpha < .01$

Ratings on quality of equipment and facilities and on scientific discoveries were significantly higher for the centralized ISCs while all other significant measures were higher for the distributed ISCs. Centralized ISCs typically require large investments in equipment and facilities, since they are resource-dependent research and megascience (Wagner 2005a). This requirement for large investment in equipment and facilities in turn might explain the higher rating of the quality of equipment and facilities of the centralized ISCs. The nature of the distributed ISCs (health science, agriculture etc) to help address global issues may help explain the higher ratings on level of impact on S&T

capacity building in developing countries and on foreign policy, given the increased role for science in international affairs (Wagner 2002). Despite limited ability to explore these issues, some interesting results emerged.

6.5.3 Nature and Extent of Value-Creation from Large-Scale ISCs

Objective 3 of the research was to delineate the overall nature and extent of outcomes of ISCs. In the questionnaire respondents were asked to rate the value of output created or expected to be created from the ISC. In all, 31 questions probed the respondents on their perception of value of output created or expected to be created from the ISC for three types of benefits – intellectual capital, industrial spillovers, and political spillovers. Table 23 shows the ratings of respondents related to intellectual capital.

Table 23. Value of intellectual capital in ISC

Intellectual Capital	Mean / (std dev) N=155
Knowledge transfer	5.52 / (1.05)
Creativity	5.57 / (1.01)
Scientific discoveries	5.52 / (1.09)
Publications	5.55 / (1.21)
Patents	3.01 / (1.81)
Other scientific output	4.83 / (1.41)

On the aspect of intellectual capital, ratings above 5.5 were given to knowledge transfer, creativity, scientific discoveries and publications. Patents, however, were rated substantially lower at 3.01. A relatively broad range of scientific fields were covered in the research. Some of these fields may not necessarily be conducive to generating patentable IP. Further, each field tends to address patents and IP issues based on its own set of circumstances.

Table 24 shows the perceived value of industrial spillovers to firms directly involved in the ISCs and for the industry in general.

Table 24. Value of industrial spillovers

Industrial Spillovers	Firms directly involved	Industry in general
	Mean / (std dev) N=47	Mean / (std dev) N=120
Technological learning/knowledge transfer	4.96 / (1.30)	5.18 / (1.34)
Innovativeness	4.79 / (1.43)	5.14 / (1.36)
Creativity	4.81 / (1.45)	5.14 / (1.33)
Access to resources and expertise	5.19 / (1.28)	5.24 / (1.29)
Access to networks	5.09 / (1.21)	5.00 / (1.26)
Increased competitiveness	4.87 / (1.35)	4.94 / (1.40)
Access to new international markets	4.70 / (1.57)	4.46 / (1.70)
Prestige of public research labs	5.13 / (1.21)	5.12 / (1.53)
Improved scientific country image	5.23 / (1.15)	5.25 / (1.37)

For direct industrial spillover effects, that is for industrial firms directly involved in the ISC, the highest rating of industrial spillovers was for improved scientific country image (5.23), followed by access to resources and expertise, prestige of public research labs, and access to networks, and the lowest rating (4.70), was for access to new international markets. Similar ratings were obtained for the industry in general, with ratings ranging between 4.46 for access to new international markets to 5.25 for spillover effects from improved scientific country image. Benefits of a science country image was perceived by the respondents as providing value to the industry.

Finally, the impacts from large-scale ISCs on political spillovers are covered in Table 25.

Table 25. Value of political spillovers

Political Spillovers	Mean / (std dev) N=141
Science policy and priorities	4.35 / (1.72)
Governance of International science issues	4.21 / (1.75)
S&T Capacity building in developing countries	3.98 / (1.93)
Leverage of National public research funding	4.28 / (1.66)
Foreign Policy	3.42 / (1.88)
International relations	4.19 / (1.85)
Broader public (e.g., awareness, interest)	4.41 / (1.78)

As expected, political spillover effects were not rated as highly as intellectual capital and industry spillovers. In addition, there were wider variations in the responses as indicated by the larger standard deviations. Nonetheless, respondents appeared to recognize the impact of ISCs on broader public awareness, science policy and priorities, governance of international science issues, and international relations. Further, the need to leverage national public research funding for large-scale ISCs was recognized.

In summary, the extent of outcomes from large-scale ISCs expressed in the literature is confirmed by the respondents. Given the focus of the research on scientific collaboration, the perceived value of intellectual capital outcomes was rated higher than the ratings of industrial and political spillovers. Respondents believed that industrial spillovers benefit both firms directly involved in the ISCs as well as the industry in general. Finally, respondents were aware of the impacts of ISCs on broader political issues such as foreign policy and science policy.

6.5.4 Patterns of Relationships – Testing of Hypotheses 1-7

To explore the relationship between the variables, objective 4 of the research, correlation analysis was used. This section reports on correlation analysis among the measures of different constructs to test hypotheses H1-H7 at the individual country partner level, and for the collective.

6.5.4.1 Individual-level country framework

Correlation analyses were conducted between the constructs involved in the hypotheses of the individual-level country research framework. Results are shown in Table 26.

Table 26. Correlation analysis of constructs – Individual-level country framework

Hyp.	Positive relationships between constructs	Pearson's Correlation Coefficients			
		Canada N=151	Home Country N=71	Other Country N=111	All Countries N = 324
H1a	S&T infra. and country characteristics	.66	.59	.51	.56
H1b	S&T infrastructure and scientist characteristics	.63	.53	.62	.58
H1c	Network ties and country characteristics	.59	.48	.46	.49
H1d	Network ties and scientist characteristics	.57	.64	.61	.58
H2a	S&T infrastructure and trusting relationships	.63	.48	.53	.52
H2b	Network ties and trusting relationships	.56	.45	.48	.48
H2c	Social interaction and trusting relationships	.27	.43	.37	.32
H3a	Country characteristics and trusting relationships	.66	.78	.79	.73
H3b	Scientist Characteristics and trusting relationship	.74	.74	.84	.77
H3c	Shared Goals and trusting relationships	.73	.77	.73	.73
H4a	S&T infrastructure and partner attractiveness	.79	.80	.79	.80
H4b	S&T infrastructure and collaboration effectiveness	.55	.50	.49	.51
H4c	Network ties and partner attractiveness	.69	.81	.74	.73
H4d	Social interaction and partner attractiveness	.33	.37	.35	.29
H4e	Social interaction and collaboration effectiveness	.36	.46	.44	.38
H5a	Country characteristics and partner attractiveness	.67	.58	.68	.63
H5b	Scientist characteristics and partner attractiveness	.82	.69	.83	.78
H5c	Shared goals and collaboration effectiveness	.74	.68	.79	.74
H6a	Trusting relationships and partner attractiveness	.73	.66	.76	.69
H6b	Trusting relationships and collaboration effectiveness	.69	.75	.78	.73
H7a	Partner attractiveness and total value creation	.63	.78	.70	.68
H7b	Collaboration effectiveness and total value creation	.77	.85	.84	.81
H7c	Collaboration effectiveness and intellectual capital	.76	.84	.79	.79
H7d	Collaboration effectiveness and industrial spillovers	.45	.66	.54	.52
H7e	Collaboration effectiveness and political spillovers	.71	.76	.77	.74

Note: All correlations are significant at $\alpha < .01$ (1-tail test)

All constructs were positively and significantly correlated, as predicted by the research framework. Pearson's correlation coefficients were highest for hypotheses involving the constructs of S&T infrastructure and partner attractiveness, scientist characteristics and partner attractiveness, as well as collaboration effectiveness and total value creation.

6.5.4.2 *Collective ISC framework*

Correlation analyses were conducted to test hypotheses H4-7 of the collective ISC framework. Results are shown in Table 27.

Table 27. Correlation analysis of constructs – Collective ISC framework

Hyp.	Positive relationships between constructs	N	Pearson's Correlation Coefficient
H4f	Resources & capabilities and collaboration effectiveness	155	.77
H4g	Network ties and collaboration effectiveness	155	.84
H5d	Shared goals and collaboration effectiveness	155	.82
H5e	Management of collaboration and collaboration effectiveness	155	.76
H6c	Trust and collaboration effectiveness	155	.74
H7f	Collaboration effectiveness and intellectual capital	155	.73
H7g	Collaboration effectiveness and industrial spillovers (direct)	56	.53
H7h	Collaboration effectiveness and industrial spillovers (indirect)	120	.60
H7i	Collaboration effectiveness and political spillovers	155	.29

Note: All correlations are significant at $\alpha < .01$ (1-tail test)

All constructs were positively and significantly correlated, as predicted by the collective ISC research framework. Pearson's correlation coefficient was highest for the relationship between network ties and collaboration effectiveness and between shared goals and collaboration effectiveness. Measures of the network ties construct differed

between the two frameworks. In the collective ISC framework, measures were directly related to ties, interaction, and communication among collaborators while measures were at a higher country level for the individual-level country framework. Likewise, measures composing political spillovers in the collective ISC were different from the measures of political spillovers of the individual-level country framework. In the collective ISC framework, measures of political spillovers were at a higher and broader level. For instance, measures centered on broader science policy concerns such as science policy and priorities, governance of international science issues, S&T capacity building, foreign policy, and international relations. Measures for political spillovers used for the individual-level country framework were related to more immediate political benefits accruing to a country by its participation in the ISC. For example, measures included enhanced reputation and credibility of a country, its access to knowledge from other countries, and its access to other ISCs with other countries. This may explain the lower Pearson's correlation coefficient for the relationships between collaboration effectiveness and political spillovers in the collective ISC framework.

Having established the positive and significant relationships between the linked constructs of each research framework as hypothesized, the analysis could now confidently proceed with regression analysis to test the patterns of relationships.

6.5.5 Patterns of Relationships - Regression Analysis

Correlation analyses demonstrated that the variables are positively related as predicted by the research frameworks. However, individual correlation analyses do not help in understanding the relative role of multiple predictors on an outcome or the pattern of

relationships among these multiple predictors. Therefore, linear regression analysis was used to test for these patterns and relative effects. First, simple and multiple regressions between a single and multiple predictors respectively and an outcome variable were run to explore the direct size of explanatory relationships in the paths of the research frameworks. Then, the mediation effects of the third variable in the paths were tested.

A mediating variable serves to clarify the nature of the relationship between the independent and the dependent variable sets. The amount of mediation is indicated by the reduction in the effect of the initial variable on the outcome as the result of the presence of the mediating variable (Kenny 2006). Mediation provides a more complete understanding of the pattern of relationships among related constructs in the research frameworks. Mediation analysis was conducted using the methodology of Kenny (2006), which tests simple and multiple regressions among the independent, dependent, and mediating variables to establish partial or complete mediation. Specifically, using Kenny's (2006) methodology, each predictor (independent) variable was correlated with the outcome (dependent) variable, as well as with the mediator using simple regression analysis. The mediator was also shown to affect the outcome variable with a regression equation using the independent variable and the mediator as predictors and the dependent variable as the outcome variable. Adjusted R^2 and standardized Beta coefficients are reported. The most commonly used test, the Sobel mediation test (Preacher and Leonardelli, 2006) was employed to assess the statistical significance of the mediation. Details of the methodology are found in Appendix H. The research frameworks were

tested in stages using relevant sets of three constructs with one as the focal mediating variable.

The analysis first used the variance inflation factor (VIF) to test for the presence of multicollinearity among variables. Multicollinearity exists when there is a strong correlation between two or more predictors in a regression model. High levels of multicollinearity increase the probability that a good predictor of the outcome will be found non-significant and rejected from the model (Field 2005). VIF measures the impact of multicollinearity on the regression coefficients and ranges from one to infinity. When a variable is orthogonal to the remaining variables, its VIF will equal one. A high VIF, generally greater than 10, therefore indicates that a variable may be affected by multicollinearity. Multicollinearity of the multiple regressions for both research frameworks was found not to be an issue as all measures of VIF were below 3.4, hence below the threshold of 10.

6.5.5.1 Direct paths for individual-level country framework

Simple and multiple regression analysis were conducted with the variables of the individual-level country framework to discover the predictive power of the variables without mediation effects. To do so, simple regression analyses were run for each dependent variable and each of its predictors based on the framework and its hypotheses. Then, multiple regression analyses between a dependent variable and combinations of relevant predictors from the framework were run. Figure 6 is reintroduced to show again the hypothesized relationships of the individual-level country framework. Table 28 reports the adjusted R^2 and the standardized Beta coefficients of the simple and multiple

linear regression analyses. For easier reading, results are presented by order of dependent variable instead of order of hypotheses.

Figure 6. Individual-level country framework

Table 28. Simple and multiple regression analysis – Individual-level country framework

Hyp	Dependent variable	Predictors	R ²	Beta	F
H1a	Country characteristics	S&T infrastructure	.311	.559	146.46
H1c	Country characteristics	Network ties	.239	.491	102.45
	Country characteristics	S&T infrastructure Network Ties	.312	.477 n.s.	74.13
H1b	Scientist characteristics	S&T infrastructure	.333	.579	159.89
H1d	Scientist characteristics	Network ties	.338	.583	163.38
	Scientist characteristics	S&T infrastructure Network ties	.367	.308 .331	93.25
H2a	Trusting relationships	S&T infrastructure	.266	.518	118.01
H2b	Trusting relationships	Network ties	.232	.484	98.71
H2c	Trusting relationships	Social interaction	.102	.324	32.36
	Trusting relationships	S&T infrastructure Network ties Social interaction	.329	.414 n.s. .225	46.18
H3a	Trusting relationships	Country characteristics	.531	.730	367.37
H3b	Trusting relationships	Scientist characteristics	.586	.766	450.38
	Trusting relationships	Country characteristics Scientist characteristics	.651	.368 .503	297.36

Hyp	Dependent variable	Predictors	R ²	Beta	F
H3c	Trusting relationships	Shared goals	.534	.731	361.40
	Trusting relationships	Country characteristics Scientist characteristics Shared goals	.717	.345 .271 .354	262.83
	Trusting relationships	S&T infrastructure Network ties Social interaction Country characteristics Scientist characteristics Shared goals	.739	n.s. n.s. n.s. .358 .251 .339	127.16
H4a	Partner attractiveness	S&T infrastructure	.630	.795	549.62
H4c	Partner attractiveness	Network ties	.526	.726	358.17
H4d	Partner attractiveness	Social interaction	.080	.289	25.12
	Partner attractiveness	S&T infrastructure Network ties Social interaction	.648	.602 .197 .123	170.66
H5a	Partner attractiveness	Country characteristics	.396	.631	211.86
H5b	Partner attractiveness	Scientist characteristics	.603	.777	484.12
	Partner attractiveness	Country characteristics Scientist characteristics	.612	.143 .675	251.58
H6a	Partner attractiveness	Trusting relationships	.473	.689	289.45
	Partner attractiveness	Country characteristics Scientist characteristics Trusting relationships	.623	n.s. .581 .188	176.10
	Partner attractiveness	S&T infrastructure Network ties Social interaction Country characteristics Scientist characteristics Trusting relationships	.791	.428 n.s. n.s. n.s. .394 .170	174.60
H4b	Collaboration effectiveness	S&T infrastructure	.253	.505	109.13
H4e	Collaboration effectiveness	Social interaction	.145	.384	47.35
	Collaboration effectiveness	S&T infrastructure Social interaction	.323	.431 .310	66.35
H5c	Collaboration effectiveness	Shared goals	.549	.742	380.41
H6b	Collaboration effectiveness	Trusting relationships	.525	.725	354.08
	Collaboration effectiveness	S&T infrastructure Social Interaction Shared goals Trusting relationships	.655	.136 .105* .377 .364	127.52
H7a	Total value creation	Partner attractiveness	.458	.678	271.45
H7b	Total value creation	Collaboration effectiveness	.653	.809	600.26
	Total value creation	Partner attractiveness Collaboration effectiveness	.673	.203 .664	327.59
H7c	Intellectual capital	Collaboration effectiveness	.618	.787	516.03
H7d	Industrial spillovers	Collaboration effectiveness	.272	.524	114.11
H7e	Political spillovers	Collaboration effectiveness	.541	.736	373.24

Coefficients are all significant at $\alpha < .001$ except * significant at $\alpha < .05$

Given the number of regression and beta tests, a more conservative level of .01 was chosen for determination of significance to reduce chances of type II error. In fact, all but one beta and F were significant at $\alpha < .001$. Overall, these results support all the direct relationship hypotheses of the framework.

Exploring the results of the regression analyses from the beginning of the framework, the construct of quality of a country's S&T infrastructure used measures from the national innovation system literature (OECD 2003b, Soltani and Birang 2005, Van Looy *et al.* 2006). S&T infrastructure was found to be highly important in explaining variance in the perception of the following: country image (H1a), country's scientists (H1b), trusting relationships (H2a), and partner attractiveness (H4a).

However, S&T infrastructure alone is not sufficient. The extent of network ties of a country within the global scientific community also positively impacted on a country image (H1c), the perception of that country's scientists (H1d) trusting relationships (H2b) with that country's scientists, and partner attractiveness (H4c).

Alone, social interaction (H2c) was found to be a relatively weak predictor of trusting relationships ($R^2=.102$, $\beta=.324$). However, a multiple regression of the structural dimension constructs, S&T infrastructure, network ties and social interaction, as predictors of trusting relationships was run. In this regression ($R^2=.329$), network ties was not significant while S&T infrastructure was an important predictor ($\beta=.414$) followed by social interaction ($\beta=.225$).

Country characteristics (H3a) and scientists characteristics (H3b) were found to be important predictors of trusting relationships, as well as important predictors of partner attractiveness (H5a and H5b) as evidenced by the results of the simple regressions. Taken together in a multiple regression, country characteristics remained important ($\beta=.368$) but scientists characteristics explained a greater proportion of the variance of trusting relationships ($\beta=.503$). The shared goals construct (H3c) was found to be the most important predictor of trusting relationships ($\beta=.731$). A multiple regression of all three constructs of the cognitive dimension of social capital as predictors of trusting relationships showed a high proportion of variance explained ($R^2=.717$) with the three constructs – country characteristics, scientist characteristics and shared goals – being important predictors ($\beta=.345$, $.271$ and $.354$ respectively).

To further explore trusting relationships, a multiple regression with all constructs of both structural dimension and cognitive dimension of social capital as predictors of trusting relationships were run. A very high proportion of variance was explained ($R^2=.739$) with the regression. However, the constructs of the structural dimension – S&T infrastructure, network ties and social interaction, – were not significant. On the other hand, all three constructs of the cognitive dimension – country characteristics, scientist characteristics and shared goals – remained important predictors ($\beta=.358$, $.251$ and $.339$ respectively).

Taken together, the three constructs of the structural dimension of social capital – S&T infrastructure, network ties and social interaction – were all important predictors of

partner attractiveness. However, S&T infrastructure made the highest contribution as a predictor of partner attractiveness compared to network ties and social interaction (beta=.602, .197, and .123 respectively).

In addition to predictors of partner attractiveness already covered, trusting relationships (H6a) was also a significant predictor of partner attractiveness, while social interaction (H4d) was found to be less so ($R^2=.080$). A multiple regression of all six predictors of partner attractiveness from the three dimensions of social capital – structural, cognitive and relational dimensions – explained 79% of the variance ($R^2=.791$) in partner attractiveness. Network ties, social interaction and country characteristics were not significant in this regression. However, S&T infrastructure, scientist characteristics and trusting relationships (beta=.428, .394 and .170 respectively) were all significant. This finding highlights the importance of national support for infrastructure and funding of large-scale ISCs as well as the quality and visibility of scientists.

In simple regressions, S&T infrastructure (H4b), social interaction (H4e), shared goals (H5c) and trusting relationships (H6b) were significant predictors of collaboration effectiveness. Combined together in a multiple regression ($R^2=.655$), the shared goals construct had the highest beta (.377) followed by trusting relationships (.364) and S&T infrastructure (.136). Social interaction (beta=.105) approached significance ($\alpha < .05$ vs. $\alpha < .001$ for other regression analyses).

In prior research using the Nahapiet and Ghoshal (1998) framework, Tsai and Ghoshal (1998) found that reputational information such as reputation, credibility, reliability and honesty had significant effects on resource exchange and combination. They also found that social interaction and shared vision were two different sources of trustworthiness. In this research, results indicate a direct and significant relationship between social interaction and trusting relationships on the one hand, and between shared goals and trusting relationships ($R^2 = .534$, $F = 361.40$, $\beta = .731$ at $\alpha < .001$) on the other hand, hence similar to their findings. Further, the authors found that shared vision influenced resource exchange and combination only indirectly, via its influence on trust. In this research, however, shared goals was a key predictor of collaboration effectiveness along with trusting relationships, S&T infrastructure and social interaction. However, because Tsai and Ghoshal (1998) studied business units of a large multinational enterprise, their measures for shared vision were about shared goals and missions of the whole organization. In the context of this research, shared goals were around the team and the collaboration. It can be concluded at this stage that in the individual-level country framework, shared goals directly influenced collaboration effectiveness.

As noted in prior research on trust (Rocco, Finholt *et al.* 2001, Shrum, Chompalov *et al.*, 2001, McKnight, Cummings *et al.* 1998, Zaheer, McEvily *et al.* 1998), the importance of the relational dimension of social capital, operationalized in this research with interpersonal, interorganizational and institutional trust (trusting relationships), was clearly demonstrated in the results of this study. The construct of trusting relationships was a strong predictor of partner attractiveness (H6a) and of collaboration effectiveness

(H6b). Prior empirical work using the Nahapiet and Ghoshal (1998) framework tended to focus on simpler models, with fewer constructs and measures. More importantly, sampling was either with high-tech firms in one country (Yli-Renko, Autio *et al.* 2001) or with units of a large multinational company (Tsai and Ghoshal 1998), or project teams within a global high-tech company (Chen, Chang *et al.* 2006). Therefore, this research augments the empirical foundation of the Nahapiet and Ghoshal (1998) framework.

Hypothesis H7b, which relates the contribution of a country to the effectiveness of the collaboration with the contribution of that country to the total value creation, is of particular relevance to the framework. This hypothesis is perhaps the most critical as it represents the central question of exploring the relationships between the dimensions of social capital, the effectiveness of the collaboration and the outcomes from the collaboration. The regression model of this hypothesis indicates that collaboration effectiveness accounts for 65.3% of the variation in total value creation ($R^2=.653$). The construct of value creation incorporates intellectual capital, industrial spillovers and political spillovers. The standardized beta coefficient for collaboration effectiveness is quite large at .809. This means that an increase in one standard deviation in collaboration effectiveness increases total value creation by .809 standard deviation.

Although both partner attractiveness (H7a) and collaboration effectiveness (H7b) were important predictors of total value creation in simple regressions, collaboration effectiveness was found to be more important in a multiple regression (beta=.664 vs. .203). As can be expected given the focus of the research on scientific collaboration,

intellectual capital (H7c) was an important outcome of collaboration effectiveness. Intellectual capital comprised measures of scientific output and knowledge transfer. Collaboration effectiveness is a stronger predictor of intellectual capital than a predictor of industrial spillovers (H7e, $R^2 = .541$, $\beta = .736$, vs. H7d, $R^2 = .272$, $\beta = .524$). At the individual-level country, measures of political spillovers covered the reputation and credibility of a country due to the ISC, its access to knowledge and to other ISCs of other countries. Measures of the industrial spillovers were more elaborate in the collective ISC framework covered later.

6.5.5.2 Mediated paths for individual-level country framework

Analyses of direct relationships using simple and multiple regressions demonstrated important and significant relationships supporting the hypotheses of the framework. However, they did not take into consideration potential mediation effects. In order to detect such effects, mediation analysis was conducted with mediator variables from the framework that could potentially explain the mechanisms underlying the observed relationship between an independent variable and a dependent variable. Kenny's (2006) method described earlier was used for mediation analysis. Table 29 displays the results of the mediation analysis. More detailed information regarding R^2 and beta coefficients and t-test statistics used to calculate the Sobel tests can be found in Appendix H.

Table 29. Mediation analysis – Individual-level country framework

Hyp	Dependent	Independent	Mediator	ΔR^2	Beta change for independent variable	% Δ Beta	Sobel	Mediation effect*
H2a	Trusting relationships	S&T Infrastructure	Country characteristics	.282	-.358	69	9.21	High
			Scientist characteristics	.328	-.406	79	9.92	High
H2b	Trusting relationships	Network ties	Country characteristics	.319	-.318	66	8.42	High
			Scientist characteristics	.355	-.484	100	10.10	Fully
H4 a	Partner attractiveness	S&T infrastructure	Country characteristics	.049	-.152	19	6.10	Low
			Scientist characteristics	.152	-.276	35	9.63	Moderate
			Trusting relationships	.104	-.197	25	7.81	Low
H4b	Collaboration effectiveness	S&T infrastructure	Trusting relationships	.294	-.325	64	8.68	High
H4c	Partner attractiveness	Network ties	Country characteristics	.097	-.177	24	6.78	Low
			Scientist characteristics	.193	-.305	42	9.60	Moderate
			Trusting relationships	.147	-.214	29	7.66	Low
H4d	Partner attractiveness	Social interaction	Trusting relationships	.418	-.221	77	5.33	High
H4e	Collaboration effectiveness	Social interaction	Trusting relationships	.424	-.220	57	5.37	Moderate
H5a	Partner attractiveness	Country characteristics	Trusting relationships	.110	-.357	57	7.79	Moderate
H5b	Partner attractiveness	Scientist characteristics	Trusting relationships	.019	-.168	22	4.02	Low
H5c	Collaboration effectiveness	Shared goals	Trusting relationships	.077	-.300	40	7.44	Moderate

* Note: there is no guidance from authors on size of mediation effect. A decision was made to use the following as the basis for judging the size of the mediation effect: High >60, Moderate 30-60, Low<30

Country characteristics played a fairly high mediation role between S&T infrastructure and trusting relationships, and between network ties and trusting relationships. A key contribution of this research was the addition of a multi-dimensional approach for the measures of trusting relationships – interpersonal trust, interorganizational trust and institutional trust. Therefore, this suggests that scientists make use of a broader mental picture of the country with whom they are collaborating (general impression of the country and its people) in developing trust above and beyond trust with their

collaborators from that country. For instance, it is plausible that measures around institutional trust, that is trust that people have in institutions or organizations in a given society, would be an important basis of the mediation by country characteristics.

On the other hand, country characteristics had a very low mediating effect between S&T infrastructure and partner attractiveness, as well as between network ties and partner attractiveness. In these relationships, the focus was on the overall quality of a country's S&T system in directly assessing the attractiveness of a country as a scientific collaborator and did not seem to depend as much on general impressions of the country and its people. Therefore, country characteristics may be more important in the working of the collaboration and in the development of trust in that process.

The relationship between the extent of network ties of a country within the global scientific community and trusting relationships with that country's scientists was fully mediated by scientist characteristics. This is plausible given the small R^2 of the simple regression between network ties and trusting relationships. Intuitively, characteristics of scientists would seem more important to the development of trusting relationships than extent of network ties, which are in this framework operationalized with measures at the broader country level compared to measure of network ties of the collective ISC framework. Likewise, scientist characteristics highly mediated the relationship between S&T infrastructure and trusting relationships. On the other hand, the mediating role of scientist characteristics was moderate between S&T infrastructure and partner attractiveness, and between network ties and partner attractiveness.

Trusting relationships only played a high mediating role between social interaction and partner attractiveness, and between S&T infrastructure and collaboration effectiveness. These findings confirmed that trust is required to be an attractive partner and that without trusting relationships, S&T infrastructure alone will not ensure an effective collaboration. All other relationships mediated by trusting relationships are moderate to low. For instance, trusting relationships played a moderate mediating role between country characteristics and partner attractiveness and a low mediating role between scientist characteristics and partner attractiveness. This may be because measures of partner attractiveness focused on capabilities, resources and position within scientific networks as opposed to people and relationships. Finally, trusting relationships played a moderate role in mediating the relationship between shared goals and collaboration effectiveness, therefore reinforcing earlier findings from simple and multiple regressions that shared goals directly influenced collaboration effectiveness.

6.5.5.3 Direct paths for collective ISC framework

Similar analyses of simple and multiple regressions followed by mediation analysis were conducted for the variables of the collective ISC framework. Figure 7 reintroduces the collective ISC framework. The collective ISC framework covered all collaborators from all countries for the entire ISC. In this framework the emphasis was on collective resources, network, trust, shared goals and management of the ISC entity rather than specific contributions by countries. Table 30 reports on the results of the simple and multiple linear regression analysis among the predictors and dependent variables based on the hypotheses of the collective ISC framework.

Figure 7. Collective ISC framework

Table 30. Simple and multiple regression analyses – Collective ISC framework

Hyp	Dependent	Predictors	R ²	Beta	F*
H4f	Collaboration effectiveness	Resources & capabilities	.583	.765	217.57
H4g	Collaboration effectiveness	Network ties	.709	.843	378.71
	Collaboration effectiveness	Resources & Capabilities Network ties	.728	.245 .646	208.94
H5d	Collaboration effectiveness	Shared goals	.662	.815	301.07
H5e	Collaboration effectiveness	Management of collaboration	.581	.764	214.95
	Collaboration effectiveness	Shared Goals Mngt of collaboration	.709	.569 .321	185.98
H6c	Collaboration effectiveness	Trust	.547	.741	186.77
	Collaboration effectiveness	Resources & cap. Network ties Shared goals Mngt of collaboration Trust	.770	n.s. .439 .272 .160 n.s.	102.02
H7f	Intellectual capital	Collaboration effectiveness	.535	.734	179.60
H7g	Industrial spillovers - direct	Collaboration effectiveness	.264	.527	20.77
H7h	Industrial spillovers - indirect	Collaboration effectiveness	.350	.596	63.36
H7i	Political spillovers	Collaboration effectiveness	.077	.290	12.82

* Significant at $\alpha < .001$. n.s. = Not significant

Based on the simple linear regressions, all hypotheses of the collective ISC framework were supported at $\alpha < .001$. As indicated in Table 30, measures of some of the constructs of this research framework differed from the broader country level framework given the emphasis on the collective effort by all collaborators in the collective ISC framework. In particular, network ties in this framework included measures related to the quality of network ties among collaborators, as well as measures around social interaction. Measures of resources and capabilities were equipment and facilities, funding, scientific capabilities, quality of collaborators and use of internet-based tools. Direct industrial spillovers were related to firms directly involved in the ISCs while indirect industrial spillovers concerned benefits to the industry in general. In the context of this framework, it would then appear that network ties were more important than resources and capabilities for the effectiveness of the collaboration. Similarly, shared goals were more important than management of collaboration for the effectiveness of the collaboration. Measures of management of collaboration included management of data, management of IP issues, and overall management and coordination. Although management of the collaboration was raised as an important attribute of successful ISCs, shared goals was cited as the top critical success factor in the interviews.

Consistent with the broader individual-level country framework, positive and significant relationships were observed between shared goals and collaboration effectiveness, and value creation and collaboration effectiveness. Again, collaboration effectiveness explained more variance in intellectual capital than industrial spillovers and political spillovers. Measures of political spillovers in this framework were around broader

science policy concerns compared to measures used in the individual-level country framework, hence the lower effects. A multiple regression of all predictors of collaboration effectiveness showed that network ties, shared goals and management of collaboration were the only significant predictors of collaboration effectiveness, in that order of importance. This does not mean that trust is unimportant as trust may be more concretely manifested through shared goals (not modelled).

6.5.5.4 Mediated paths for collective ISC framework

As for the individual-level country framework, mediation analysis was conducted on the collective ISC framework. Based on the framework, only collaboration effectiveness can be considered a potential mediator. Results are displayed in Table 31.

Table 31. Mediation analysis – Collective ISC framework

Dependent	Independent	Mediator	ΔR^2	Change in Standardized Coefficient Beta	% Δ Beta	Sobel**	Mediation effect***
Intellectual capital	Resources & capabilities	Collaboration effectiveness	.123	-.421	64	6.03	High
Intellectual capital	Network ties	Collaboration effectiveness	.097	-.496	74	5.57	High
Intellectual capital	Trust	Collaboration effectiveness	.261	-.527	100	7.69	Fully
Intellectual capital	Shared goals	Collaboration effectiveness	.127	-.643	100	6.13	Fully
Intellectual capital	Mngt of collab	Collaboration effectiveness	.118	-.411	62	5.89	High
Direct ind spillovers	Resources & capabilities	Collaboration effectiveness	-.010	-.052	8	.35	Not significant
Direct ind spillovers	Network ties	Collaboration effectiveness	.002	-.538	-	1.06	Not significant
Direct ind spillovers	Trust	Collaboration effectiveness	.151	-.345	100	3.28	Fully
Direct ind spillovers	Shared goals	Collaboration effectiveness	.007	-.543	-	1.23	Not significant
Direct ind spillovers	Mngt of collab	Collaboration effectiveness	-.004	-.596	-	.81	Not significant
Indirect industrial spillovers	Resources & capabilities	Collaboration effectiveness	.034	-.258	43	2.70	Moderate
Indirect industrial spillovers	Network ties	Collaboration effectiveness	.045	-.560	-	2.99	Fully

Dependent	Independent	Mediator	ΔR^2	Change in Standardized Coefficient Beta	% Δ Beta	Sobel**	Mediation effect***
Indirect industrial spillovers	Trust	Collaboration effectiveness	.092	-.523	-	3.99	Fully
Indirect industrial spillovers	Shared goals	Collaboration effectiveness	.025	-.239	39	2.36	Moderate
Indirect industrial spillovers	Mngt of collab	Collaboration effectiveness	.091	-.521	100	4.00	Fully
Political spillovers	Resources & capabilities	Collaboration effectiveness	-.004	-.336	-	.69	Not significant
Political spillovers	Network ties	Collaboration effectiveness	.108	-.660	100	4.66	Fully
Political spillovers	Trust	Collaboration effectiveness	.054	-	-	-	-
Political spillovers	Shared goals	Collaboration effectiveness	-.002	-.320	-	.83	Not significant
Political spillovers	Mngt of collab	Collaboration effectiveness	-.006	-.055	15	.61*	Not significant

* Not significant, $p > .01$ ** Not significant, Sobel test < 1.96 *** High > 60 , Moderate 30-60 Low < 30

Collaboration effectiveness fully mediated the following relationships between:

- Trust and intellectual capital
- Trust and direct industrial spillovers
- Trust and indirect industrial spillovers
- Network ties and indirect industrial spillovers
- Network ties and political spillovers
- Shared goals and intellectual capital
- Mngt of collab and indirect industrial spillovers

These findings suggest that the relationships as hypothesized and modelled hold.

Furthermore, collaboration effectiveness highly mediated the relationships between:

- Resources & capabilities and intellectual capital
- Network ties and intellectual capital
- Mngt of collab and intellectual capital

This would suggest a mediation role for collaboration effectiveness with the structural dimension (resources & capabilities, network ties), and a construct of the cognitive dimension (management of collaboration) for the creation of intellectual capital. Only network ties and political spillovers were fully mediated by collaboration effectiveness. Direct industrial spillovers and political spillovers were less well explained by collaboration effectiveness in the direct paths. It would appear that indirect industrial benefits are obtained only if the collaboration is working while even if the collaboration does not totally work, industrial firms directly involved in the ISCs will derive benefits by just being part of the ISCs. Likewise, political spillovers will be derived regardless of the effectiveness of the collaboration.

Finally, collaboration effectiveness moderately mediated the relationship between:

- Resources & capabilities and indirect industrial spillovers
- Shared goals and indirect industrial spillovers

These moderate mediated relationships are plausible given that indirect industrial spillovers in the framework were actual or potential value of benefits arising from the ISC for the industry in general.

This concludes the analyses of the data obtained from the in-depth interviews and the survey. The next section provides an overview of the results as well as the theoretical and managerial implications of the findings.

7 DISCUSSION

7.1 Overview of Results

The primary goal of the research was to integrate three theoretical perspectives relevant to the field of ISCs, namely underlying theories of strategic alliances, country image literature, and social capital under a novel framework – the Integrated Framework of Interorganizational Social Capital in ISC, to better understand the value, bases and processes of international collaborations. This was achieved by building on the social capital framework of Nahapiet and Ghoshal (1998). That framework was then applied to an international and interorganizational setting for the exploration of large-scale, publicly-funded international scientific collaborations in scientific fields of strong interest to Canada, that involve Canadian and foreign government laboratories from selected developed and emerging economies.

Objective 1 of the research was the exploration of motives and desired benefits for scientists from government laboratories to embark in large-scale ISCs. The literature is replete with motives for participation and expected benefits from such collaborations. In particular, the resource-based view focuses on achieving competitive advantage and superior long-term performance (Barney 1991), while the relational view maintains that competitive advantage derives also from capabilities embedded in dyadic and network relationships (Dyer and Singh 1998). Madhok (2005) emphasizes the strategic importance of social aspects of relationships. Broadly speaking, motives generally fall into two main categories: to overcome obstacles and to improve results. Benefits have usually centered on the more immediate impact of scientific collaboration, such as

discoveries, patents, and publications, as well as access to data, knowledge, and unique resources (Katz and Hicks 1997, Katz and Martin 1997, Bozeman 2000, Melin 2000). More recent literature puts emphasis on enhanced visibility and credibility and on access to a wider network of human capital (Beaver 2001, Agrawal, Cockburn *et al.* 2003, Niks, 2004, Cummings and Kiesler 2005), in addition to the usual visible scientific output.

Findings from the in-depth interviews of 21 Canadian senior scientists and policy makers involved in large-scale ISCs within Canadian federal government research laboratories support the literature on the aspect of motives. Primary motives identified include complementarities of skills and access to expertise and facilities, as well as increased scope of the research and faster progress to advance their science. Peer recognition from publications was considered a major driver as well. Interestingly, the notion of ‘fun’ was repeatedly mentioned in the context of liking to work with the foreign collaborators as an important attribute to a successful collaboration. This supports the importance of social factors given the notion that science is a socio-cognitive practice (Stern 1996 in Melin, 2000). Most interviewees believe that foreign scientists share similar motives. The nature of the benefits underlined in the literature was generally confirmed by the participants. Consistent with recent research, the enhanced visibility of Canada and the positive ramifications of such visibility from participation in large-scale ISCs was repeatedly noted by the participants. To be sure, all participants believed that the perceived gains from ISCs far outweigh the costs. For example, one participant involved in the International Polar Year, the largest ever international research program in the Polar regions, expects that the leverage of government funds to the project will be fivefold.

Objective 2 was to research the desired characteristics of international scientific collaborators, at the country and at the scientist level, and the attractiveness of Canada as a scientific partner. At the country level, desirable characteristics were studied from the perspectives of the strategic alliance, the national innovation system, and the country image literature. At the scientist level, desirable characteristics were derived from the social network theory, the literature on trust, and, the social capital literature. Relevant constructs from these streams of literature were organized following the structural, cognitive, and relational dimensions of social capital of the research framework.

Respondents were asked to rate two or three countries involved in an ISC – Canada, their home country if not working in Canada, and another country significantly involved in the ISC. MANOVA analysis was used to compare the characteristics between the ratings of the different groups – Canada, Home Country, and Other country. Out of the 13 constructs composing the individual-level country framework, MANOVA results showed that only three display statistically significant differences among the three groups: S&T infrastructure, social interaction and partner attractiveness. This finding points to the relevance of integrating the national innovation system in the social capital framework as the measures of the S&T infrastructure are all drawn from the NIS literature (OECD 2003b, Soltani and Birang 2005, Van Looy, Debackere *et al.* 2006). Further, this finding provides clear evidence that scientists take a broad view of countries when selecting potential scientific collaborators, above and beyond looking at public research organizations and foreign scientists. Country and scientist characteristics, trusting relationships, shared goals, collaboration effectiveness, and the constructs of the value

creation dimension did not display statistically significant differences among the three groups. Therefore, respondents did not perceive significant difference in these constructs among the three groups.

MANOVA analyses of individual measures of these three significant constructs revealed that for S&T infrastructure, all but one rating of the measures were significantly higher for Other Country. Only the rating of scientific capabilities was not significantly different among the three groups although, again, the rating was highest for Other Country. The key idea conveyed by this specific analysis is that other countries with whom Canadian and foreign scientists are collaborating are believed to be strong partners and often stronger than Canada on this dimension. For social interaction, the nature of relationships with scientific collaborators, all ratings were significantly higher for Home Country. In other words, foreign scientists rated their interaction with other scientists from their home country significantly higher. A bias might have been introduced by the selection of foreign respondents and the operationalization of this construct. Ratings for Canada were lowest on all four measures of social interaction. This finding may go hand in hand with the lower rating of Canada on linkages among public research organizations and with the overall low level of coordination among key players in the Canadian innovation system. Of the eight measures composing the partner attractiveness construct, it was observed that funding level was the only differentiator. Canada displayed the lowest rating on level of funding but not significantly lower than the rating of Home Country.

From the MANOVA analyses, significant inter-country differences that could infer a desirable scientific collaborator for large-scale ISC emerged as a country that exhibits the five following characteristics:

1. a country with good resources (funding, highly qualified personnel in S&T),
2. scientifically productive,
3. with strong coordination among the players of its innovation system,
4. a favourable S&T and regulatory environment,
5. with high level of social interaction among scientific collaborators (length of relationship, frequency and intensity of relationships, strength of ties with scientific networks).

The relative attractiveness of Canada as a scientific collaborator on these measures as perceived by the respondents can be assessed. The S&T infrastructure of Canada was rated significantly lower than that of other countries assessed in the ISC. This suggests that both Canadian and foreign scientists believed that the S&T infrastructure of other countries they are collaborating with was superior to their own. However, for Canada, the measures of S&T infrastructure – funding of S&T, quality of linkages among public research organizations, S&T policies, regulatory policies, and IP policies and practices – were all rated lowest among the three groups. On the funding aspect, a Canadian survey respondent provided this rather grim observation: “The ISC provided a level of research support that I could not have received in Canada. Indeed, postdoctoral fellows (in the U.S.) generally had as much research money available to them as I do after almost 20 years in the Canadian system.” These were particularly important findings, as despite the

generally well recognized strength of Canadian scientific capabilities and research excellence, there were no significant differences among the three groups on this measure. This finding implies that scientific capabilities and research excellence are a necessary but not the only condition to be considered a desirable scientific collaborator. These findings suggest considerable homogeneity among partners in current collaboration in the significant constructs of the structural dimension of social capital of the framework but still important differences on a few measures where Canada lags behind Home Country and Other Country in funding of S&T, quality of linkages among public research organizations, S&T policies, regulatory policies, and social interaction. Knorr-Cetina (1999) found that within collaborations in high-energy physics, what was known about collaborators was more important than the money they brought to the collaboration as a selection mechanism. Her finding is not supported in the context of this research. Funding is a differentiator and plays a crucial role in a partner attractiveness.

Canada's ratings on the five significant characteristics of desirable scientific collaborator described above were all lower than those of Other Country, and either lower or at par with Home Country. Furthermore, S&T policies and regulatory policies in particular were substantially lower. Yet, according to the Council of Canadian Academies (2006), the regulatory system can be regarded as an element of soft infrastructure that has a significant impact on and relationship to S&T. Good science is needed to inform wise and effective regulation. Intellectual property regulation has important implications for the incentives to innovate in Canada, while business framework regulations can either enhance or degrade the environment for entrepreneurial activity.

Network ties, another construct of the structural dimension, were not seen to be significantly different among the three groups. However, a consistent pattern was observed in which Other Country is rated highest and Canada lowest. Looking at ratings of the three measures composing the network ties construct, ties within the global scientific community and the number of world-renowned research clusters showed statistically significant differences. Other Country obtained the highest ranking while Canada was at par with Home Country for clusters. This is a significant finding given the emphasis on the development of world-class research clusters in Canada and elsewhere. Strong world-class research clusters are part and parcel of a strong S&T infrastructure and provide an element of attractiveness as a scientific collaborator.

The relational dimension comprised trusting relationships. The ratings of trusting relationships were not seen to be significantly different among the three groups although ratings of trusting relationships were numerically higher for Canada. This latter findings go hand in hand with the high ratings of Canada on the measures of country characteristics.

To gain an appreciation of possible differences of perceptions between Canadian and foreign scientists, MANOVA analyses were conducted to contrast the views of the two groups of Canada and Other Country. Overall, Canadian scientists tended to be more critical of themselves and their situation but also of others as evidenced by lower ratings compared to ratings of foreign scientists on the same measures. From Canadian scientists' perspective of Canada and Other Country, out of the 13 constructs of the

framework, only three displayed significant statistical differences – S&T infrastructure, network ties and partner attractiveness. In each case, Canadian scientists rated the Other Country significantly higher than Canada. The same analysis from the perspective of foreign scientists also found the same three significant constructs, in addition to social interaction and country characteristics that displayed significant differences. Ratings on these five constructs were all significantly higher for the Other Country except for country characteristics where Canada was superior.

To further explore this last finding about country characteristics, a MANOVA of the ten measures of this construct was run for the foreign scientists. Measures of country characteristics were about general impressions of Canada and its people. Two measures – level of education and overall achievement in science – were significantly different, with lower ratings for Canada compared to Other Country. Not surprisingly, however, friendliness, trustworthiness, likeability, and concerns for others were judged as significantly higher for Canada than for Other Country. Interestingly on these measures, Canadian scientists did not rate Canada significantly different than Other Country. However, looking at results at the measure level, they do rate people characteristics of trustworthiness and concerns for others higher for Canada than for Other Country. T-tests between Canadian and foreign scientists found that consistently, foreign scientists think more highly of Canada and its people than Canadian scientists do, especially for measures related to the nature of Canadians, such as friendliness, trustworthiness, likeability, honesty, and credibility. The well-known affable nature of Canadians is yet again recognized (Anholt 2006, Mandel-Campbell 2007). A survey respondent summed

it up nicely: “I found Canada by far the most wonderful place to collaborate. The Canadians are polite, well-intentioned people, and the research collaborations I have had with them have been my great privilege.”

At the measure level of Canada, a large number of statistically significant differences between the ratings of Canadian and foreign scientists on Canada were observed. In fact, t-tests of the 66 measures composing the individual-level country framework showed that 32 of these measures exhibited a statistically significant difference of ratings. Again, foreign scientists were more generous with their assessment of Canada than Canadian scientists. On every single one of these measures, ratings of the foreign scientists were higher than ratings of the Canadian scientists.

The conclusion of the MANOVA analyses is that Canada appears as a player on the edge on the measures where inter-country differences were detected. The Home Country as well the Other Country groups were comprised of several scientifically advanced countries, and sample size did not allow for further analysis at the specific country level and was, in any case, beyond the scope of the study. However, standard variations of measures across groups were consistently small and therefore MANOVA analyses could detect real differences among the groups. Further, analyses contrasting the views of Canadian and foreign scientists found similar results. Therefore the strong and consistent set of findings provide confidence in the interpretation of the results.

The second research framework, the collective ISC, concentrated on constructs relative to the collaboration effectiveness of the entire ISC and expanded on the measures of value creation. The framework explored ten constructs related to factors of believed importance for the effectiveness of an international scientific collaboration, as well as for value creation from the collaboration. The overall MANOVA F-test of the constructs of the collective ISC framework was not significant, indicating no significant differences at the aggregate level between Canadian and foreign scientists on the collective ISC framework. However, a cautious look at individual measures with t-tests between ratings of Canadian and foreign scientists highlighted significant differences for quality of network ties, level of interaction among collaborators, quality of communication among members, management of IP issues, and benefits to firms directly involved in ISC from improved scientific country image. Similarly to the pattern for the individual-level country framework, ratings of Canadian scientists are significantly lower on these measures compared to ratings of foreign scientists. Most of these measures centered on the social interaction aspect of the ISC. It would appear from the findings that foreign scientists perceived higher level of social interaction among collaborators in the ISCs than Canadian scientists did.

Objective 3 of the research was an exploration of the nature and extent of value-creation from large-scale ISCs. In the questionnaire respondents were asked to rate the value of output created or expected to be created from the ISC. On the aspect of intellectual capital, ratings above 5.5 on a 7-point scale were given to knowledge transfer, creativity, scientific discoveries and publications. Patents, however, were rated substantially lower

at 3.01. A relatively broad range of scientific fields were covered in the survey. Some of these fields may not necessarily be conducive to generating patentable IP. Further, each field tends to address patents and IP issues based on its own set of circumstances. The questionnaire covered direct, as well as indirect industrial spillover effects with identical measures, building on the knowledge-based view (Kogut and Zander 2003), the organizational learning (Cohen and Levinthal 1990), and social network theories (Melin 2000, Adler and Kwon 2002). For direct industrial spillover effects, that is for industrial firms directly involved in the ISC, the highest rating was for improved scientific country image (5.23), followed by access to resources and expertise, prestige of public research labs, and access to networks. The lowest rating (4.70), was given to access to new international markets. Similar ratings were obtained for the industry in general, with ratings ranging between 4.46 for access to new international markets to 5.25 for spillover effects from improved scientific country image. These are indeed valuable findings that tend to empirically support the work of Autio, Hameri *et al.* (2004). These authors developed propositions on the strategic and technological learning benefits that accrue to industrial companies from their interaction with international big-science centers, in this case the Large Hadron Collider of CERN. Benefits of a science country image was in fact perceived by the respondents as providing value to the industry.

Overall, mediation analysis of the collective ISC framework showed that direct industrial benefits accrued to firms as long as there was trust in the ISC, and regardless of the effectiveness of the collaboration. In other words, there is value for firms in being there. However, collaboration effectiveness was shown to be required for indirect industrial

benefits to occur. These are substantial findings that validate the relevance of various government efforts to promote the participation of the private sector in public sector research collaboration and in ISCs.

As expected, the perceived value of political spillover effects of large-scale ISCs was not rated as high as intellectual capital and industry spillovers. Nonetheless, respondents appeared to recognize the impact of ISCs on broader public awareness, science policy and priorities, governance of international science issues and leverage of public research funding, and international relations. Similar to findings related to direct industrial benefits in the mediation analysis, political spillovers will occur regardless of the effectiveness of the collaboration, as long as there are, in this case, strong network ties among collaborators. In distributed ISCs, such as in life science, biotechnologies, agricultural and animal science, ratings of political spillovers were higher than ratings of the more centralized ISCs (Space, earth research, physics). In particular, ratings of leverage of national public research funding, international relations, and S&T capacity building in developing countries were higher for distributed ISCs. International collaboration in science is increasing given the complexity of global issues needing to be addressed. Political spillovers will increasingly be recognized as important benefits from ISCs, not only to firms but to governments and nations. As eloquently put by a survey respondent; “international scientific collaboration will enhance the precious humanity and openness of the collaborators involved and that is a treasure in addition to scientific and industrial development advancement.”

Objective 4 of the research was to test the pattern of relationships between the components of the novel research frameworks. This objective was achieved with regression analysis and mediation analysis. Relationships from the individual-level country framework were explored. All relationships of the framework were found to be significant thereby supporting the general nature of direct relationships of the framework. In particular, the quality of a country's S&T infrastructure was found to be highly related to that country's image, to the perception of that country's scientists as well as to trusting relationships, and finally to the attractiveness of that country as a scientific collaborator and to the perceived effectiveness of the collaboration. Hence, the quality of a country's S&T infrastructure was, without a doubt, a key driver in the whole process. This suggests that Canada's underperformance in this dimension can seriously hamper its attractiveness as a scientific partner. In the short run, people like Canada and like working with Canadians but in the long run, if Canada is not bringing something to the table, Canadians will be pushed away as competition increases steadily in the scientific arena.

Scientist characteristics and to a lesser extent country characteristics were found to be important predictors of trusting relationships. An important aspect of the research was to explore the extent to which the relational dimension of social capital – trust and trustworthiness – relate, directly or indirectly, to partner attractiveness and collaboration effectiveness. As expected, the trusting relationships concept was a strong predictor of the attractiveness of a country as a scientific collaborator. Prior work in this area using the Nahapiet and Ghoshal (1998) framework tended to concentrate on the interpersonal dimension of trust (Tsai and Ghoshal 1998, Inkpen and Tsang 2005, Chen, Chang *et al.*

2006). Thus, these findings help support the need to examine trust using a multidimensional approach. The importance of shared goals for trusting relationships, effectiveness of the collaboration, and ultimately value creation demonstrated in prior empirical work was also supported in this research. Overall, these findings support prior work by Nahapiet and Ghoshal (1998) and Tsai and Ghoshal (1998) on which this research was built. It also highlights the important role of reputational information for selection of partners in interorganizational collaboration (Andersen and Sorensen, 1999). Canada has a strong reputation as a country and so do its scientists but clearly Canada's reputation for supporting its public-sector scientists may not be as strong.

The scientist characteristics construct fully mediated the relationship between network ties and trusting relationships. In addition, the relationship between network ties and trusting relationships was highly mediated by country characteristics, suggesting that scientists form a broader mental image of the country with whom they are collaborating to help them develop trust with research organizations from that country, again supporting the importance of interorganizational and institutional trust. Integration of relevant aspects of the country image literature in the framework did provide a broader understanding of the dynamics between Canadian and foreign scientists related to large-scale ISCs.

Although both partner attractiveness and collaboration effectiveness were important predictors of total value creation, as modelled, collaboration effectiveness was by far the more important. Results showed a stronger relationship between collaboration

effectiveness and intellectual capital in explaining the outcome of ISCs versus industrial and political spillovers.

At the collective ISC level, which assessed the total ISC effort rather than individual members, all modelled direct relationships were supported as hypothesized. The network ties construct, which in this framework related to ties as well as social interaction, shared goals, and management of collaboration, were significant predictors of collaboration effectiveness. Management of the collaboration construct contained measures relative to management of data, IP, and overall management and coordination. Findings relative to the importance of the management of the collaboration supported prior exploration (Kuada 2002, Hara, Solomon *et al.* 2003). These findings were also supported by the in-depth interviews. Interviewed scientists cited shared vision/goals, complementarities of capacities, and management of the collaboration. According to one of the respondents: “Lousy management of ISCs can kill trust.”

Interestingly, the resources and capabilities construct was not an important predictor of collaboration effectiveness compared to network ties, shared goals and management of collaboration in the survey but was raised by the interviewees. This perplexing finding may suggest that within the entire collaboration, the social aspects or “soft infrastructure” might be considered more important than the hard infrastructure or technical aspects. It may also indicate that the resources and capabilities were more related to partner attractiveness rather than being related to collaboration effectiveness – not important in the collective framework but highly significant in the individual-level country

framework. Consequently, for the effectiveness of the collaboration as a whole, other aspects become more important.

As in the individual-level country framework, collaboration effectiveness was more strongly related to intellectual capital than other types of value creation. Using collaboration effectiveness as a mediating variable, all relationships as modelled held for creation of intellectual capital. The framework as modelled also held for the relationships leading to indirect benefits, meaning that the ISC would need to be an effective collaboration for broader general industrial spillovers to happen. However, the relationships as hypothesized did not hold for the direct industrial spillovers. Interestingly, and an insightful finding, even if the collaboration is not effective, industrial firms directly involved in the ISC will derive benefits by just being part of the ISCs and pulling on the resources, sharing goals and generally being involved. A similar finding was found for political spillovers that will be derived even if the collaboration is not effective.

7.2 Theoretical and Research Implications

To sum up the theoretical implications of the research, the Integrated Framework of Interorganizational Social Capital in ISCs offers a number of contributions to the understanding of large-scale international scientific collaboration. First, the results of both the qualitative and quantitative phases of research validated the expected contributions of this research, that is the relevance of adding constructs from the literature

and prior research on strategic alliances and country image to Nahapiet and Ghoshal's (1998) social capital framework. Second, the findings built on and added to each stream of research of interest. Third, it provided much needed empirical evidence of the importance and relevance of studying collaboration within a broader context and examining the interrelationships among the various dimensions of the frameworks.

The results of this research provided strong support for the argument that social capital facilitates value creation, as per Nahapiet and Ghoshal (1998) framework. The three dimensions of social capital assessed had significant effects on resource exchange and combination. Further, the extent of resource exchange and combination was related to value creation. Specific enhancements to Nahapiet and Ghoshal (1998) work include an extension of the framework from intraorganizational to interorganizational relationships, an emphasis on polyadic relationships, an examination of network ties and trust in a more complex setting, and a broadening of the value creation dimension to include not only intellectual capital but also industrial and political spillovers. The end result is a more comprehensive picture of the dynamics of partner attractiveness, collaboration effectiveness, and value creation in large-scale ISCs. Most notably, empirical evidence from this research suggests that adding constructs from a broader range of theoretical perspectives make a valuable contribution to prior work on social capital. Clearly, positive results from factor analysis, correlation and regression analyses confirmed the relevance of augmenting Nahapiet and Ghoshal's (1998) social capital framework with a broader set of constructs. In addition to providing validity for the Nahapiet and Ghoshal

(1998) framework, the results of the study opens the doors for future investigation of more complex models and settings.

The findings built on and added to each stream of research incorporated in the framework – strategic alliances, network ties, trust, and country image. The literature on strategic alliances is broad and extensive. Falling under this umbrella is the resource-based view (RBV) (Barney 1991), and its more recent extension, the relational-based view, as well as other theoretical approaches linked to RBV such as social exchange theory, and the national innovation system. A variety of measures were extracted, adapted, and incorporated in the research frameworks and tested. Results demonstrated that a broader set of resources than previously explored can form the basis of a collaborative advantage in large-scale ISCs. In particular, the national innovation literature had not previously been examined in the context of large-scale ISCs. Yet, the results of this research clearly demonstrated the strategic importance of S&T infrastructure for the attractiveness of a country as a scientific collaborator.

The research built on Nahapiet and Ghoshal (1998), Tsai and Ghoshal (1998) and Hagedoorn, Cloudt *et al.* (2005) to explore the concept of the network ties in the context of large-scale ISCs. Tie strength is central to many contributions to social network theory and is based on Granovetter's (1973) seminal contribution. An important question in the debate around strength of ties is whether strong or weak ties are preferable among collaborators to improve performance. To date, most of the literature has analysed network ties in the context of individuals and small groups only (Hagedoorn, Cloudt *et al.*

2005). This research exploited measures from Tsai and Ghoshal (1998) and Chen, Chang *et al.* (2006) and Hagedoorn, Cloudt *et al.* (2005). In the context of interorganizational and polyadic relationships that are large-scale ISCs, the results confirmed the importance of network ties as a predictor of trusting relationships and partner attractiveness. However, when considered together with other constructs, the direct importance became non-significant, and was mediated by scientist characteristics. This finding is similar to the results of Hagedoorn, Cloudt *et al.* (2005) who concluded that a combination of stronger and weaker R&D ties appeared to be most beneficial for the technological performance of high-tech firms in specific industries. Therefore, this research adds another perspective to the further refinement of the concept of ties strength.

Another contribution of this research is the exploration of broader dimensions of trust given that trust is central in the social capital literature and therefore, in Nahapiet and Ghoshal's (1998) social capital framework. There is a clear stream of work that identifies trust and trustworthiness as significant factors in effective collaboration (McAllister 1995, Zaheer, McEvily *et al.* 1998, Zaheer, Lofstrom *et al.* 2002, Carson, Madhok *et al.* 2003, Christiansen and Vendeke 2003). Previous researchers have argued that trust, both within organizations and in interorganizational settings, may foster innovation (Dakhli and de Clercq 2004). Specifically, the research set out to investigate the effects of organizational and institutional levels of trust on partner attractiveness and collaboration effectiveness of large-scale ISCs in addition to the interpersonal level of trust. Therefore, the goal was to move from trust in dyadic relations to trust in aggregate social systems. The results demonstrated that trusting relationships were indeed a strong

predictor of partner attractiveness and collaboration effectiveness in the context of large-scale ISCs. The results positively support Adler and Kwon's (2002) claim that trust is a key source of social capital. Certainly, these results provided valid ground for incorporating the various levels of trust in future empirical research on group collaborations.

A key contribution of this research was the successful integration of constructs of the country image literature into each of the three dimensions of Nahapiet and Ghoshal' (1998) social capital framework. In particular, measures of the country characteristics construct were adapted from the extensive literature on country image (Heslop and Papadopoulos 1993, Papadopoulos 2004, Laroche, Papadopoulos *et al.* 2005). Country characteristics emerged as a key predictor of trusting relationships. In fact, of the six possible predictors of trusting relationships in the research framework, only three were significant – country characteristics was the most significant, followed by shared goals and scientist characteristics. Scientist characteristics are related to characteristics of people, which are important in the country image literature. Therefore, this research successfully extends the country image literature beyond consumers and businesses to scientists collaborating in large-scale ISCs.

An investigation of broader value creation of large-scale ISCs with the collective ISC framework is contributing to the rather limited number of studies covering the subject. The research built in particular on Autio, Hameri *et al.* (2004) for the industrial spillovers from ISCs. Autio, Hameri *et al.* (2004), also using Nahapiet and Ghoshal's

(1998) social capital framework, developed a set of propositions around industrial knowledge spillovers to industrial suppliers of a big-science center. Although rooted in interorganizational learning, several of the propositions were relevant to the context of large-scale ISCs and were therefore adapted as measures to assess the direct and indirect industrial spillovers. Specifically, technological learning and knowledge transfer, access to resources, expertise, networks and markets, prestige of public research laboratories were integrated into the construct of industrial spillovers. From the country image literature, the measure of industrial spillover effect from an improved scientific country image was also integrated in the industrial spillover construct. Taking into consideration that less than a third of the respondents reported that an industrial firm was directly involved in the ISC, results nonetheless indicated support for these measures both as direct and indirect industrial spillovers. In particular, benefits from the prestige of public research laboratories and from an improved scientific country image were rated highly.

On the pragmatic side, researching international scientific collaborations involving Canada can be challenging. Methodology for future research would need to take into considerations the following aspects. Unlike other areas of research, there are currently no national or international formal databases or repertories of large-scale ISCs available. In addition, given that the majority of ISCs are informal collaborations, researching formal ISCs necessitates diligence in ensuring that the sample truly represents the population in the selected area of research. To be successful, a reasonable sample size covering a broad range of scientific fields and geographical regions is required. In turn, extensive contacts nationally and internationally are required to identify potential ISCs

and key collaborators, validate the nature of the collaboration, the scientific field, and the leadership of the ISCs. For this reason, the use of random sampling would not be appropriate and could lead to erroneous conclusions. Language barriers can become an issue, especially when sampling Asian scientists. It would be advisable to have the survey translated into Mandarin and/or Cantonese. The methodology developed in this research can be applied to specific scientific fields and to other forms of collaborations in other contexts.

7.3 Managerial Implications

Lastly, managerial implications can be derived from these empirical results. The findings of this study have a number of implications and direction for government policy makers, for heads of government federal laboratories and scientists, and for industry.

At a higher level, the benefits of a science-based country image are very important for countries and industry. How a country is perceived and the impact of its positioning in the global scientific network on participation in ISCs were confirmed. Active involvement in large-scale ISCs enhance both a science-based image and the visibility of the country. The opportunity to play a leadership role in major international science facilities is often an indication of being the world's best in a science domain. Further, the institutional capacity a country possesses may affect its ability to access and retain knowledge created in a global network (Wagner and Leydesdorff 2005a). However, global issues and the science required to solve them are both increasing in complexity, hence the need and opportunities for countries to collaborate. For example, the

assessment of potential impacts of present and future variability and change in the Arctic Ocean requires a significant increase in oceanographic research efforts. Because of its Arctic responsibilities and as one of the first countries that will be impacted, Canada must play a leading role in the present international effort to study the changing of the Arctic Ocean.

Substantial levels of government support are required for a country to develop and maintain a world class expertise and to be recognized as such so as to increase its attractiveness as a suitable scientific collaborator and consequently derive benefits from such participation. This translates into substantial funding for resources and equipment, but also active involvement in scientific networks and other venues. In turn, major research facilities attract direct investment, highly qualified personnel, as well as resources and opportunities. A Canadian example is the Canadian Light Source. Located at the University of Saskatchewan in Saskatoon, the CLS is Canada's national synchrotron research facility. Synchrotron light is used to understand the structure of matter at its fundamental level, leading to improved medical imaging, new drugs, advanced materials, better mineral extraction techniques and enhanced environmental monitoring. The region has been attracting highly qualified researchers and resources with this world's class facility. Furthermore, the CLS has been signing several high level agreements for large-scale ISCs with foreign countries, for instance recently with France and Australia. However, funding is coming from a variety of sources and is short-term, leaving the senior management of CLS to spend inordinate amount of time on managing

and securing funding. This situation is common in other Canadian government research laboratories.

The cluster created by scientifically advanced countries has expanded, and new entrants have joined regional networks. Even the smallest countries are now players in global science (Wagner and Leydesdorff 2005a). In this new configuration, a mid-sized country such as Canada may fall into global obscurity given the strong impetus of Asian countries in science. A trend has also been noted toward distributed collaborative research. With distributed or networked ISCs, it becomes even more challenging to enhance visibility compared to centralized ISCs that tend to be found around large infrastructure (Wagner 2005a).

The key importance of the constructs of the structural dimension of the framework and, in particular, the S&T infrastructure, is corroborated with a recent government study of the state of S&T in Canada (Council of Canadian Academies 2006). The results, reflecting 1,490 responses from Canada's senior S&T community, found that the integrated view of Canada's strength in science and technology is somewhat more pessimistic than survey respondents' opinion of S&T strengths in specific areas of research, technology application, and infrastructure. Fewer than half of respondents ranked Canada as strong overall in S&T and roughly a quarter believe that Canada is weak relative to the average of other economically advanced countries. The perception of the overall trend is rather pessimistic – almost 40% believe Canada is losing ground, while only 28% see us gaining. The net trend, again, is considerably more pessimistic

than is the case for the outlook in the specific areas of research and technology application. Again, the results of this research clearly show how important the S&T infrastructure of a country is for both partner attractiveness and collaboration effectiveness.

As stated in the newly released *Mobilizing Science & Technology to Canada's Advantage, the new S&T strategy*, “Canada must continue to strengthen its knowledge base. S&T capacity is more widely distributed around the world today, with countries such as China and India moving increasingly into higher segments of the value chain based on their cost advantages and considerable number of highly qualified personnel. To succeed in an increasingly competitive global arena, Canadians must be at the leading edge of important developments that generate health, environmental, societal, and economic benefits. Now that we have built a strong research foundation, we must strive for excellence in Canadian science and technology” (Government of Canada 2007, p. 9). However, the strategy contains few specifics on international collaboration in general and on international scientific collaboration in particular.

At the S&T policy level, only through a bold, clearly articulated, focused, and adequately resourced strategy can countries position themselves and succeed in the global arena of key science players. Several other countries have embarked into bold S&T strategies where international collaboration is front and center. Some of these countries have even included Canada as their scientific partner of choice in their strategy, for instance, the U.K.. The view of one Canadian scientist interviewee is that “There is not a broad

political understanding of the importance of science on the Hill (Ottawa – Parliament Hill). They are pretty illiterate of science. They understand technology development, university, quality of education, well-being, but not science per se.” Others lamented that Canada is currently badly equipped to participate in current large-scale ISCs, and they fear that the situation will worsen given the trends toward larger, more complex ISCs involving more countries as well as newcomers. The fear expressed is that Canada might slip to irrelevance as a scientific collaborator.

Canada and its people are well liked and respected. Canadians come across as being friendly, nice, honest, credible and trustworthy. Studies have consistently validated these attributes of Canada and Canadians. Mandel-Campbell (2007) notes, “Canadians generally are considered to be more honest, straightforward and reliable than many other nationalities. In a world where personal trust regularly usurps contractual obligations, Canada’s reputation for fairness and decency is an invaluable commodity” (Mandel-Campbell 2007, p. 269). Results from this research showed that ratings from foreign scientists on the measures of country characteristics were very high. One foreign scientist survey respondent supplied the following comment: “It is my great pleasure to share some of my experiences from the last 10 years of intense collaboration with Canada with you. In these years I not only learned to like the way we worked together, I strongly fell in love with this neat little country.” Further, averages on the question of interest in working with Canada again was very high. In other words, others like Canada and its people. This strong country image of Canada is certainly an aspect that government can capitalize on. This, however, is clearly not enough to be considered an attractive

scientific collaborator. The evidence from this research is strong and consistent. Of the six predictors of partner attractiveness of the framework, only S&T infrastructure, scientist characteristics and trusting relationships, by order of importance, were significant predictors. Although country characteristics strongly mediated the relationships between S&T infrastructure and trusting relationships and between network ties and trusting relationships, it had a very low mediating effect between the constructs of the structural dimension and partner attractiveness.

The attributes of a desirable scientific collaborator developed from this research are a country with adequate resources (funding, highly qualified personnel), scientifically productive, strongly coordinated players within its innovation system, and a favourable S&T and regulatory environment. On this line of thought, a Canadian scientist interviewed offered this comment, “ultimately people will only collaborate with you if they see that you are bringing something significant to the table, whether you are big or small.” On the crucial aspect of coordination among players of the innovation system, and as noted by Papadopoulos, Heslop *et al.* (2000) and others, Canada lacks a focused and coordinated effort among various levels of government and departments. This shortcoming was confirmed by the findings of this research with Canada displaying the lowest ratings for quality of linkages among public research organizations, supportive S&T policies and quality of regulatory policies. Further, although most Canadian federal science-based departments have active involvement in large-scale ISCs, few actually have an international mandate, adding to the coordination issue.

On the positive side for Canada, however, the fact that there were no large differences among the countries related to scientific capabilities confirms the findings of several Canadian and foreign reports of the excellent Canadian scientific reputation. Canadian researchers are at the forefront of important scientific developments in many fields of inquiry, ranking first in the G-7 in the number of publications produced on a per-capita basis. (Government of Canada 2007, 2006, OECD 2003b). These findings are also confirmed by the Canadian scientists interviewed in Phase I.

Along the thoughts of insufficient financial resources, a key irritant raised during the interviews and regularly experienced by scientists within federal government laboratories is the lack of support for foreign travel. Because of financial constraints and the somewhat negative perceptions of the public associated with foreign travel, federal government researchers are often prevented from active participation in international venues and collaboration. This situation further decreases the visibility of Canadian researchers and the opportunities to build trusting relationships that may lead to productive collaboration. In addition, the ramifications of disgruntled Canadian scientists who can easily compare themselves with better resourced foreign scientists must not be trivialized. Yet, several studies and the result of this research raise the importance of trusting relationships to help develop a reputation of trustworthiness (Nahapiet and Ghoshal, 1998), and the ‘trust-need-touch’ hypothesis (Gallié and Guichard 2002), emphasizes the importance of face-to-face interactions in developing and maintaining trust. Aptly summed up by a Canadian interviewee, “Trust does not happen over emails.” This research supports these findings. Key predictors of collaboration effectiveness

within the entire ISC were network ties among collaborators and shared goals, in addition to management of collaboration. These critical factors for collaboration effectiveness necessarily entail regular face-to-face interactions.

More and more, industrial firms need to collaborate to access global knowledge and to translate this knowledge into innovative products and services successfully to global markets. In countries predominantly composed of small and medium firms (SMEs) such as Canada, collaboration for SMEs, even within their own country, can be daunting and success elusive. Government can and needs to provide support and incentives to encourage and nurture such collaboration, and this among a variety of knowledge suppliers – other firms, universities, government laboratories and others in their home country and abroad. Autio and Hameri (2004) note, “while the fundamental science mission of big-science centers should continue to be dominant, we believe that greater attention should be paid to maximizing the technological learning benefits that such collaborations may potentially confer. Big-science member countries should encourage their industrial companies to cooperate with big-science centers and provide the necessary help and advice to companies willing to participate” (Autio and Hameri 2004, p. 124). Hence again, the need for a strong and focused S&T strategy at national levels is stressed. The results showed that industrial firms directly involved in ISCs will derive benefits even if the collaboration is not effective by simply being there and participating. An example indicative of spillover effects was offered by an Canadian scientist interviewed in the field of metrology (science of measurement of standards). The interviewee mentioned that through his involvement with a CIDA project to help develop

metrology infrastructure in Latin America, he came to appreciate diversity in culture and in ways of doing things. He notes; “although at first everything appeared like utter chaos, by and large, things got done. If we want to trade with these countries, we need to pay attention to metrology as measurement problems can create technical barriers to trade.” This is a striking example of the far-reaching political spillovers of international collaboration in science that will eventually translate into industrial benefits. Further, this example clearly accentuates the findings of this research related to industrial and political spillovers from ISCs.

8 CONCLUSION

The goal of this study was to enrich the understanding of large-scale ISCs by examining the phenomena from three broad streams of research with a novel research framework, the Integrated Framework of Interorganizational Social Capital in ISCs. The specific study benefits outlined earlier and summarized here are fourfold. First, each of the main streams of research of interest - strategic alliances, country image and social capital - benefited from advances found in the others. Second, the empirical research was the first time that key aspects of these streams of literature were assessed within the same study, enabling the examination of interrelationships among the three concepts in the context of large-scale ISCs. Third, the study provided much needed empirical evidence of the importance of social capital as a value creation mechanism in ISCs in interorganizational and multi-country settings, with more broadly defined value creation activities. Lastly, based on the empirical results it was possible to draw implications and to make policy and strategy recommendations. This section will cover limitations of the study and its expected contribution.

8.1 Limitations and Future Research

The research framework purposely focused on the integration of key constructs from the strategic alliance, country image, and social capital literature. Therefore, constructs related to organizational learning and absorptive capacity, often covered in both the strategic alliance literature and the social capital literature, were not included to avoid introduction of factors outside the current scope of study. Further, constructs related to

culture and its potential effect on trust formation and collaboration effectiveness were not considered, primarily based on findings of the in-depth interviews and to avoid adding an extra level of complexity to already charged research frameworks. Given the successful integration of constructs from these streams of literature, future research could enlarge the frameworks to introduce constructs from these streams of literature.

The research centered on the positive aspects of social capital. However, the literature has suggested negative aspects and pitfalls of social capital. These aspects represent an interesting future avenue of research in the context of ISC. Furthermore, the study focused only on the creation of intellectual capital and not the exploitation aspects. Yet, value creation from ISCs helps competitiveness and prosperity of nations. Therefore, future research could focus on aspects such as economic gains versus costs of ISCs.

The sample size was statistically more than adequate for the purpose of the research and statistical methodology. However, at this first level of analysis, the use of statistical techniques such as path analyses and structural equation modeling was not explored. Given the successful validation of the exploratory research frameworks, additional analyses and verification with statistical techniques such as path analyses and structural equation modeling could be explored to confirm the robustness of the results obtained on framework testing. Further, a finer exploration of the specific countries and scientific fields resulted in very small sample sizes and therefore unreliable statistical analyses. However, such country and field-based knowledge was not the object of this research. A future area of research could either increase the overall sample size or decrease the

number of countries and scientific fields to allow for such comparison among fields and countries.

Senior scientists actively involved in large-scale ISCs were the subject matter experts. A possible next phase of research would be to survey Canadian and foreign industrial firms involved in such ISCs to get their perspective on all constructs of the frameworks but specifically on the industrial spillover effects. In this fashion, the exploitation of the value creation could be further investigated.

Scientists from scientifically advanced countries actively involved with Canada on large-scale ISCs were selected. Given global issues and the need to build capacity in developing countries, government of several scientifically advanced countries are actively promoting and providing incentives for ISCs with developing countries. This research only broached S&T capacity building in developing countries as a potential political spillover effect. There is a need to transpose the research in a context of scientifically advanced vs. developing and integrate cultural aspects into the frameworks. In this fashion, predictors of successful collaboration relevant to this particular context could be identified. Further, the role and impacts of inter-country organizations mandated to foster ISCs for the benefits of developed as well as developing countries could be examined.

Complex studies of relationships involving multiple variables from diverse literature background can be fraught with limitations. The relationships between strategic

alliances, country image and social capital are based on an extensive review of existing literature. However, the combination of constructs from several streams of literature within one framework was a first attempt through this study, and as such, empirical results of the framework application must be interpreted with caution. In addition, statistical evidence was limited by contextual study boundaries. In this case, boundaries are established through the selection of specific scientific fields, respondents, and countries. The selected constructs were by no means exhaustive, but were, however, reflective of the specific study objectives.

8.2 Contributions of the Research

From an academic perspective, the research was novel as it incorporates key constructs from the several streams of literature to complement the social capital framework of Nahapiet and Ghoshal (1998). By doing so, a more complete picture of the dynamics of partner attractiveness, collaboration effectiveness, and value creation from large-scale ISCs has emerged. Most authors agree that high levels of social capital usually are developed in contexts characterized by high levels of mutual interdependence, a situation typical of large-scale ISCs. Specific enhancements to the social capital framework included an extension of the framework from intraorganizational relationships to interorganizational relationships, an emphasis on polyadic relationships, an examination of tie strength in a broader and more complex setting, and a broadening of the concept of intellectual capital to include industrial and political spillovers. The research, therefore, explored beyond the traditional patents, citations, co-authorships nature of scientific output.

Science is increasingly complex and advances in information technologies have enabled distant collaboration. However, the literature has been calling for a social capital approach to the study of collaboratories, that is the human and behavioural aspects of these collaborations, to complement research on technical infrastructure, such as remote access to and control of remote instruments required. In this respect, this research contributes to the growing literature on the understanding of the social processes of interorganizational dynamics of ISCs for the selection of scientific collaborators and value creation, and this, both at the individual-level country and at the collective level.

Another significant aspect of the research is the enrichment to the country image literature. Several constructs drawn from the country image literature and the national innovation system literature formed the S&T infrastructure part of the structural dimension of the social capital of the research framework. In conjunction with dimensions related to the cognitive dimension of social capital, this enabled an analysis of the relationships between country image with the relational dimension of social capital on the one hand, and with the attractiveness of international scientific collaborators on the other hand. The results helped situate the relative role of the various dimensions of country image in large-scale ISCs.

From a practitioner perspective, the study helped characterize the promoting and inhibiting conditions of ISCs for the attractiveness of collaborators, collaboration effectiveness, and value creation from ISCs. So far, no integrative framework had been developed for the analysis of large-scale ISCs-industry interactions. The aim was to

contribute toward such a framework by identifying causal mechanisms that contribute to the creation of knowledge spillovers in large-scale ISCs. Further, the study extended the social capital theory into firm relationships with government research laboratories. In all, 21 Canadian scientists participated in the in-depth interviews and 177 senior Canadian and foreign government scientists participated in the survey. The survey covered eight scientific fields and over ten countries. A two-stage methodology added strength to the research. Given this broad empirical work, insights were gained from the views of respondents that will help guide pragmatic aspects of forming large-scale ISCs and deriving value from them.

The managerial implications can be summarized as follows:

- S&T infrastructure of a country is a key predictor of partner attractiveness and collaboration effectiveness, therefore highlighting the crucial importance of a world-class S&T infrastructure.
- Country characteristics and scientist characteristics play a key role for the establishment of trusting relationships. Who is 'in' depends on how countries are viewed. Therefore, a strong science-based country image and the visibility of a country and its scientists are vital.
- Trusting relationships are significant in the whole ISC process.
- Network ties and shared goals among collaborators as well as the management of a collaboration are key factors for collaboration effectiveness.
- Industry benefit, both directly and indirectly, from ISCs, hence the justification for incentives for their involvement in ISCs.

- A broad range of political spillovers are derived from ISCs.

The managerial implications of the study for Canada can be summarized as follows:

- Canada and its people are well respected.
- Canada has strong scientific capabilities and HQP.
- However, the Canadian S&T infrastructure needs enhancements:
 - Level of funding
 - Quality of linkages among public research organizations
 - Number of world-class research clusters
 - Quality of the S&T environment: S&T policies, regulatory policies, IP policies and practices
 - Visibility
 - Level of interaction among scientists
- Canada lacks proper mechanisms, processes, and central funding for large-scale ISCs.
- Substantial and sustained government support is required to be an attractive scientific collaborator – yet Canada appears to be losing ground and risks slipping to irrelevance as a scientific collaborator while countries like China and India are increasingly moving up.

Finally, from a policy perspective, public policy makers at the national level can benefit from the assessment of the importance of specific country and people characteristics in the selection of collaborators, and particularly the crucial importance of a strong S&T

infrastructure. The study mapped out the positioning of Canada as perceived by both Canadian and foreign scientists. This, in turn, can inform national S&T policies and priorities. Importantly, it can also help articulate not only the scientific benefits but the political benefits accruing from participation in large-scale ISCs. At the industry level, the findings could help position government industrial assistance to firms to both enhance their participation in large-scale ISCs with government research laboratories and to derive benefits from such participation.

In conclusion, the result of this work resulted in a viable new framework of large-scale ISCs specifically focusing on attractiveness of scientific collaborators, collaboration effectiveness, and value creation. It is hoped that the framework will be replicated in other settings, applied to other fields, countries and situations, to enhance strategic alliances, country image and social capital theories, and to further our understanding of international scientific collaborations.

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Appendices

Appendix A	Phase I – In -Depth Interview Questionnaire
Appendix B	Selected Comments from Phase I – In-Depth Interviews
Appendix C	Phase II – Final Questionnaire
Appendix D	Phase II Survey – Hypotheses and Measures
Appendix E	Overview of Individual Measures
Appendix F	MANOVA Multivariate Analyses of Individual Measures
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Appendix A – Phase I In-Depth Interview Questionnaire

The overall purpose of this interview is to discover from you key aspects of importance for international scientific collaborations with Canada. This piece of research will then lead to exploring in depth these key aspects via an international survey of government research laboratories.

A) ISC specifics

Can you tell me some details about your involvement in international scientific collaborations, such as:

1. Scientific field
2. Type of ISC (big science, distributed research, country-to-country, lab-to-lab, peer-to-peer etc)
3. Mechanism (treaty, MOU, other formal mechanisms, exchanges, informal mechanism)
4. Motives
5. Foreign country
6. Dyad or team
7. Duration

B) Country attractiveness

Explore the underlying characteristics of the people and country that might support beliefs about our being a good country for ISC. For instance, factors such as country image, reputation, culture, beliefs, economic and political development, role in world politics, quality of people such as industrious, innovative, trustworthy, likeable, desire for closer ties, National Innovation System and infrastructure, scientific capacity, education, research output, science and other government policies, leadership, national S&T priorities, linkages, coordinating mechanism, and resources

8. What is our image abroad: How is Canada being perceived on the international scientific scene?
9. How do foreign countries perceive our scientific capacity? (Infrastructure, NIS, research output, education, policies etc.)
10. What would signal Canada as a great country to collaborate scientifically with?
11. Are there Canadian key factors supporting or inhibiting foreign countries wanting to collaborate with us?

C) Canadian Government Lab

Explore institutional cachet : research excellence, research output, quality and reputation of scientists, networks, resources, ISC management mechanisms

12. What aspects of Canadian labs make it attractive to foreign government science laboratories to want to collaborate with us?
13. Why would foreign labs not want to collaborate with Canadian labs?

D) Canadian Scientists

Explore attributes of scientists: scientific reputation, trustworthiness, values, reliability, propensity to collaborate, collaborative skills, disseminative capacity, social capital

14. From the perspective of a foreign scientist, what attributes of Canadian scientists make them good scientific collaborators?
15. Are there aspects about the way Canadian scientists think, work, organize, their values, ease of communication that supports or inhibit foreign scientists wanting to collaborate with us?
16. What are the key motives/drivers of Canadian scientists wanting to collaborate with foreign scientists?
17. What are the key motives/drivers of foreign scientists wanting to collaborate with Canadian scientists?

E) Potential factors impacting on ISCs

Explore a variety of factors that could have positive or negative impacts on ISC such as: Inter-cultural environment (language, expectations, norms, values), initial set up, governance and research management, IPR, partner size (symmetry or asymmetry), impacts of networks on ISCs, trends in ISCs such as lab-to-lab vs. scientist-to-scientist collaborations, trust, public funding.

18. In your experience, what factors proved important to successful ISCs?
19. What could you tell me about the impact of trust : at beginning and during the relationship?
20. Does public funding of ISCs have an impact (+ or -) on the collaboration?

F) Desired Benefits

Explore potential benefits such as: knowledge transfer and spillovers, inter-organizational learning, enhanced prestige, reputation, scientific output, enhanced coordination of international science issues, augmented scientific networks and collaborators, impacts on industry such as industrial innovation, enhanced visibility of country, innovation system benefits.

22. I am interested in exploring benefits from ISCs, not only from a scientific perspective but also from economic and political perspectives. What have you observed as benefits overall?
23. Overall, do believe industry benefit from ISCs? What circumstances or conditions of ISCs would positively impact industry?
24. Based on your experience, what can you tell me about the perceived gains of ISCs versus their costs?

Appendix B – Selected Comments from Phase I – In-depth Interviews

Selected Comments on image of Canada

Characteristics	Quotes
Tolerance	"We have this image of friendly, cooperative, non combative, so that makes us easier to work with."
Peaceful	"Historically, Canada has been perceived as a very decent country overall." "Canada has a reputation for diplomacy and fairness; this is a Canadian trait that goes beyond peace keeping role."
Friendly to foreigners	"Foreign scientists really like the Canadian environment: it is pleasant, open-minded, well linked. There are lots to be gained from promoting this nature of Canada and Canadian scientists." "Scientists and engineers from India were impressed by how polite and respectful we are."
Research capacity	"Most countries think very highly of Canada, of our research capacity. They always seem to be very amazed at how we do so much with very little." "They feel we are the best in specific areas." "The general perception from other countries is that science in Canada is underfunded, but there is the perception that the quality of science is very good and probably better bang for the buck than in most other countries. If they have their choice though, they will work with the U.S." "Some groups see us as very small player in S&T, they know individual scientists but have learned over the years that we are not able to play the game : we can't really do big projects with them and we're not aggressive enough."
Networks	"We are perceived as a country that networks and collaborates more."
Visibility	"Genome Canada would spring to mind for people working in that field as it has been very successful in marketing itself on the international scene." "With the failure of the shuttle, we don't see the Canadarm on the television; we have lost a major promotional opportunity." "In some fields, I think it's more Canadians that come to mind, not Canada." "Personal reputation and visibility comes by doing difficult things. If you are at the top of your game, you are recognized."
Education	"Canada is perceived as a good place to get an education, after the U.S. and Europe." "We're certainly not worse than the U.S. and we might be better." "They feel we are easy on our children on the education side."
Support for ISCs	"Our reputation is one of the biggest positive factors, but we might be wearing out our welcomes with G8 colleagues. We're still a G8 member but sometimes we don't deserve to be at the table because we don't follow through, we don't bring the cards to the table." "Foreign countries find that contradictory: we say something and we do something else." "Because of a combination of our inability to market ourselves and excellent group of people running on shoestring budget, we are not taken seriously." "NRC is still a good brand internationally; there is this assumption of quality up front. But we still have to be able to match contribution to collaborate." "There are frustrations among foreign collaborators about our bureaucracy, rules and regulations, issues of co-funding and matching funds. You cannot get money easily and quickly, and you cannot easily transfer money to our foreign partners." "If we had the flexibility to move and use our money more quickly, yet with accountability, that would increase our reputation considerably."

Characteristics	Quotes
Other factors	<p>"The decentralized nature of Canada is not understood by foreigners, especially those from centralized foreign governments."</p> <p>"Because Canada does not have a strong science policy and strategic directions for R&D, we do not have a very structured approach to international S&T, and no supporting mechanisms to coordinate international S&T, it is all fragmented."</p> <p>"The enhanced security requirements for federal organizations result in delays in hiring foreign individuals. This conveys an image of bureaucratic organizations."</p> <p>"The image is that U.S. is warmer, foreign scientists think that the weather is good only one month here, it is very hard to change that perception."</p>

Perceived attributes of Canadian Scientists

Attributes	Quotes
Collaborative	<p>"We come across as very collaborative and innovative." 'Canadian scientists do not have mammoth ego.'</p> <p>"This is the type of society we are, not aggressive, sometimes we are our worse enemy: we are not aggressive enough for commercial deals, but we are good solid researchers."</p>
Inter-cultural skills	<p>"You become a better scientist from working with different culture. You learn a lot from others. You grow a little more with each collaboration. The cultural aspect is fascinating. You become more curious, more agile linguistically; it makes you a better person."</p> <p>"You need to learn across the cultural boundaries and understand the way science is done elsewhere. You need to try to understand their context and how they are funded and rewarded. If they are not rewarded the way we are, we might be driven to do different things and then you end up miscommunicating."</p>
Motivation	<p>"Science is so global that it is a 'must' to remain competitive, issues and projects are too big."</p> <p>"To get several pieces of the puzzle, instead of just yours."</p>

Critical Success Factors in ISCs

Success Factors	Quotes
Complementarities	"ISCs are about collaborating with the best."
Chemistry	"Most of the time it is because you know the people and you like working with them. It's fun and that should not be discounted."
Trust	<p>"Trust is of giant importance. That's why you have to meet the people, visit their labs, get to understand the circumstances they are working under to build trust."</p> <p>"If there is trust, in all its levels and implications, it almost guarantees the success of a good relationship. If it is not there, you can almost guarantee that it will not be a successful collaboration."</p> <p>"Many cultural aspects play a role in cultivating trust. You could be sending a lot of wrong messages by approaching it wrongly, that's why it is important to have the right individual with cultural sensitivities."</p>
Communication	"Face-to-face meetings are important. Trust does not happen over emails."
Visibility	<p>"There is a community for each scientific area. If you're not there, you're not a player."</p> <p>"Visibility is the main thing. We have to have a presence and make Canada visible, not just specific scientists. We need a branding strategy."</p>
Management of ISCs	<p>"Lousy management of ISCs can kill trust."</p> <p>"The Asian culture is based on relationships and not on legal documents, so they don't understand the North American preoccupation with legal agreements and IP."</p>
Funding	<p>"Collaborations may never happen without money for people to meet and develop a shared vision."</p> <p>"Ultimately people will only collaborate with you if they see that you are bringing something significant to the table, whether you are big or small."</p>

Appendix C – Final Questionnaire

INTERNATIONAL SCIENTIFIC COLLABORATION SURVEY²

International scientific collaborations (ISCs) have proven invaluable in answering a range of important scientific questions. However, collaboration can often be problematic and challenging, especially geographically distributed and multidisciplinary collaborations.

I work for the National Research Council of Canada and am conducting a multi-country research on international scientific collaborations involving Canada (research project and doctoral thesis under the supervision of Dr. Louise Heslop from Carleton University). The focus is on formal international scientific collaborations with a strong involvement of a Canadian or foreign government laboratory. Collaborators can be government laboratories, universities, research centres, and/or the private sector.

Essentially, the research is attempting to answer the following:

- What desired benefits drive the formation of large-scale ISCs among government research laboratories in Canada and abroad?
- What are the desired characteristics of international partners in such collaborations?
- What is the attractiveness of Canada compared to other countries as scientific partner in ISCs?
- What is the nature and extent of benefits and outcomes from ISCs?
- What are the relationships between the selection of scientific collaborators, the quality and effectiveness of the collaboration and the outcomes from the collaboration?

We are aiming to complete the data collection by mid-June 2007. We believe that the results will provide relevant findings to the scientific community and government. Participants will receive a summary of the results.

Thank you for taking time off your busy schedule to participate in our survey: It is much appreciated and your feedback truly matters. You may withdraw at any time during the survey. It should take approx. 15 to 20 minutes to complete. The survey has been vetted by a research ethics committee. If you have any questions or concerns about the research, please feel free to contact:

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² The questionnaire was deployed with Zoomerang, a web-based survey software. Visual layout was superior than this Word version.

INTERNATIONAL SCIENTIFIC COLLABORATION SURVEY

The purpose of this survey is to study formal International Scientific Collaborations (ISCs) involving Canada. The focus of the research is on past or current collaborations involving a Canadian or foreign government laboratory. Collaborators can be government laboratories, universities, research centres, and/or the private sector.

In the context of this research, ISCs are specific research projects (as opposed to informal exchange of information and personnel). These collaborations would typically involve resources *(funding, people), be of some duration, and, but not always, be under some form of agreement among collaborating parties such as a research collaboration agreement or a Memorandum of Understanding among institutions and/or countries.

Specifically, we are interested in your perceptions of the effects of several factors on the desired attributes of international partners, on the effectiveness of large-scale ISCs, and the outcomes and benefits from ISCs.

The questionnaire is composed of three sections:

- A) Selected country collaborators
- B) Entire International scientific collaboration
- C) General Information

Within each of these three sections, you may skip questions that you cannot or do not want to answer and still complete the survey.

SECTION A: SELECTED COUNTRY COLLABORATORS

Please answer this survey based on a formal ISC involving Canada and one or more countries that you were or are currently taking part in. If you are or were part of more than one ISC, please choose the largest, most significant collaboration.

1. Canada: Please answer the following questions with respect to Canada (All respondents).

1) Please give your general impressions of Canada's Science and Technology (S&T) system (e.g., government laboratories, universities, private sector, clusters, and networks).

	Low						High
Scientific capabilities of the country	1	2	3	4	5	6	7
Level of scientific productivity	1	2	3	4	5	6	7
Level of funding of S&T	1	2	3	4	5	6	7
Availability of highly qualified personnel	1	2	3	4	5	6	7
Quality of human resources in S&T	1	2	3	4	5	6	7
Quality of linkages among public	1	2	3	4	5	6	7

research organizations							
Quality of scientific networks	1	2	3	4	5	6	7
Ties to others in the global scientific community	1	2	3	4	5	6	7
Number of world-renowned research clusters	1	2	3	4	5	6	7
Supportive S&T Policies	1	2	3	4	5	6	7
Quality of regulatory policies	1	2	3	4	5	6	7
Quality of Intellectual Property policies and practices	1	2	3	4	5	6	7
Overall quality of Canada's S&T System	1	2	3	4	5	6	7

2) Please give your general impressions of Canada and its people concerning the following

	Poor				Excellent		
Friendliness	1	2	3	4	5	6	7
Trustworthiness	1	2	3	4	5	6	7
Likeability	1	2	3	4	5	6	7
Honesty	1	2	3	4	5	6	7
Credibility	1	2	3	4	5	6	7
Concern for others	1	2	3	4	5	6	7
Level of education	1	2	3	4	5	6	7
Innovative/entrepreneurial culture	1	2	3	4	5	6	7
Overall achievements in science	1	2	3	4	5	6	7
Openness to international trade	1	2	3	4	5	6	7

3) Specific to the ISC, please provide information on the nature of your relationship with scientific collaborators from Canada. (Please skip to the next question if you are a Canadian scientist and are not collaborating with other Canadian scientists in the ISC):

	Low				High		
Length of relationship in years: (1=one year or less, 7=seven or more years)	1	2	3	4	5	6	7
Frequency of interaction	1	2	3	4	5	6	7
Intensity of relationships	1	2	3	4	5	6	7
Strength of ties with Canadian scientific networks (Weak=1, strong=7)	1	2	3	4	5	6	7

4) Specific to the ISC, please give your general impressions of scientific collaborators from Canada:

	Poor				Excellent		
Reputation	1	2	3	4	5	6	7
Technological competencies	1	2	3	4	5	6	7
Connected within domestic scientific networks	1	2	3	4	5	6	7
Connected within global scientific networks	1	2	3	4	5	6	7
Interpersonal relationship skills	1	2	3	4	5	6	7
Ability to deal with collaborators from other cultures	1	2	3	4	5	6	7
Willingness to trust	1	2	3	4	5	6	7
Trustworthiness	1	2	3	4	5	6	7
Willingness to collaborate	1	2	3	4	5	6	7
Flexibility	1	2	3	4	5	6	7

Tolerance	1	2	3	4	5	6	7
International experience in ISCs	1	2	3	4	5	6	7
Management skills	1	2	3	4	5	6	7

5) Specific to the ISC, how would you rate the attractiveness of Canada as a collaborator on the following:

	Low				High		
Scientific capabilities	1	2	3	4	5	6	7
Equipment and facilities	1	2	3	4	5	6	7
Complementarity of resources	1	2	3	4	5	6	7
Position within domestic scientific networks	1	2	3	4	5	6	7
Position within global scientific networks	1	2	3	4	5	6	7
Level of funding	1	2	3	4	5	6	7
Quality of Intellectual Property protection	1	2	3	4	5	6	7
Quality of data sharing	1	2	3	4	5	6	7

6) Please indicate your level of agreement with the following. With respect to other collaborators of the ISC, scientific collaborators from Canada:

	Strongly Disagree				Strongly Agree		
Share the vision of the team's purpose	1	2	3	4	5	6	7
Share common goals and objectives	1	2	3	4	5	6	7
Agree with task priorities	1	2	3	4	5	6	7

7) Please indicate your agreement with the following sentences:

	Strongly Disagree				Strongly Agree		
Collaborators from Canada can be relied upon to fulfill their commitments	1	2	3	4	5	6	7
It is easy to share ideas and feelings with these collaborators	1	2	3	4	5	6	7
Organization(s) the collaborator(s) belong to are trustworthy	1	2	3	4	5	6	7
Canadian institutions are trustworthy	1	2	3	4	5	6	7
Canada is competently governed	1	2	3	4	5	6	7

8) In the ISC, how would you rate the contribution of Canada on:

	Low				High		
The quality of the collaboration	1	2	3	4	5	6	7
The efficiency of the collaboration	1	2	3	4	5	6	7
The productivity of the collaboration	1	2	3	4	5	6	7
The success of the collaboration	1	2	3	4	5	6	7

9) How would you rate the contribution of Canada on the output created or expected to be created from the ISC:

	Low						High
The value of the knowledge transfer	1	2	3	4	5	6	7
The value of the scientific output	1	2	3	4	5	6	7
The value of industry benefits	1	2	3	4	5	6	7

10) In the ISC, to what extent has the contribution of Canada enhanced:

	Low						High
Its reputation and credibility	1	2	3	4	5	6	7
Its access to knowledge from other countries	1	2	3	4	5	6	7
Its access to other ISCs with other countries	1	2	3	4	5	6	7

11) Non-Canadian scientists: Please provide your perception on the following:

	Low						High
Interest in working with Canada and its scientists again	1	2	3	4	5	6	7
Likelihood of selecting Canada for future collaborations	1	2	3	4	5	6	7

2. Please answer the following questions with respect to your home country or country where you are currently working.

12) Please specify the country where you are currently working:*

- ☐ My home country is Canada and I am working in Canada
- ☐ My home country is not Canada but I am working in Canada
- ☐ I am working in the following country: _____ (please go to section 2 below).

* If Canada is your home country or you are currently working in Canada, please go to section 3.

13) Questions 13-22 refer to the country where you are working as you indicated in question 12, and labelled 'your country' in the following questions. Please give your general impressions of the Science & Technology system of your country:

	Low						High
Scientific capabilities of the country	1	2	3	4	5	6	7
Level of scientific productivity	1	2	3	4	5	6	7
Level of funding of S&T	1	2	3	4	5	6	7
Availability of highly qualified personnel	1	2	3	4	5	6	7
Quality of human resources in S&T	1	2	3	4	5	6	7
Quality of linkages among public research organizations	1	2	3	4	5	6	7
Quality of scientific networks	1	2	3	4	5	6	7
Ties to others in the global scientific community	1	2	3	4	5	6	7

Number of world-renowned research clusters	1	2	3	4	5	6	7
Supportive S&T Policies	1	2	3	4	5	6	7
Quality of regulatory policies	1	2	3	4	5	6	7
Quality of Intellectual Property policies and practices	1	2	3	4	5	6	7
Overall quality of the country's S&T System	1	2	3	4	5	6	7

14) Please give your general impressions of your country and its people on the following:

	Poor					Excellent	
Friendliness	1	2	3	4	5	6	7
Trustworthiness	1	2	3	4	5	6	7
Likeability	1	2	3	4	5	6	7
Honesty	1	2	3	4	5	6	7
Credibility	1	2	3	4	5	6	7
Concern for others	1	2	3	4	5	6	7
Level of education	1	2	3	4	5	6	7
Innovative/entrepreneurial culture	1	2	3	4	5	6	7
Overall achievements in science	1	2	3	4	5	6	7
Openness to international trade	1	2	3	4	5	6	7

15) Specific to the ISC, please provide information on the nature of your relationship with scientific collaborators from your country. (Please skip to the next question if you are not collaborating with other scientists from your country in the ISC):

	Low					High	
Length of relationship in years: (1=one year or less, 7=seven or more years)	1	2	3	4	5	6	7
Frequency of interaction	1	2	3	4	5	6	7
Intensity of relationships	1	2	3	4	5	6	7
Strength of ties with your country's scientific networks (Weak=1, strong=7)	1	2	3	4	5	6	7

16) Specific to the ISC, please give your general impressions of scientific collaborators from your country:

	Poor					Excellent	
Reputation	1	2	3	4	5	6	7
Technological competencies	1	2	3	4	5	6	7
Connected within domestic scientific networks	1	2	3	4	5	6	7
Connected within global scientific networks	1	2	3	4	5	6	7
Interpersonal relationship skills	1	2	3	4	5	6	7
Ability to deal with collaborators from other cultures	1	2	3	4	5	6	7
Willingness to trust	1	2	3	4	5	6	7
Trustworthiness	1	2	3	4	5	6	7
Willingness to collaborate	1	2	3	4	5	6	7
Flexibility	1	2	3	4	5	6	7
Tolerance	1	2	3	4	5	6	7
International experience in ISCs	1	2	3	4	5	6	7
Management skills	1	2	3	4	5	6	7

17) Specific to the ISC, how would you rate the attractiveness of your country as a collaborator on the following:

	Low						High
Scientific capabilities	1	2	3	4	5	6	7
Equipment and facilities	1	2	3	4	5	6	7
Complementarity of resources	1	2	3	4	5	6	7
Position within domestic scientific networks	1	2	3	4	5	6	7
Position within global scientific networks	1	2	3	4	5	6	7
Level of funding	1	2	3	4	5	6	7
Quality of Intellectual Property protection	1	2	3	4	5	6	7
Quality of data sharing	1	2	3	4	5	6	7

18) Please indicate your level of agreement with the following. With respect to other collaborators of the ISC, scientific collaborators from your country:

	Strongly Disagree				Strongly Agree		
Share the vision of the team's purpose	1	2	3	4	5	6	7
Share common goals and objectives	1	2	3	4	5	6	7
Agree with task priorities	1	2	3	4	5	6	7

19) Please indicate your level of agreement with the following statements:

	Strongly Disagree				Strongly Agree		
Collaborators from my country can be relied upon to fulfill their commitments	1	2	3	4	5	6	7
It is easy to share ideas and feelings with collaborators from my country	1	2	3	4	5	6	7
Organization(s) collaborator(s) from my country belong to are trustworthy	1	2	3	4	5	6	7
Institutions of my country are trustworthy	1	2	3	4	5	6	7
My country is competently governed	1	2	3	4	5	6	7

20) In the ISC, how would you rate the contribution of your country on:

	Low						High
The quality of the collaboration	1	2	3	4	5	6	7
The efficiency of the collaboration	1	2	3	4	5	6	7
The productivity of the collaboration	1	2	3	4	5	6	7
The success of the collaboration	1	2	3	4	5	6	7

21) How would you rate the contribution of your country on the output created or expected to be created from the ISC:

	Low						High
The value of the knowledge transfer	1	2	3	4	5	6	7
The value of the scientific output	1	2	3	4	5	6	7
The value of industry benefits	1	2	3	4	5	6	7

22) In the ISC, to what extent has the contribution of your country enhanced:

	Low					High	
Its reputation and credibility	1	2	3	4	5	6	7
Its access to knowledge from other countries	1	2	3	4	5	6	7
Its access to other ISCs with other countries	1	2	3	4	5	6	7

3. Please answer the following questions with respect to another country significantly involved in the collaboration.

23) Is there another country significantly involved in the collaboration?

If yes, please specify the country. If there is more than one country, please select and type below **one country** to answer the next questions based on that selected country.

If No, please skip to **SECTION B**.

24) Questions 24-34 refer to the country significantly involved in the collaboration that you indicated in question 23. Please give your general impressions of this country's S&T system (e.g., government laboratories, universities, private sector, clusters, and networks):

	Low					High	
Scientific capabilities of the country	1	2	3	4	5	6	7
Level of scientific productivity	1	2	3	4	5	6	7
Level of funding of S&T	1	2	3	4	5	6	7
Availability of highly qualified personnel in S&T	1	2	3	4	5	6	7
Quality of human resources in S&T	1	2	3	4	5	6	7
Quality of linkages among public research organizations	1	2	3	4	5	6	7
Quality of scientific networks	1	2	3	4	5	6	7
Ties to others in the global scientific community	1	2	3	4	5	6	7
Number of world-renowned research clusters	1	2	3	4	5	6	7
Supportive S&T Policies	1	2	3	4	5	6	7
Quality of regulatory policies	1	2	3	4	5	6	7
Quality of Intellectual Property policies and practices	1	2	3	4	5	6	7
Overall quality of the country's S&T System	1	2	3	4	5	6	7

25) Please give your general impressions of this country and its people concerning the following:

	Poor					Excellent	
Friendliness	1	2	3	4	5	6	7
Trustworthiness	1	2	3	4	5	6	7
Likeability	1	2	3	4	5	6	7

Honesty	1	2	3	4	5	6	7
Credibility	1	2	3	4	5	6	7
Concern for others	1	2	3	4	5	6	7
Level of education	1	2	3	4	5	6	7
Innovative/entrepreneurial culture	1	2	3	4	5	6	7
Overall achievements in science	1	2	3	4	5	6	7
Openness to international trade	1	2	3	4	5	6	7

26) Specific to the ISC, please provide information on the nature of your relationship with scientific collaborators from this country.

	Low					High	
Length of relationship in years: (1=one year or less, 7=seven or more years)	1	2	3	4	5	6	7
Frequency of interaction	1	2	3	4	5	6	7
Intensity of relationships	1	2	3	4	5	6	7
Strength of ties with this country's scientific networks (Weak=1, strong=7)	1	2	3	4	5	6	7

27) Specific to the ISC, please give your general impressions of scientific collaborators from this country.

	Poor					Excellent	
Reputation	1	2	3	4	5	6	7
Technological competencies	1	2	3	4	5	6	7
Connected within domestic scientific networks	1	2	3	4	5	6	7
Connected within global scientific networks	1	2	3	4	5	6	7
Interpersonal relationship skills	1	2	3	4	5	6	7
Ability to deal with collaborators from other cultures	1	2	3	4	5	6	7
Willingness to trust	1	2	3	4	5	6	7
Trustworthiness	1	2	3	4	5	6	7
Willingness to collaborate	1	2	3	4	5	6	7
Flexibility	1	2	3	4	5	6	7
Tolerance	1	2	3	4	5	6	7
International experience in ISCs	1	2	3	4	5	6	7
Management skills	1	2	3	4	5	6	7

28) Specific to the ISC, how would you rate the attractiveness of this country as a collaborator on the following:

	Low					High	
Scientific capabilities	1	2	3	4	5	6	7
Equipment and facilities	1	2	3	4	5	6	7
Complementarity of resources	1	2	3	4	5	6	7
Position within domestic scientific networks	1	2	3	4	5	6	7
Position within global scientific networks	1	2	3	4	5	6	7
Level of funding	1	2	3	4	5	6	7
Quality of Intellectual Property protection	1	2	3	4	5	6	7
Quality of data sharing	1	2	3	4	5	6	7

29) Please indicate your level of agreement with the following. With respect to other collaborators of the ISC, scientific collaborators from this country:

	Strongly Disagree				Strongly Agree			
Agree								
Share the vision of the team's purpose	1	2	3	4	5	6	7	
Share common goals and objectives	1	2	3	4	5	6	7	
Agree with task priorities	1	2	3	4	5	6	7	

30) Please indicate your level of agreement with the following sentences:

	Strongly Disagree				Strongly Agree			
Collaborators from this country can be relied upon to fulfill their commitments	1	2	3	4	5	6	7	
It is easy to share ideas and feelings with these collaborators	1	2	3	4	5	6	7	
Organization(s) the collaborator(s) belong to are trustworthy	1	2	3	4	5	6	7	
Institutions of this country are trustworthy	1	2	3	4	5	6	7	
This country is competently governed	1	2	3	4	5	6	7	

31) In the ISC, how would you rate the contribution of this country on:

	Low				High			
The quality of the collaboration	1	2	3	4	5	6	7	
The efficiency of the collaboration	1	2	3	4	5	6	7	
The productivity of the collaboration	1	2	3	4	5	6	7	
The success of the collaboration	1	2	3	4	5	6	7	

32) How would you rate the contribution of this country on the output created or expected to be created from the ISC:

	Low				High			
The value of the knowledge transfer	1	2	3	4	5	6	7	
The value of the scientific output	1	2	3	4	5	6	7	
The value of industry benefits	1	2	3	4	5	6	7	

33) In the ISC, to what extent has the contribution of this country enhanced:

	Low				High			
Its reputation and credibility	1	2	3	4	5	6	7	
Its access to knowledge from other countries	1	2	3	4	5	6	7	
Its access to other ISCs with other countries	1	2	3	4	5	6	7	

34) Please provide your perception on the following:

	Low				High			
Interest in working with this country and its scientists again	1	2	3	4	5	6	7	
Likelihood of selecting this country for future collaborations	1	2	3	4	5	6	7	

SECTION B: ENTIRE INTERNATIONAL SCIENTIFIC COLLABORATION

The questions in this section cover the entire collaboration, including all collaborators from all countries. (All respondents)

35) For the entire ISC, including all collaborators from all countries, how would you rate each of the following:

	Low						High
Quality of the equipment and facilities	1	2	3	4	5	6	7
Complementarity of resources	1	2	3	4	5	6	7
Level of funding	1	2	3	4	5	6	7
Scientific capabilities	1	2	3	4	5	6	7
Quality of the collaborators	1	2	3	4	5	6	7
Quality of network ties among collaborators	1	2	3	4	5	6	7
Level of interaction among collaborators	1	2	3	4	5	6	7
Quality of communication among members	1	2	3	4	5	6	7
Use of internet-based tools to collaborate (excluding emails)	1	2	3	4	5	6	7
Level of flexibility among collaborators	1	2	3	4	5	6	7
Level of tolerance among collaborators	1	2	3	4	5	6	7
Level of trust among collaborators	1	2	3	4	5	6	7
Extent of a shared vision	1	2	3	4	5	6	7
Extent of common goals and objectives	1	2	3	4	5	6	7
Level of agreement with task priorities	1	2	3	4	5	6	7
Management of data	1	2	3	4	5	6	7
Management of Intellectual Property issues	1	2	3	4	5	6	7
Overall management and coordination	1	2	3	4	5	6	7

36) Overall, how would you rate each of the following:

	Low						High
The quality of the collaboration	1	2	3	4	5	6	7
The efficiency of the collaboration	1	2	3	4	5	6	7
The productivity of the collaboration	1	2	3	4	5	6	7
The success of the collaboration	1	2	3	4	5	6	7

37) Overall, how would you rate the value of the scientific output created or expected to be created from the ISC:

	Low						High
Knowledge transfer	1	2	3	4	5	6	7
Creativity	1	2	3	4	5	6	7
Scientific discoveries	1	2	3	4	5	6	7
Publications	1	2	3	4	5	6	7
Patents	1	2	3	4	5	6	7
Other scientific output	1	2	3	4	5	6	7

38) If industrial firms are or were directly involved in the ISC, please indicate your perceptions of the actual or potential value of the benefits arising from the ISC on these firms (Please skip to the next question if no industrial firms were involved):

	Low						High
Technological learning/knowledge transfer	1	2	3	4	5	6	7
Innovativeness	1	2	3	4	5	6	7
Creativity	1	2	3	4	5	6	7
Access to resources and expertise	1	2	3	4	5	6	7
Access to networks	1	2	3	4	5	6	7
Increased competitiveness	1	2	3	4	5	6	7
Access to new international markets	1	2	3	4	5	6	7
Prestige of public research labs	1	2	3	4	5	6	7
Improved scientific country image	1	2	3	4	5	6	7

39) For the industry in general (globally), please indicate your perceptions of the actual or potential value of the benefits arising from the ISC:

	Low						High
Technological learning/knowledge transfer	1	2	3	4	5	6	7
Innovativeness	1	2	3	4	5	6	7
Creativity	1	2	3	4	5	6	7
Access to resources and expertise	1	2	3	4	5	6	7
Access to networks	1	2	3	4	5	6	7
Increased competitiveness	1	2	3	4	5	6	7
Access to new international markets	1	2	3	4	5	6	7
Prestige of public research labs	1	2	3	4	5	6	7
Improved scientific country image	1	2	3	4	5	6	7

40) Globally, how would you rate the impact of the ISC on:

	Low						High
Science policy and priorities	1	2	3	4	5	6	7
Governance of international science issues	1	2	3	4	5	6	7
S&T capacity building in developing countries	1	2	3	4	5	6	7
Leverage of national public research funding	1	2	3	4	5	6	7
Foreign policy	1	2	3	4	5	6	7
International relations	1	2	3	4	5	6	7
Broader public (e.g., awareness, interest)	1	2	3	4	5	6	7

SECTION C: GENERAL INFORMATION

41) Please select the scientific field(s) that best describes the area of your selected international scientific collaboration:

- ☐ Space research
- ☐ Earth research
- ☐ Biotechnologies

- ☐ Metrology
- ☐ Nanosciences and nanotechnologies
- ☐ Health research
- ☐ Advanced engineering and manufacturing
- ☐ Energy
- ☐ Other, please specify _____

42) Type of your organization :

- ☐ Government laboratory
- ☐ University
- ☐ Non Government Organization
- ☐ Private Firm
- ☐ Other, please specify _____

43) Home country _____

44) Name of the selected ISC (example International Polar Year) _____

45) How many countries participated or are participating in this ISC? _____

46) What is or was the total duration of this ISC (in years)? _____

47) Please specify your role in the international scientific collaboration:

- ☐ Principal Investigator
- ☐ Senior scientist
- ☐ Junior member
- ☐ Manager
- ☐ Other, please specify _____

48) Please provide any additional comments you may have. Please indicate your email address if you would like to receive a summary report of the results.

Your participation is greatly appreciated. Rest assured that your answers will be completely confidential. Answers from all respondents will be aggregated and all reports will deal with aggregated data only. Individual respondents will not be identified. A summary of the results will be made available to the participants.

Thank you for your participation!

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Appendix D – Phase II Survey - Hypotheses and Measures

Questionnaire and Measures - Individual-level country framework

Hyp.	Hypotheses	Question Number	Number of measures	Scale number
H1a	The perceived quality of a country's S&T infrastructure is positively related to that country's image	1	10	a,b,c,d,e,f,j,k,l,m
		2	10	All
H1b	The perceived quality of a country's S&T infrastructure is positively related to the perception of that country's scientists	1	10	a,b,c,d,e,f,j,k,l,m
		4	13	All
H1c	The extent of network ties of a country within the global scientific community is positively related to that country's image	1	3	g,h,i
		2	10	All
H1d	The extent of network ties of a country within the global scientific community is positively related to the perception of that country's scientists	1	3	g,h,i
		4	13	All
H2a	The perceived quality of a country's S&T infrastructure is positively related to trusting relationships with that country's scientists	1	10	a,b,c,d,e,f,j,k,l,m
		7	5	All
H2b	The extent of network ties of a country within the global scientific community is positively related to trusting relationships with that country's scientists	1	3	g,h,i
		7	5	All
H2c	The extent of social interaction is positively related to trusting relationships with that country's scientists	3	4	All
		7	5	All
H3a	The characteristics of a country are positively related to trusting relationships with that country's scientists	2	10	All
		7	5	All
H3b	The characteristics of a country's scientists are positively related to trusting relationships with that country's scientists	4	13	All
		7	5	All
H3c	The extent to which scientific collaborators from a country share the team's goals is positively related to trusting relationships with that country's scientists	6	3	All
		7	5	All
H4a	The perceived quality of a country's S&T infrastructure is positively related to the attractiveness of that country as a scientific collaborator for large-scale ISCs	1	10	a,b,c,d,e,f,j,k,l,m
		5	8	All
		11	2	All
H4b	The perceived quality of a country's S&T infrastructure is positively related to the contribution of that country on the perceived effectiveness of the collaboration	1	10	a,b,c,d,e,f,j,k,l,m
		8	4	All
H4c	The extent of network ties of a country within the global scientific community is positively related to the attractiveness of that country as a scientific collaborator for large-scale ISCs	1	3	g,h,i
		5	8	All
		11	2	All
H4d	The extent of social interaction is positively related to the attractiveness of that country as a scientific collaborator for large-scale ISCs	3	4	All
		5	8	All
		11	2	All

Hyp.	Hypotheses	Question Number	Number of measures	Scale number
H4e	The extent of social interaction is positively related to the perceived effectiveness of the collaboration	3	4	All
		8	4	All
H5a	The characteristics of a country are positively related to the attractiveness of that country as a scientific collaborator for large-scale ISCs	2	10	All
		5	8	All
		11	2	All
H5b	The characteristics of a country's scientists are positively related to the attractiveness of that country as a scientific collaborator for large-scale ISCs	4	13	All
		5	8	All
		11	2	All
H5c	The extent to which scientific collaborators from a country share the team's goals is positively related to the contribution of that country on the perceived effectiveness of the collaboration	6	3	All
		8	4	All
H6a	The level of trusting relationships with a country's scientists is positively related to the attractiveness of that country as a scientific collaborator	7	5	All
		5	8	All
		11	2	All
H6b	The level of trusting relationships with a country's scientists is positively related to the contribution of that country on the perceived effectiveness of the collaboration	7	5	All
		8	4	All
H7a	The attractiveness of a country as a scientific collaborator is positively related to that country's contribution to the value creation from the large-scale ISC	5	8	All
		9	3	All
		10	3	All
H7c	The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the creation of intellectual capital	8	4	All
		9	2	a,b
H7d	The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the creation of industrial spillovers	8	4	All
		9	1	c
H7e	The contribution of a country to the perceived effectiveness of the collaboration is positively related to the contribution of that country to the creation of political spillovers	8	4	All
		10	3	All

Questionnaire and Measures – Collective ISC

Hyp.	Hypotheses	Question Number	Number of measures	Scale Number
H4f	The perceived quality of resources and capabilities in the ISC is positively related to the perceived effectiveness of the collaboration	35	6	a,b,c,d,e,i
		----- 36	----- 4	----- All
H4g	The perceived quality of network ties among collaborators of the ISC is positively related to the perceived effectiveness of the collaboration	35	5	f,g,h,j,k
		----- 36	----- 4	----- All
H5d	The extent to which scientific collaborators share the team's goals is positively related to the perceived effectiveness of the collaboration	35	3	m,n,o
		----- 36	----- 4	----- All
H5e	The perceived quality of the management of the ISC is positively related to the perceived effectiveness of the collaboration	35	3	p,q,r
		----- 36	----- 4	----- All
H6b	The level of trust among collaborators of the ISC is positively related to the perceived effectiveness of the collaboration	35	1	l
		----- 36	----- 4	----- All
H7f	The perceived effectiveness of the collaboration is positively related to the creation of intellectual capital	36	4	All
		----- 37	----- 6	----- All
H7g	The perceived effectiveness of the collaboration is positively related to the creation of direct industrial spillovers	36	4	All
		----- 38	----- 9	----- All
H7h	The perceived effectiveness of the collaboration is positively related to the creation of indirect industrial spillovers	36	4	All
		----- 39	----- 9	----- All
H7i	The perceived effectiveness of the collaboration is positively related to the creation of political spillovers	36	4	All
		----- 40	----- 7	----- All

Appendix E – Overview of Individual Measures

Individual-level country framework

Structural Dimension

S&T Infrastructure	Means and Standard Deviations			Factor Loadings		
General impressions of country's S&T system	Canada N=151	Home Country N=72	Other Country N=101	Canada	Home Country	Other Country
Scientific capabilities	5.60 (1.05)	5.43 (1.16)	5.67 (0.96)	.776	.735	.793
Level of scientific productivity	5.32 (1.11)	5.19 (1.17)	5.54 (1.01)	.746	.739	.786
Level of funding of S&T	4.22 (1.37)	4.14 (1.31)	5.16 (1.35)	.768	.717	.740
Availability of highly qualified personnel in S&T	5.11 (1.28)	4.90 (1.30)	5.51 (0.97)	.789	.827	.742
Quality of human resources in S&T	5.26 (1.11)	4.90 (1.34)	5.35 (1.01)	.707	.808	.679
Quality of linkages among public research organizations	4.29 (1.25)	4.96 (1.23)	4.96 (1.11)	.771	.799	.752
Supportive S&T Policies	4.06 (1.36)	4.14 (1.42)	5.17 (1.30)	.813	.794	.833
Quality of regulatory policies	3.98 (1.35)	4.44 (1.30)	4.58 (1.17)	.789	.683	.776
Quality of IP policies and practices	4.32 (1.23)	4.56 (1.31)	4.73 (1.32)	.697	.507	.721
Overall quality of country's S&T System	4.86 (1.16)	4.66 (1.27)	5.20 (1.16)	.902	.911	.888

Network Ties	Means and Standard Deviations			Factor Loadings		
	Canada N=148	Home Country N=72	Other Country N=100	Canada	Home Country	Other Country
Quality of scientific networks	4.71 (1.28)	5.04 (1.14)	5.02 (1.28)	.879	.812	.884
Ties to others in the global scientific community	4.99 (1.26)	5.26 (1.20)	5.34 (1.24)	.880	.890	.847
Number of world-renowned research clusters	4.51 (1.20)	4.52 (1.35)	5.15 (1.41)	.853	.839	.871

Social Interaction	Means and Standard Deviations			Factor Loadings		
	Canada N=117	Home Country N=60	Other Country N=101	Canada	Home Country	Other Country
Length of relationship	5.03 (1.95)	5.98 (1.69)	4.99 (1.96)	.594	.877	.642
Frequency of interaction	4.56 (1.54)	5.83 (1.55)	4.66 (1.47)	.887	.897	.878
Intensity of relationships	4.68 (1.50)	5.63 (1.34)	4.86 (1.39)	.912	.866	.890
Strength of ties with country's scientific networks	4.17 (1.57)	5.27 (1.66)	4.41 (1.46)	.834	.770	.827

Cognitive Dimension

Country Characteristics	Means and Standard Deviations			Factor Loadings		
	Canada N=150	Home Country N=72	Other Country N=100	Canada	Home Country	Other Country
Friendliness	6.00 (0.88)	5.63 (1.00)	5.62 (0.98)	.774	.702	.737
Trustworthiness	5.93 (0.81)	5.90 (0.97)	5.42 (1.07)	.822	.806	.908
Likeability	5.84 (0.85)	5.65 (1.01)	5.47 (0.97)	.833	.808	.850
Honesty	5.91 (0.87)	5.93 (1.05)	5.53 (0.95)	.907	.810	.885
Credibility	5.87 (0.87)	5.86 (0.91)	5.58 (1.05)	.860	.859	.873
Concern for others	5.69 (0.95)	5.43 (1.24)	4.95 (1.15)	.769	.713	.748
Level of education	5.62 (0.95)	5.49 (1.07)	5.73 (1.06)	.750	.689	.518
Innovative/entrepreneurial culture	4.82 (1.18)	4.91 (1.50)	5.25 (1.24)	.629	.580	.446
Overall achievements in science	5.24 (1.00)	5.14 (1.33)	5.49 (1.03)	.746	.535	.535
Openness to international trade	5.29 (1.11)	5.27 (1.48)	5.30 (1.22)	.636	.483	.536

Scientist Characteristics	Means and Standard Deviations			Factor Loadings		
General impressions of collaborators from country	Canada N=148	Home Country N=70	Other Country N=101	Canada	Home Country	Other Country
Reputation	5.59 (0.98)	5.41 (1.06)	5.69 (1.11)	.644	.746	.705
Technological competencies	5.68 (0.95)	5.42 (1.12)	5.70 (0.98)	.777	.798	.696
Connected within domestic scientific networks	5.14 (1.13)	5.17 (1.14)	5.30 (1.19)	.676	.705	.529
Connected within global scientific networks	5.12 (1.28)	5.21 (1.18)	5.15 (1.20)	.718	.806	.648
Interpersonal relationship skills	5.48 (1.12)	5.16 (1.20)	5.35 (1.11)	.822	.867	.812
Ability to deal with collaborators from other cultures	5.50 (1.17)	5.39 (1.17)	5.27 (1.22)	.856	.810	.842
Willingness to trust	5.66 (1.04)	5.57 (1.04)	5.48 (1.08)	.811	.801	.746
Trustworthiness	5.84 (0.90)	5.81 (1.00)	5.50 (1.05)	.800	.761	.824
Willingness to collaborate	5.71 (1.03)	5.61 (1.09)	5.68 (1.04)	.812	.842	.740
Flexibility	5.34 (1.15)	5.21 (1.25)	5.14 (1.26)	.860	.800	.855
Tolerance	5.61 (1.02)	5.30 (1.13)	5.26 (1.21)	.754	.750	.831
International experience in ISCs	5.26 (1.18)	5.22 (1.31)	5.43 (1.23)	.729	.780	.718
Management skills	5.07 (1.30)	4.91 (1.23)	5.18 (1.19)	.784	.784	.761

Shared Goals	Means and Standard Deviations			Factor Loadings		
Collaborators from country:	Canada Mean (std dev) N=145	Home Country Mean (std dev) N=71	Other Country Mean (std dev) N=100	Canada	Home Country	Other Country
Share the vision of the team's purpose	5.43 (1.15)	5.69 (1.10)	5.49 (1.18)	.951	.967	.942
Share common goals and objectives	5.43 (1.12)	5.68 (1.08)	5.52 (1.11)	.961	.967	.961
Agree with task priorities	5.40 (1.14)	5.61 (1.09)	5.48 (1.09)	.932	.911	.952

Relational Dimension

Trust	Means and Standard Deviations			Factor Loadings		
	Canada N=150	Home Country N=72	Other Country N=102	Canada	Home Country	Other Country
Collaborators from country can be relied upon to fulfill their commitments	5.71 (1.03)	5.68 (0.95)	5.45 (1.08)	.818	.863	.852
It is easy to share ideas and feelings with these collaborators	5.67 (1.05)	5.65 (1.00)	5.27 (1.22)	.832	.798	.826
Organizations the collaborators belong to are trustworthy	5.67 (1.01)	5.80 (1.06)	5.46 (1.11)	.895	.920	.891
Country's institutions are trustworthy	5.67 (0.99)	5.74 (1.10)	5.41 (1.12)	.846	.908	.902
Country is competently governed	4.96 (1.36)	4.87 (1.62)	4.94 (1.33)	.658	.555	.721

Resource Exchange and combination

Partner Attractiveness	Means and Standard Deviations			Factor Loadings		
	Canada N=150	Home Country N=72	Other Country N=100	Canada	Home Country	Other Country
Scientific capabilities	5.74 (1.03)	5.50 (1.29)	5.82 (0.98)	.827	.869	.816
Equipment and facilities	5.42 (1.16)	5.28 (1.36)	5.50 (1.20)	.811	.874	.828
Complementarity of resources	5.37 (1.06)	5.20 (1.24)	5.44 (1.19)	.769	.846	.753
Position within domestic scientific networks	4.98 (1.11)	5.34 (1.27)	5.18 (1.14)	.811	.770	.806
Position within global scientific networks	5.03 (1.30)	5.14 (1.26)	5.18 (1.25)	.787	.885	.828
Level of funding	4.04 (1.45)	4.09 (1.67)	5.03 (1.43)	.670	.674	.621
Quality of IP protection	4.82 (1.29)	4.76 (1.34)	4.60 (1.21)	.683	.667	.673
Quality of data sharing	5.23 (1.13)	5.24 (1.44)	5.13 (1.28)	.657	.794	.613
Interest in working with country and its scientists again	6.14 (1.16) N=70	---	5.98 (1.16)	.719		.680
Likelihood of selecting country for future collaborations	5.93 (1.36) N=70	---	5.90 (1.19)	.692		.674

Collaboration Effectiveness	Means and Standard Deviations			Factor Loadings		
	Canada N=149	Home Country N=70	Other Country N=101	Canada	Home Country	Other Country
Quality of collaboration	5.63 (1.06)	5.63 (1.05)	5.60 (1.15)	.907	.911	.931
Efficiency of collaboration	5.37 (1.17)	5.47 (1.03)	5.40 (1.15)	.913	.930	.932
Productivity of collaboration	5.50 (1.13)	5.57 (1.06)	5.53 (1.18)	.937	.909	.955
Success of collaboration	5.61 (1.06)	5.60 (1.05)	5.67 (1.13)	.915	.921	.952

Value Creation

Intellectual Capital, Industrial Spillovers and Political Spillovers

Total value creation	Means and Standard Deviations			Factor Loadings		
	Canada N=150	Home Country N=70	Other Country N=101	Canada	Home Country	Other Country
Contribution of country on the output - Value of the knowledge transfer	5.46 (1.02)	5.49 (1.10)	5.40 (1.18)	.820	.760	.833
Value of scientific output	5.59 (0.98)	5.61 (1.06)	5.62 (0.96)	.847	.876	.778
Value of industry benefits	4.70 (1.35)	4.73 (1.53)	4.78 (1.44)	.675	.714	.721
Contribution of country on - Its reputation and credibility	5.54 (1.07)	5.30 (1.13)	5.33 (1.13)	.846	.901	.874
Its access to knowledge from other countries	5.46 (1.15)	5.33 (1.20)	5.22 (1.19)	.825	.882	.838
Its access to other ISCs with other countries	5.06 (1.27)	5.14 (1.21)	5.03 (1.30)	.770	.877	.812

Collective ISC Framework

Structural Dimension

Resources and Capabilities	Mean (std dev) N=155	Factor loadings
Quality of the equipment and facilities	5.51 (.96)	.904
Complementarity of resources	5.49 (.97)	.841
Level of funding	4.60 (1.15)	.702
Scientific capabilities	5.68 (1.00)	.886
Quality of the collaborators	5.79 (.98)	.851
Use of internet-based tools to collaborate (excluding email)	4.24 (1.58)	.410

Network Ties	Mean (std dev) N=155	Factor Loadings
Quality of network ties among collaborators	5.32 (1.08)	.821
Level of interaction among collaborators	5.24 (1.08)	.898
Quality of communication among members	5.26 (1.09)	.909
Level of flexibility among collaborators	5.16 (1.06)	.871
Level of tolerance among collaborators	5.48 (.98)	.790

Cognitive Dimension

Shared Goals	Mean (std dev) N=154	Factor Loadings
Extent of a shared vision	5.52 (1.04)	.950
Extent of common goals and objectives	5.45 (1.03)	.962
Level of agreement with task priorities	5.40 (1.01)	.939

Management of Collaboration	Mean (std dev) N=154	Factor Loadings
Management of data	5.23 (1.11)	.898
Management of IP issues	4.74 (1.15)	.860
Overall management and coordination	5.24 (1.05)	.927

Resource Exchange and Combination

Collaboration Effectiveness	Mean (std dev) N=155	Factor Loadings
Quality of the collaboration	5.70 (1.05)	.937
Efficiency of the collaboration	5.41 (1.18)	.930
Productivity of the collaboration	5.47 (1.18)	.950
Success of the collaboration	5.62 (1.15)	.947

Value Creation

Intellectual Capital	Mean (std dev) N=155	Factor Loadings
Knowledge transfer	5.52 (1.05)	.847
Creativity	5.57 (1.01)	.857
Scientific discoveries	5.52 (1.09)	.857
Publications	5.55 (1.21)	.760
Patents	3.01 (1.81)	.522
Other scientific output	4.83 (1.41)	.656

Direct industrial Spillovers	Mean (std dev) N=47*	Factor Loadings
Technological learning/knowledge transfer	4.96 (1.30)	.836
Innovativeness	4.79 (1.43)	.792
Creativity	4.81 (1.45)	.817
Access to resources and expertise	5.19 (1.28)	.761
Access to networks	5.09 (1.21)	.818
Increased competitiveness	4.87 (1.35)	.840
Access to new international markets	4.70 (1.57)	.677
Prestige of public research labs	5.13 (1.21)	.786
Improved scientific country image	5.23 (1.15)	.754

Indirect Industrial Spillovers	Mean (std dev) N=120	Factor Loadings
Technological learning/knowledge transfer	5.18 (1.34)	.874
Innovativeness	5.14 (1.36)	.851
Creativity	5.14 (1.33)	.864
Access to resources and expertise	5.24 (1.29)	.860
Access to networks	5.00 (1.26)	.837
Increased competitiveness	4.94 (1.40)	.853
Access to new international markets	4.46 (1.70)	.749
Prestige of public research labs	5.12 (1.53)	.810
Improved scientific country image	5.25 (1.37)	.837

Political Spillovers	Mean (std dev) N=141	Factor Loadings
Science policy and priorities	4.35 (1.72)	.862
Governance of International science issues	4.21 (1.75)	.893
S&T Capacity building in developing countries	3.98 (1.93)	.827
Leverage of National public research funding	4.28 (1.66)	.757
Foreign Policy	3.42 (1.88)	.895
International relations	4.19 (1.85)	.858
Broader public (e.g., awareness, interest)	4.41 (1.78)	.789

Appendix F – MANOVA Multivariate Analyses of Individual Measures

Individual-Level Country Framework Structural dimension constructs and measures

Constructs/Measures	Canada (N=65)	Home Country (N=38)	Other Country (N=65)	F	Sig.
S&T Infrastructure					
Scientific capabilities	5.57 ^a	5.58 ^a	<u>5.72^a</u>	.43	.653
Scientific Productivity	5.24 ^a	5.16 ^a	<u>5.60^a</u>	1.27	.283
Funding of S&T	4.20 ^a	4.26 ^a	<u>5.15^b</u>	9.57	.000
Availability of HPQ in S&T	5.08 ^{a,b}	4.87 ^a	<u>5.54^b</u>	4.97	.008
Quality of HR in S&T	5.14 ^a	5.00 ^a	<u>5.32^a</u>	1.04	.356
Quality of linkages among public research organizations	4.29 ^a	4.97 ^b	<u>5.00^b</u>	6.46	.002
S&T Policies	4.00 ^a	4.32 ^a	<u>5.09^b</u>	11.82	.000
Regulatory Policies	3.97 ^a	4.39 ^{a,b}	<u>4.65^b</u>	5.33	.006
IP Policies and Practices	4.29 ^a	4.42 ^a	<u>4.75^a</u>	2.38	.096
Overall Quality of S&T System	4.85 ^a	4.76 ^a	<u>5.17^a</u>	1.86	.159
Network Ties					
Quality of scientific networks	4.63 ^a	<u>5.13^a</u>	5.00 ^a	2.36	.097
Ties within global scientific community	4.80 ^a	<u>5.50^b</u>	5.32 ^{a,b}	4.54	.012
Number of world-renowned research clusters	4.35 ^a	4.50 ^a	<u>5.11^b</u>	6.02	.003
Social Interaction					
Length of relationships	4.97 ^a	<u>5.95^b</u>	5.05 ^a	3.73	.026
Frequency of interaction	4.55 ^a	<u>5.74^b</u>	4.65 ^a	8.62	.000
Intensity of relationships	4.60 ^a	<u>5.68^b</u>	4.82 ^a	7.18	.001
Strength of ties with scientific networks	4.08 ^a	<u>5.37^b</u>	4.40 ^a	8.86	.000

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$. Underlined values represent highest means.

Cognitive Dimension constructs and measures

Constructs/Measures	Canada	Home Country	Other Country	F	Sig.
Country Characteristics					
Friendliness	<u>5.91^a</u>	5.61 ^a	5.51 ^a	2.79	.064
Trustworthiness	<u>5.86^b</u>	5.84 ^{a,b}	5.40 ^a	4.18	.017
Likeability	<u>5.78^a</u>	5.61 ^a	5.46 ^a	1.82	.165
Honesty	5.78 ^a	<u>5.87^a</u>	5.46 ^a	2.57	.079
Credibility	5.83 ^a	<u>5.84^a</u>	5.51 ^a	2.04	.133
Concern for others	<u>5.60^b</u>	5.50 ^b	4.85 ^a	9.31	.000
Level of education	5.52 ^a	5.29 ^a	<u>5.75^a</u>	2.61	.077
Innovative/entrepreneurial culture	4.80 ^a	4.95 ^a	<u>5.26^a</u>	2.48	.087
Overall achievements in science	5.12 ^a	5.05 ^a	<u>5.46^a</u>	2.27	.107

Constructs/Measures	Canada	Home Country	Other Country	F	Sig.
Openness to international trade	5.11 ^a	5.39 ^a	5.31 ^a	.80	.450
Scientist Characteristics					
Reputation	5.48 ^a	5.26 ^a	5.69 ^a	2.19	.115
Technological competencies	5.63 ^a	5.39 ^a	5.69 ^a	1.27	.284
Connected within domestic scientific networks	5.12 ^a	5.00 ^a	5.23 ^a	.57	.568
Connected within global scientific networks	5.03 ^a	5.24 ^a	5.15 ^a	.41	.663
Interpersonal relationship skills	5.38 ^a	4.95 ^a	5.29 ^a	2.02	.136
Ability to deal with collaborators from other cultures	5.42 ^a	5.16 ^a	5.18 ^a	.84	.434
Willingness to trust	5.57 ^a	5.55 ^a	5.38 ^a	.51	.602
Trustworthiness	5.69 ^a	5.76 ^a	5.45 ^a	1.44	.241
Willingness to collaborate	5.63 ^a	5.63 ^a	5.62 ^a	.004	.996
Flexibility	5.20 ^a	5.13 ^a	5.05 ^a	.25	.778
Tolerance	5.46 ^a	5.13 ^a	5.22 ^a	1.34	.266
International experience in ISCs	5.29 ^a	5.24 ^a	5.40 ^a	.25	.782
Management skills	5.00 ^a	4.68 ^a	5.11 ^a	1.50	.227
Shared Goals					
Share the vision of the team's purpose	5.29 ^a	5.50 ^a	5.38 ^a	.38	.682
Share common goals and objectives	5.26 ^a	5.42 ^a	5.43 ^a	.42	.658
Agree with task priorities	5.20 ^a	5.53 ^a	5.40 ^a	1.16	.316

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$. Underlined values represent highest means.

Relational dimension constructs and measures

Constructs/Measures	Canada	Home Country	Other Country	F	Sig.
Trust					
Collaborators from Country can be relied upon to fulfill their commitments	5.57 ^a	5.58 ^a	5.34 ^a	.89	.414
It is easy to share ideas and feelings with these collaborators	5.48 ^a	5.50 ^a	5.26 ^a	.74	.479
Organizations the collaborators belong to are trustworthy	5.60 ^a	5.58 ^a	5.46 ^a	.31	.735
Country's institutions are trustworthy	5.57 ^a	5.66 ^a	5.46 ^a	.43	.651
Country is competently governed	4.88 ^a	4.97 ^a	4.95 ^a	.08	.919

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$. Underlined values represent highest means.

Resource Exchange and Combination

Constructs/Measures	Canada	Home Country	Other Country	F	Sig.
Partner Attractiveness					
Scientific capabilities	5.66 ^a	5.61 ^a	<u>5.77^a</u>	.32	.727
Equipment and facilities	5.46 ^a	5.47 ^a	<u>5.52^a</u>	.05	.949
Complementarity of resources	5.26 ^a	5.32 ^a	<u>5.34^a</u>	.08	.927
Position within domestic scientific networks	4.91 ^a	<u>5.37^a</u>	5.22 ^a	2.47	.088
Position within global scientific networks	4.95 ^a	<u>5.37^a</u>	5.12 ^a	1.38	.254
Level of funding	3.94 ^a	4.39 ^{a,b}	<u>5.06^b</u>	9.10	.000
Quality of IP protection	4.83 ^a	4.63 ^a	4.58 ^a	.72	.486
Quality of data sharing	5.03 ^a	5.16 ^a	5.06 ^a	.12	.884
Collaboration Effectiveness					
Quality of collaboration	5.51 ^a	<u>5.66^a</u>	5.46 ^a	.39	.677
Efficiency of collaboration	5.25 ^a	<u>5.45^a</u>	5.28 ^a	.38	.684
Productivity of collaboration	5.31 ^a	<u>5.55^a</u>	5.43 ^a	.58	.559
Success of collaboration	5.57 ^a	<u>5.61^a</u>	5.57 ^a	.02	.983

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$. Underlined values represent highest means.

Value Creation

Constructs/Measures	Canada	Home Country	Other Country	F	Sig.
Intellectual capital					
Value of knowledge transfer	<u>5.43^a</u>	5.37 ^a	5.38 ^a	.05	.951
Value of scientific output	5.49 ^a	<u>5.53^a</u>	5.52 ^a	.02	.979
Industrial Spillovers	<u>4.74^a</u>	4.68 ^a	4.68 ^a	.04	.961
Political Spillovers					
Reputation and credibility	<u>5.42^a</u>	5.29 ^a	5.28 ^a	.30	.740
Access to knowledge from other countries	<u>5.46^a</u>	5.26 ^a	5.14 ^a	1.33	.268
Access to other ISCs with other countries	4.98 ^a	<u>5.26^a</u>	4.943 ^a	.93	.398

Note: Means with the same superscript on each measure are not significantly different at $\alpha < .05$. Underlined values represent highest means.

Appendix G – Results of t-test Analyses

Individual-level country framework

t-tests between scientists working in Canada versus working in another country on measures relative to Canada

Constructs Canada	Working in Canada Mean (std dev) N=80	Working in another country Mean/(std dev) N=71	T	sig
Scientific capabilities	5.39/(1.04)	5.85/(1.02)	2.723	.007
Level of scientific productivity	5.18/(1.07)	5.49/(1.13)		
Level of funding of S&T	3.66/(1.11)	4.88/(1.35)	5.986	.000
Availability of highly qualified personnel in S&T	4.68/(1.28)	5.61/(1.101)	4.687	.000
Quality of human resources in S&T	5.10/(1.03)	5.43/(1.17)		
Quality of linkages among public research organizations	3.83/(1.11)	4.86/(1.18)	5.424	.000
Quality of scientific networks	4.35/(1.13)	5.12/(1.33)	3.755	.000
Ties to others in the global scientific community	4.73/(1.16)	5.27/(1.31)	2.656	.009
Number of world-renowned research clusters	4.27/(1.07)	4.79/(1.29)	2.695	.008
Supportive S&T Policies	3.47/(1.23)	4.82/(1.13)	6.601	.000
Quality of regulatory policies	3.51/(1.30)	4.57/(1.17)	4.763	.000
Quality of IP policies and practices	4.05/(1.25)	4.69/(1.11)	2.953	.004
Overall quality of Canada's S&T System	4.46/(1.02)	5.33/(1.15)	4.923	.000
General Impressions of Canada and its people - Friendliness	5.77/(.92)	6.25/(.75)	3.489	.001
Trustworthiness	5.75/(.72)	6.13/(.86)	2.934	.004
Likeability	5.68/(.84)	6.01/(.84)	2.410	.017
Honesty	5.75/(.88)	6.08/(.82)	2.412	.017
Credibility	5.68/(.90)	6.07/(.80)	2.773	.006
Concern for others	5.53/(.93)	5.87/(.95)	2.178	.031
Level of education	5.46/(.96)	5.81/(.91)	2.339	.021
Innovative/entrepreneurial culture	4.44/(1.05)	5.25/(1.18)	4.414	.000
Overall achievements in science	5.10/(.91)	5.40/(1.07)		
Openness to international trade	5.12/(1.11)	5.48/(1.09)	1.998	.048
Nature of relation with Canadian Collaborators - Length of relationship	5.41/(1.79)	4.75/(2.03)		
Frequency of interaction	4.67/(1.30)	4.47/(1.70)		
Intensity of relationships	4.69/(1.29)	4.67/(1.64)		
Strength of ties with Canadian scientific networks	4.19/(1.45)	4.16/(1.65)		
General impressions of collaborators from Canada - Reputation	5.45/(.98)	5.73/(.97)		
Technological competencies	5.57/(.81)	5.81/(1.08)		
Connected within domestic scientific networks	4.83/(.99)	5.47/(1.19)	3.556	.001
Connected within global scientific networks	4.95/(1.17)	5.31/(1.38)		
Interpersonal relationship skills	5.37/(.89)	5.59/(1.32)		
Ability to deal with collaborators from other cultures	5.43/(.90)	5.59/(1.41)		
Willingness to trust	5.56/(.75)	5.77/(1.28)		

Constructs Canada	Working in Canada Mean /(std dev) N=80	Working in another country Mean/(std dev) N=71	T	sig
Trustworthiness	5.63/(.69)	6.06/(1.03)	2.978	.003
Willingness to collaborate	5.59/(.80)	5.85/(1.22)		
Flexibility	5.16/(.88)	5.54/(1.36)	2.048	.042
Tolerance	5.46/(.81)	5.78/(1.19)		
International experience in ISCs	5.05/(.98)	5.49/(1.33)	2.236	.027
Management skills	4.88/(1.10)	5.28/(1.47)		
Attractiveness of Canada - Scientific capabilities	5.59/(.93)	5.90/(1.12)		
Equipment and facilities	5.27/(1.02)	5.59/(1.28)		
Complementarity of resources	5.21/(.90)	5.54/(1.19)		
Position within domestic scientific networks	4.74/(.95)	5.26/(1.22)	2.847	.005
Position within global scientific networks	4.78/(1.16)	5.31/(1.40)	2.530	.012
Level of funding	3.58/(1.15)	4.57/(1.59)	4.353	.000
Quality of IP protection	4.50/(1.15)	5.21/(1.35)	3.225	.002
Quality of data sharing	5.13/(.95)	5.35/(1.30)		
Scientific collaborators from Canada - Share the vision of the team's purpose	5.29/(1.10)	5.59/(1.19)		
Share common goals and objectives	5.29/(1.06)	5.60/(1.17)		
Agree with task priorities	5.27/(.98)	5.55/(1.29)		
Collaborators from Canada can be relied upon to fulfill their commitments	5.66/(.95)	5.77/(1.11)		
It is easy to share ideas and feelings with these collaborators	5.45/(.98)	5.92/(1.08)	2.779	.006
Organizations the collaborators belong to are trustworthy	5.48/(.93)	5.89/(1.06)	2.535	.012
Canadian Institutions are trustworthy	5.46/(.91)	5.90/(1.04)	2.747	.007
Canada is competently governed	4.70/(1.34)	5.27/(1.34)	2.574	.011
Contribution of Canada on Quality of collaboration	5.57/(.90)	5.70/(1.21)		
Efficiency of collaboration	5.29/(1.06)	5.46/(1.27)		
Productivity of collaboration	5.49/(.97)	5.50/(1.28)		
Success of collaboration	5.57/(.94)	5.67/(1.18)		
Contribution of Canada on the output				
Value of the knowledge transfer	5.35/(.98)	5.59/(1.06)		
Value of scientific output	5.63/(.80)	5.55/(1.15)		
Value of industry benefits	4.59/(1.25)	4.82/(1.46)		
Its reputation and credibility	5.58/(.86)	5.48/(1.29)		
Its access to knowledge from other countries	5.54/(.97)	5.36/(1.33)		
Its access to other ISCs with other countries	5.08/(1.15)	5.05/(1.42)		

t-tests between Canadian and Foreign Scientists on Measures Relative to Other Country

Constructs Other country	Working in Canada Mean /(std dev) N=80	Working in another country Mean/(std dev) N=21	T	sig
Scientific capabilities	5.59/ (.95)	6.00/ (.95)		
Level of scientific productivity	5.44/ (.99)	5.95/ (.97)		
Level of funding of S&T	5.21/ (1.32)	4.95/ (1.50)		
Availability of highly qualified personnel in S&T	5.35/ (.93)	6.10/ (.91)	3.203	.002
Quality of human resources	5.19/ (.97)	5.95/ (.95)	3.139	.002
Quality of linkages among public research organizations	4.89/ (1.06)	5.21/ (1.27)		
Quality of scientific networks	4.91/ (1.15)	5.47/ (1.68)		
Ties to others in the global scientific community	5.19/ (1.14)	5.90/ (1.45)	2.402	.018
Number of world-renowned research clusters	4.93/ (1.41)	5.95/ (1.15)	2.974	.004
Supportive S&T Policies	5.16/ (1.27)	5.22/ (1.44)		
Quality of regulatory policies	4.52/ 1.12)	4.82/ (1.38)		
Quality of IP policies and practices	4.63/ (1.30)	5.20/ (1.32)		
Overall quality of the country's S&T System	5.13/ (1.17)	5.47/ (1.12)		
General impressions of other country and its people - Friendliness	5.62/ (.97)	5.62/ (1.02)		
Trustworthiness	5.40/ (1.06)	5.52/ (1.12)		
Likeability	5.49/ (.94)	5.43/ (1.12)		
Honesty	5.47/ (.94)	5.71/ (1.01)		
Credibility	5.50/ (1.02)	5.86/ (1.15)		
Concern for others	4.97/ (1.14)	4.86/ (1.20)		
Level of education	5.63/ (1.03)	6.10/ (1.09)		
Innovative/entrepreneurial culture	5.20/ (1.13)	5.45/ (1.64)		
Overall achievements in science	5.37/ (1.02)	5.95/ (.97)	2.368	0.20
Openness to international trade	5.35/ (1.07)	5.10/ (1.68)		
Nature of relationship with collaborators from other country - Length of relationship	4.84/ (1.91)	5.57/ (2.09)		
Frequency of interaction	4.63/ (1.46)	4.81/ (1.50)		
Intensity of relationships	4.73/ (1.40)	5.38/ (1.28)		
Strength of ties with this country's scientific networks	4.23/ (1.40)	5.10/ (1.51)	2.476	.015
General impressions of collaborators from other country - Reputation	5.58/ (1.05)	6.14/ (1.24)	2.120	0.36
Technological competencies	5.58/ (.91)	6.14/ (1.11)	2.385	.019
Connected within domestic scientific networks	5.24/ (1.14)	5.55/ (1.36)		
Connected within global scientific networks	4.97/ (1.14)	5.81/ (1.21)	2.949	.004
Interpersonal relationship skills	5.30/ (1.11)	5.55/ (1.15)		
Ability to deal with collaborators from other cultures	5.21/ (1.22)	5.48/ (1.21)		
Willingness to trust	5.46/ (1.08)	5.57/ (1.12)		
Trustworthiness	5.48/ (1.04)	5.57/ (1.12)		
Willingness to collaborate	5.63/ (1.06)	5.90/ (.94)		
Flexibility	5.18/ (1.23)	5.00/ (1.41)		
Tolerance	5.33/ (1.17)	5.00/ (1.34)		
International experience in ISCs	5.33/ (1.19)	5.81/ (1.33)		

Constructs Other country	Working in Canada Mean /(std dev) N=80	Working in another country Mean/(std dev) N=21	T	sig
Management skills	5.15/(1.17)	5.29/(1.27)		
Attractiveness of other country - Scientific capabilities	5.68/(.91)	6.33/(1.07)	2.797	.006
Equipment and facilities	5.41/(1.16)	5.86/(1.32)		
Complementarity of resources	5.42/(1.10)	5.50/(1.54)		
Position within domestic scientific networks	5.12/(1.08)	5.42/(1.35)		
Position within global scientific networks	4.95/(1.15)	6.05/(1.24)	3.827	.000
Level of funding	5.17/(1.37)	4.52/(1.57)		
Quality of IP protection	4.53/(1.22)	4.88/(1.15)		
Quality of data sharing	5.08/(1.30)	5.35/(1.23)		
Collaborators from other country: Share the vision of the team's purpose	5.42/(1.18)	5.76/(1.14)		
Share common goals and objectives	5.48/(1.11)	5.67/(1.11)		
Agree with task priorities	5.46/(1.07)	5.57/(1.17)		
Collaborators from this country can be relied upon to fulfill their commitments	5.43/(1.11)	5.52/(.98)		
It is easy to share ideas and feelings with these collaborators	5.23/(1.25)	5.43/(1.12)		
Organizations the collaborators belong to are trustworthy	5.41/(1.10)	5.67/(1.11)		
Institutions of this country are trustworthy	5.40/(1.07)	5.48/(1.33)		
This country is competently governed	4.99/(1.24)	4.75/(1.68)		
Contribution of other country on: The quality of collaboration	5.53/(1.19)	5.90/(.94)		
The efficiency of collaboration	5.33/(1.18)	5.67/(1.02)		
The productivity of collaboration	5.46/(1.22)	5.81/(.98)		
The success of collaboration	5.59/(1.18)	6.00/(.89)		
The value of the knowledge transfer	5.34/(1.21)	5.62/(1.02)		
The value of the scientific output	5.57/(1.00)	5.81/(.81)		
The value of industry benefits	4.60/(1.47)	5.45/(1.10)	2.408	.018
Its reputation and credibility	5.23/(1.17)	5.71/(.90)		
Its access to knowledge from other countries	5.10/(1.23)	5.67/(.91)		
Its access to other ISCs with other countries	4.89/(1.32)	5.55/(1.10)	2.053	.043
Interest in working with this country and its scientists again	5.86/(1.22)	6.45/(.76)	2.053	.043
Likelihood of selecting this country for future collaborations	5.81/(1.24)	6.25/(.91)		

Collective ISC Framework

T-tests between Canadian and Foreign Scientists

Constructs Other country	Working in Canada Mean /(std dev) N=89	Working in another country Mean/(std dev) N=66	T	sig
Quality of the equipment and facilities	5.45/(.88)	5.56/(1.19)	.67	.505
Complementarity of resources	5.46/(.97)	5.52/(1.13)	.37	.714
Level of funding	4.65/(1.14)	4.51/(1.35)	.72	.475
Quality of the collaborators	5.70/(1.03)	5.89/(1.06)	1.15	.252
Quality of network ties among collaborators	5.14/(1.04)	5.54/(1.26)	2.13	.035
Level of interaction among collaborators	4.97/(1.11)	5.57/(1.13)	3.30	.001
Quality of communication among members	5.05/(1.12)	5.52/(1.17)	2.55	.012
Use of internet-based tools to collaborate (excluding email)	4.21/(1.62)	4.27/(1.91)	.21	.835
Level of flexibility among collaborators	5.09/(1.07)	5.25/(1.24)	.82	.413
Level of tolerance among collaborators	5.39/(1.04)	5.58/(1.06)	1.13	.261
Level of trust among collaborators	5.53/(.96)	5.77/(1.22)	1.33	.184
Extent of a shared vision	5.42/(1.04)	5.63/(1.20)	1.12	.263
Extent of common goals and objectives	5.41/(1.07)	5.48/(1.17)	.41	.685
Level of agreement with task priorities	5.32/(1.08)	5.48/(1.11)	.88	.381
Management of data	5.17/(1.19)	5.29/(1.20)	.60	.552
Management of IP issues	4.55/(1.20)	5.04/(1.39)	2.14	.034
Overall management and coordination	5.11/(1.18)	5.40/(1.11)	1.53	.129
Quality of the collaboration	5.64/(1.00)	5.77/(1.12)	.72	.470
Efficiency of the collaboration	5.28/(1.14)	5.55/(1.21)	1.43	.155
Productivity of the collaboration	5.44/(1.10)	5.50/(1.30)	.32	.751
Success of the collaboration	5.61/(1.08)	5.63/(1.27)	.10	.924
Value of intellectual capital - Knowledge transfer	5.47/(1.01)	5.55/(1.10)	.44	.663
Creativity	5.47/(.99)	5.69/(1.04)	1.30	.195
Scientific discoveries	5.48/(.96)	5.58/(1.26)	.56	.576
Publications	5.61/(1.08)	5.48/(1.37)	.67	.507
Patents	2.93/(1.61)	3.13/(2.08)	.61	.543
Other scientific output	4.82/(1.28)	4.82/(1.60)	.01	.993
Value of direct industrial spillovers - Technological learning/knowledge transfer	4.74/(1.26)	5.13/(1.46)	1.05	.300
Innovativeness	4.52/(1.30)	5.22/(1.70)	1.68	.099
Creativity	4.64/(1.28)	5.22/(1.59)	1.43	.160
Access to resources and expertise	4.93/(1.25)	5.57/(1.16)	1.87	.067
Access to networks	4.83/(1.31)	5.26/(1.14)	1.25	.216
Increased competitiveness	4.62/(1.43)	5.17/(1.30)	1.44	.155
Access to new international markets	4.32/(1.57)	5.14/(1.56)	1.82	.075
Prestige of public research labs	4.85/(1.38)	5.36/(.95)	1.48	.147
Improved scientific country image	4.89/(1.34)	5.61/(.94)	2.16	.036
Indirect industry spillovers- Technological learning/knowledge transfer	5.01/(1.27)	5.46/(1.38)	1.81	.074
Innovativeness	4.96/(1.34)	5.48/(1.26)	2.11	.037
Creativity	5.01/(1.27)	5.37/(1.39)	1.42	.158
Access to resources and expertise	5.13/(1.36)	5.45/(1.12)	1.34	.183
Access to networks	4.84/(1.32)	5.29/(1.10)	1.89	.061

Constructs Other country	Working in Canada Mean /(std dev) N=89	Working in another country Mean/(std dev) N=66	T	sig
Increased competitiveness	4.80/(1.36)	5.20/(1.44)	1.50	.137
Access to new international markets	4.24/(1.60)	4.86/(1.80)	1.87	.064
Prestige of public research labs	4.99/(1.56)	5.37/(1.45)	1.30	.195
Improved scientific country image	5.15/(1.29)	5.44/(1.46)	1.11	.268
Political spillovers - Science policy and priorities	4.28/(1.58)	4.41/(1.90)	.44	.661
Governance of International science issues	4.18/(1.62)	4.19/(1.91)	.05	.961
S&T Capacity building in developing countries	3.97/(1.84)	4.04/(2.07)	.18	.855
Leverage of National public research funding	4.28/(1.60)	4.23/(1.76)	.18	.858
Foreign Policy	3.43/(1.80)	3.39/(2.02)	.11	.911
International relations	4.16/(1.82)	4.19/(1.92)	.92	.935
Broader public (e.g., awareness, interest)	4.36/(1.79)	4.47/(1.80)	.37	.715

Appendix H – Methodology for Regression and Mediation Analyses

(Source: Preacher and Leonardelli 2006)

A variable may be considered a mediator to the extent to which it carries the influence of a given independent variable (IV) to a given dependent variable (DV). Mediation occurs when 1) the IV significantly affects the mediator, 2) the IV significantly affects the DV in the absence of the mediator, 3) the mediator has a significant unique effect on the DV, and 4) the effect of the IV on the DV shrinks upon the addition of the mediator to the model (Preacher and Leonardelli, 2006). Therefore, the amount of mediation is defined as the reduction of the effect of the initial variable (IV) on the outcome (DV). The mediator (M) is called an intervening or process variable. Complete mediation occurs when IV no longer affects DV after M has been controlled and path c is zero. In partial mediation, the path from IV to DV is reduced in absolute size but is different from zero when the mediator is controlled (Kenny, 2006).

Figure 9. Mediation analysis (Preacher and Leonardelli 2006)

In this research, mediation was used to have a more complete understanding of the interplay between the variables of the research frameworks. Mediation followed Kenny's (2006) approach: each initial variable was correlated with the outcome as well

as with the mediator via simple regression analysis. The mediator was also shown to affect the outcome variable with a regression equation using IV and the mediator as predictors and DV as the outcome variable.

To assess the statistical significance of mediation, the most commonly used test, the Sobel first proposed by Sobel (1982) test was used. The test requires the standard error of the unstandardized regression coefficient a and the standard error of a or s_a (which equals a/t_a where t_a is the t-statistic test for the difference between coefficient a and zero), and the standard error of b or s_b . An active online calculation tool for mediation tests was used to calculate the Sobel test from Preacher and Leonardelli (2006). The tool requires either a , b , s_a and s_b or alternatively, t_a and t_b can be used. The values of t_a and t_b were obtained with a regression analysis with the IV predicting the mediator for t_a and a regression analysis with the IV and mediator predicting the DV for t_b . The test calculates the critical ratio of whether indirect effect of the IV on the DV via the mediator is significantly different from zero, and is treated as a Z test (i.e., larger than 1.96 in absolute value is significant at the .05 level). The values of betas and R^2 (all significant at $p < .001$ unless indicated otherwise) as well as the values of t_a and t_b used to assess mediation in both research frameworks are shown in the tables below.

Sobel test results for Individual-level country framework

Hyp	Dependent	Independent	Mediator	Beta change for independent variable (%Δ)	R ² change	t-test	Sobel
H2a	Trusting relationships	S&T infrastructure	Country characteristics	.518-.160= -.358 (69)	.266-.548= .282	Ta 12.102 Tb 14.195	9.21 High
			Scientist characteristics	.516-.110= -.406 (79)	.264-.592= .328	Ta 12.645 Tb 15.999	9.92 High
H2b	Trusting relationships	Network ties	Country characteristics	.484 - .166= -.318 (66)	.232 -.551= .319	Ta 10.122 Tb 15.151	8.42 High
			Scientist characteristics	.484 - n.s.= -.484 (100)	.232 -.587= .355	Ta 12.782 Tb 16.491	10.10 Fully
H4a	Partner attractiveness	S&T infrastructure	Country characteristics	.795 -.643= -.152 (19)	.630 -.679= .049	Ta 12.102 Tb 7.067	6.10 Low
			Scientist characteristics	.795 -.519= -.276 (35)	.630 -.782= .152	Ta 12.645 Tb 14.848	9.63 Moderate
			Trusting relationships	.795-.598= -.197 (25)	.630-.734= .104	Ta 10.863 Tb 11.240	7.81 Low
H4b	Collaboration effectiveness	S&T infrastructure	Trusting relationships	.505-.180= -.325 (64)	.253-.547= .294	Ta 10.863 Tb 14.442	8.68 High
H4c	Partner attractiveness	Network ties	Country characteristics	.726 -.549= -.177 (24)	.526 -.623= .097	Ta 10.122 Tb 9.124	6.78 Low
			Scientist characteristics	.726 -.421= -.305 (42)	.526 -.719= .193	Ta 12.782 Tb 14.547	9.60 Moderate
			Trusting relationships	.726-.512= -.214 (29)	.526-.673= .147	Ta 9.935 Tb 12.036	7.66 Low
H4d	Partner attractiveness	Social interaction	Trusting relationships	.289-.068= -.221 (77)	.080-.498= .418	Ta 5.688 Tb 15.164	5.33 High
H4e	Collaboration effectiveness	Social interaction	Trusting relationships	.384-.164= -.220 (57)	.145-.569= .424	Ta 5.688 Tb 16.407	5.37 Moderate
H5a	Partner attractiveness	Country characteristics	Trusting relationships	.631 -.274= -.357 (57)	.396 -.506= .110	Ta 19.167 Tb 8.529	7.79 Moderate
H5b	Partner attractiveness	Scientist characteristics	Trusting relationships	.777 -.609= -.168 (22)	.603 -.622= .019	Ta 21.222 Tb 4.095	4.02 Low
H5c	Collaboration effectiveness	Shared goals	Trusting relationships	.742-.442= -.300 (40)	.549-.626= .077	Ta 19.011 Tb 8.088	7.44 Moderate

Note: There is no guidance from authors on size of mediation effect. A decision was made to use the following as the basis for judging the size of the mediating effect: Fully = 100% of change in betas, high >60%, Moderate 30-60, Low <30

Sobel test results for Collective ISC framework

Dependent	Independent	Mediator	Adjusted R ²	Change in Standardized Coefficient Beta	% Beta change	Sobel **	Mediation effect***
Intellectual capital	Resources & capabilities	Collaboration effectiveness	.434 - .557 .123	.662 - .241 -.421	64	6.03	High
Intellectual capital	Network ties	Collaboration effectiveness	.444 - .541 .097	.669 - .173 -.496	74	5.57	High
Intellectual capital	Trust	Collaboration effectiveness	.273 - .534 .261	.527 - (-.038*) -.527	100	7.69	Fully
Intellectual capital	Shared goals	Collaboration effectiveness	.410 - .537 .127	.643 - .136* -.643	100	6.13	Fully
Intellectual capital	Mngt of collab	Collaboration effectiveness	.436 - .554	.663 - .252 -.411	62	5.89	High
Direct ind spillovers	Resources & capabilities	Collaboration effectiveness	.378 - .368	.624 - .572 -.052	8	.35	Not significant
Direct ind spillovers	Network ties	Collaboration effectiveness	.276 - .278	.538 - .326* -.538	-	1.06	Not significant
Direct ind spillovers	Trust	Collaboration effectiveness	.103 - .254	.345 - (-.119*) -.345	100	3.28	Fully
Direct ind spillovers	Shared goals	Collaboration effectiveness	.282 - .289	.543 - .339* -.543	-	1.23	Not significant
Direct ind spillovers	Mngt of collab	Collaboration effectiveness	.344 - .340	.596 - .480* -.596	-	.81	Not significant
Indirect industrial spillovers	Resources & capabilities	Collaboration effectiveness	.354 - .388	.599 - .341 -.258	43	2.70	Moderate
Indirect industrial spillovers	Network ties	Collaboration effectiveness	.308 - .353	.560 - .186* -.560	-	2.99	Fully
Indirect industrial spillovers	Trust	Collaboration effectiveness	.267 - .359	.523 - .192* -.523	-	3.99	Fully
Indirect industrial spillovers	Shared goals	Collaboration effectiveness	.371 - .396	.613 - .374 -.239	39	2.36	Moderate
Indirect industrial spillovers	Mngt of collab	Collaboration effectiveness	.265 - .356	.521 - .168* -.521	100	4.00	Fully
Political spillovers	Resources & capabilities	Collaboration effectiveness	.107 - .103	.336 - .273* -.336	-	.69	Not significant
Political spillovers	Network ties	Collaboration effectiveness	.429 - .537	.660 - .072* -.660	100	4.66	Fully
Political spillovers	Trust	Collaboration effectiveness	.019 - .073	.162* - (-.096*)	-	-	-
Political spillovers	Shared goals	Collaboration effectiveness	.096 - .094	.320 - .229* -.320	-	.83	Not significant
Political spillovers	Mngt of collab	Collaboration effectiveness	.128 - .122	.371 - .316 -.055	15	.61*	Not significant

* Not significant ** Sobel not significant if < 1.96

*** Note: There is no guidance from authors on size of mediation effect. A decision was made to use the following as the basis for judging the size of the mediating effect: high >60% of change in betas, Moderate 30-60, Low <30