Innovation Happens in Systems: Implications for Science, Technology and Innovation Policy

J. Adam Holbrook [1]

Centre for Policy Research on Science and Technology
Simon Fraser University
Vancouver, Canada

1. Science and technology policy: some history

1.1. Phases of STIP

There has been a process of evolution in the way practitioners and academics have dealt with Science, Technology and Innovation Policies (STIP). Science policy in the Western world was established in the immediate aftermath of World War II. Initially, the main area of intervention and action was just science. In the late 1960s, technology emerged more clearly as an area of concern; due to budgetary constraints there was a need to be more efficient in the allocation of resources and to ameliorate the impact of technological change on the overall economy and society. From the 1980s onwards, there has been a shift in government policy agencies to a focus on innovation policy.

Christopher Freeman[2] classified STI policies from an economic perspective. He also defined three periods, similar focus and time range:

> 40s and 50s supply-side policies: focused on strengthening S&T capabilities, especially science.
>
> 60s and 70s demand-side policies: aiming at creating market needs for technology.
>
> 80s onwards: policies designed to provide effective linkages between supply and demand, and to respond to a new technological paradigm based on information and communication technologies.

1.2. What is innovation?

Policy makers in all levels of government are searching for means of understanding the role of innovation in the development of modern societies and for frameworks upon which they can construct their policies. In general, they are seeking economic frameworks; frequently they start with the work of Josef Schumpeter who identified five forms of innovation: new products, new processes, new markets, new resources, new

1 The author would like to acknowledge the work of his doctoral student , Monica Salazar, who carried out much of the research for the historical section.
2 Cited by Elzinga and Jamison (1995).

organizations. But innovation is not only an economic phenomenon but also a social one. Everett Rogers, in his book, "*Diffusion of Innovations*" looks at how innovations are communicated, adopted and adapted. In particular he draws the distinction between an inventor, the individual who generates a new idea, and the innovator, who disseminates the idea to those who implement it. Innovation is as much a matter of communication as it is of invention. In most cases innovation is seen as technological innovation, as defined by the OECD in the Oslo Manual:

> *"Technological Product and Process (TPP) Innovations comprise implemented technologically new products and processes and significant technological improvements in products and processes. A TPP innovation has been implemented if it has been introduced on the market (product innovation) or used within a production process (process innovation)"* (OECD, 1997, sec. 15.)

This, of course, is a narrower definition than that proposed by Schumpeter, but in the world of public sector policy it is more often the basis of the framework used for policy formulation. Many academics claim that there should be a broadening of this definition to encompass organizational and service innovations.

For many years technology policy was under the "umbrella" of industrial policy or research (and for that matter education) policy. When innovation policy emerged as a distinctive "flavour", it was still widely believed that innovation flowed naturally and unproblematically from scientific discovery (i.e. the linear model of innovation). The field of innovation studies has undergone major changes since then. The current rationale is based in new frameworks, such as institutional and evolutionary economics, interactive learning theories, and the chain-link model of innovation. All these developments are the foundations for the systems of innovation approach, which provides a conceptual framework to understand the complexities of the innovation process, the institutional arrangements that affect it, and contributes to broaden the scope of innovation policy-making.

1.3. Taxonomy of innovation policies

According to Metcalfe (2000), technology involves much more than science, and innovation involves much more than technology. Innovation does not always involve the application of technology, as could be the case in organizational and service innovations. Technology by itself is of no significance unless it is translated into innovation. Innovation and diffusion are primarily economic and social processes which involve many other actors and behaviours besides those directly involved in the creation of technology itself.

In the same line of argument, Dodgson and Bessant (1996) argue:

> *"It is inadequate to think of innovation in 'technological' terms alone. The process of innovation involves consideration of finance, marketing, organization, training, relationships with customers and suppliers, competitive positioning, as well as relationships between products and processes"*

Based on the above, technology policy and science policy are best presented as aspects of a broader innovation policy. What is innovation policy? Dodgson and Bessant wrote:

> *"Innovation policies aim at improving the capacity to innovate of firms, networks, industries and entire economies. Innovation is a process which involves flows of technology and information between multiple agents, including firms of all sizes and public and private research institutes. Innovation policy's principal aim is to facilitate the interaction and communication among these various actors. (...) Innovation policy is therefore different from science policy, which is concerned with the development of science and the training of scientists, and from technology policy, which has as its aims the support, enhancement and development of technology".*

What should an innovation policy include? Most of taxonomies refer to technology policy, few to innovation policy. Dodgson and Bessant (1996) organized the policy tools for innovation support under the following headings (examples in brackets):

direct financial support (grants, loans guarantees),
indirect financial support (venture capital),
information (databases, consultancy services),
scientific and technical infrastructure (public research labs, research grants),
educational infrastructure (general education and training system),
public procurement (national or local governments),
taxation (company, personal, tax credits for R&D),
regulation (patents, environment control),
public enterprise (innovation by public-owned industries),
political (regional policies, awards and honours for innovation),
public services (telecom, transport), and
trade (trade agreements, tariffs).

This classification shows the wide variety of measures, both direct and indirect, that could be implemented. Within this range of tools some are supply-oriented, others demand-oriented, and others aim to facilitate linkages between supply and demand.

<u>Innovation Policy Objectives: a summary</u>

To identify who are the innovators and what are the innovations
To differentiate between inventors, innovators and implementers
To establish the public sector infrastructure to support innovation

1.4 Complexity

Technology is becoming ever more complex, a trend that has a major influence on national innovation policies. A major challenge for policy-makers is to be able to develop technology and innovation policies effectively when all of the factors that make up the development of innovations cannot be fully understood. Kash and Rycroft (1998) have argued that many recent innovations are too complex to be understood by a single individual. In their context, 'complex' means:

> *"A technological process or product that cannot be understood in full detail by an individual expert sufficiently to communicate all of the details of the process or product across time and distance to other experts. By contrast, a simple process or product is one that can be understood and communicate by one individual"*

The effect on policy issues due to increased complexity technologies translates into a change of focus. Innovation is being done in networks therefore policy-makers should be paying more attention to organizational structures and processes or routines. Kash and Rycroft stated: *"To be effective, policy must be informed about more than just the basic characteristics of technologies and communities. Policy must be based on some appreciation of the substance of the innovation process itself. At the heart of complex innovation process is the network".*

They conclude that innovation policy must recognize five common patterns:

> Seamlessness: Policies should not focus solely or primarily on a single innovation phenomenon.
> Diversity: The capacity to gain (a) synthesis from diverse knowledge requires cooperation and trust on the part of diverse organizations located in both the private and public sectors.
> Continuous change: continuous incremental innovation along established technological paths is the primary route to commercial success in the area of complex technologies.
> Lack of understanding: it is not possible to understand, to analytically determine cause and effect relationships, how complex technologies are innovated.
> Predictability of incremental innovation: successful technological innovations along trajectories can be picked with high levels of confidence.

Thus innovation policies should:

> Facilitate close co-operation and sharing within networks and among competitors, while policies that utilize "walls of separation' and emphasize competition in all of the activities associated with innovation have substantial costs.
> Promote global monitoring and mapping of technology paths and the continuous convening of those people who might identify, and benefit from, possible areas of technological convergence and fusion.
> Be sector-specific (at least in part) and must be informed by state-of-the-art knowledge of the technologies and networks involved in those sectors.

2. The Systems of Innovation Approach

Scientific and technical knowledge is a unique commodity in that while it can be created, it cannot be destroyed. Similarly it can be transferred, but the source of the knowledge retains all of the knowledge it transfers to the recipient. Knowledge can flow from one institution to another. Thus the flow of knowledge can be described in terms of a system of innovation, either through people, or through financial flows that permit the creation of knowledge in the recipient institution.

Knowledge is an input to economic growth and social development. Governments have a mandate to increase economic well-being, social well-being, national security and administrative efficiency. Thus governments seek to promote the generation of knowledge and its application to the economy. They have a variety of policy options to implement their national vision. In general, governmental objectives for innovation policies can be described as:

> To identify who are the innovators and what are the innovations.
> To differentiate between inventors, innovators and implementers [or adopters].
> To establish and support the public sector infrastructure required for the initiation and diffusion of innovation.

A national system of innovation is constituted by components (organizations and institutions) and relations among these organizations. These relationships are usually through financial flows or movements of people. These can be described in many ways, one visualization, based on the Canadian NSI, is shown in Figure 1. One of the key elements of this type of analysis is the dependence of <u>all</u> nations on sources of technology external to their internal NSI. Thus a major policy object of a national government must be to provide a suitable environment and mechanisms by which innovations can be brought into the nation and used for its social and economic benefit.

2.1. Emergence and diffusion of the System of Innovation (SI) approach

Innovation studies moved away from the linear model after the 1980s, when the chain-link model and the innovation systems approaches emerged, which in turn were based on evolutionary and learning theories. The scholar who introduced[3] the concept of 'National Systems of Innovation' (NSI) was Freeman (1987) in a case study of Japan. Since then, many books and articles have been written about and around the concept; but the approach cannot be said to be a 'formal' theory, as many researchers have pointed out . Nevertheless, theories of interactive learning, institutional economics, together with evolutionary theories of technical change are considered to be the theoretical foundations of the systems of innovation approach .

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3 Freeman states that Lundvall was the first to use the term, but in written form it first appeared in Freeman's book. The idea of national systems of innovation was immanent in the work of the IKE-group in Aalborg already in the first half of the 80s, but they mainly talked about national systems of production

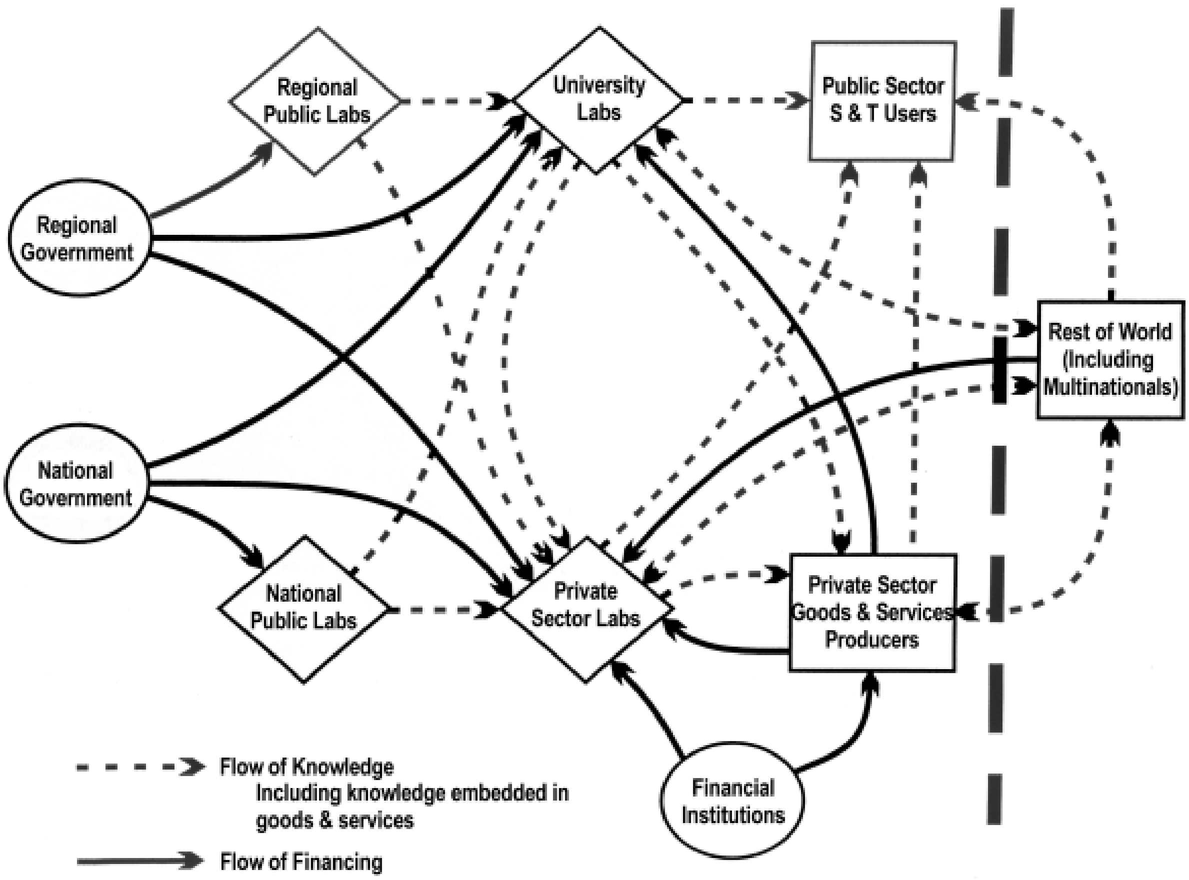

Figure 1 A National System of Innovation (Holbrook, 1997)

Within the systems of innovation (SI) approach there are different levels of analysis, both national and regional[4]. While most of the conceptual literature and empirical studies available deal with national and regional systems of innovation, Some authors affirm that both approaches, national and regional, developed in parallel, and that the regional systems of innovation (RSI) approach is not an 'off-shoot' or a 'subset' of the national strand, but a different perspective. The RSI approach comes from two streams: SI literature as such, and regional science. Castellacci *et al* (2004) assert that the RSI approach resembles the Aalborg school, not the historical-empirical version, because it also emphasizes the role of interactive learning.

With the exception of national systems of innovation, where the unit of analysis and the boundaries of the system are clearly established (the nation-state); the other levels of analysis have difficulty defining these boundaries. For instance, with respect of regions, Doloreux and Parto (2005) affirm that the debate on the appropriate scale of regional systems of innovation is far from resolved, is it a region a province/state, an agglomeration of cities, a city, a metropolitan area, or even a part of a city. In respect to technology systems, these could make reference to an specific technology in the sense of

4 only a handful of scholars have studied sectoral innovation systems and technology systems, which according to Edquist (2005) should be considered just one category

a knowledge field, to a product or an artifact, or finally to a set of related products or artifacts aimed at satisfying a particular function (e.g. transport, communication, health care) .

Holbrook and Wolfe have summarized the key characteristics of an NSI:

> Firms are part of a network of public and private sector institutions whose activities and interactions initiate, import, modify and diffuse new technologies.
> An NSI consists of linkages (both formal and informal) between institutions.
> An NSI includes flows of intellectual resources between institutions.
> Analysis of NSI emphasizes learning as a key economic resource and that geography and location matters .

There is no accepted or unique definition of national systems of innovation (NSI), and few differences can be seen when compared with definitions of regional systems of innovation, apart from the latter making reference to a limited geographic area within a nation-state. For the purposes of this paper Metcalfe's (1995) definition is clear:

> *"A system of innovation is that set of distinct institutions which jointly and individually contributes to the development and diffusion of new technologies and which provides the framework within which government form and implement policies to influence the innovation process. As such is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies"*

The systemic nature of innovation tells us different things: on the one hand, that the whole (the system) is much more than the aggregation of its parts. For instance, a national system of innovation is much more than the sum of its regional innovation systems. On the other hand, it talks about systemic interaction and performance. In this sense, the OECD (2003) notes that:

"a country's innovation performance will depend not only on how it performs on each individual element of the NSI, but how these separate elements interact"

Several authors have noted that the different levels of analysis complement each other, and it is one of the strengths of this approach. The national level will remain useful and important as long as nation states exist, even with increasing economic globalization and stronger multilateral agreements. In many cases the regional approach broaden and deepen our understanding of NSI, and point to the limitations of national policies , in particular in large and federal countries (Holbrook and Salazar, 2004). As Oughton *et.al.* (2002)and colleagues note:

> *"From a theoretical perspective the rationale for focussing on RSI lies in the fact that the factors that the NSI theory identifies as important, such as the institutional framework, the nature of inter-firm relationships, learning capability, R&D intensity and innovation activity, all differ significantly across regions*".

Although, in moving from national to regional innovation systems, the organizational and institutional framework becomes, paradoxically, less clear at least in terms of government, despite the smaller and apparently more manageable nature of the system. This is because "regions are neither autonomous nor sovereign in terms of relations with the nation-state or supranational institutions" . To define the boundaries of the system is crucial but not an easy task, especially when the unit of analysis is the region. Two main criteria could be used to identify a 'region' for innovation purposes: geographic and administrative. The most common uses administrative boundaries, useful especially from the point of view of availability of data and policy-making.

Regional or local systems of innovation shift the focus from solely economic issues and organizational set-ups to social aspects; this has two major advantages:

> "*On the one hand, it recognizes that innovation is a social process and is shaped by persons and institutions that share a common language, rules, norms and culture (i.e. common modes of communication). On the other hand, innovation is also a geographic process***,** *taking into account that technological capabilities are grounded on regional communities that share a common knowledge base"* .

The SI approach has provided useful insights to a better understanding of innovation process:

- Firms do not innovate alone; they rely on various supporting organizations and institutions.
- Interaction is central to the process of innovation.
- Evolutionary processes play an important role
- Innovation occurs in institutional, political and social contexts.
- Innovation is embedded in social relationships, and is fundamentally a geographical process.
- Innovation capabilities are sustained through local communities that share common knowledge base and common set of rules, conventions and norms.
- The SI literature highlights the interactive and cumulative aspects of learning and its importance for innovation processes.

2.2. The impact of the SI approach on innovation policy-making

A number of international organizations, such as UNCTAD, the European Union, and especially the OECD have played an important role in the diffusion of the new SI paradigms. These organizations saw innovation and technological change as central to welfare and growth problems, and they became the main advocates for innovation policy, and somewhat the think-tanks in this area of studies . The SI approach diffused quickly and became popular among researchers and policy makers, although it is neither a theory nor a policy manuscript. Maybe one of the reasons of its rapid adoption is that it provides a conceptual framework to understand the complexities of the innovation process and the institutional arrangements that affect it.

Lundvall *et.al.* (2002) and colleagues argue that another reason for its rapid diffusion was:

"that mainstream economics theory and policy have failed to deliver an understanding and control of the factors behind international competitiveness and economic development"

Biegelbauer and Borrás (2003a) are even more specific, they point that:

"until now neither institutional nor evolutionary economic theories have been developed to a point where clear ex-ante policy prescriptions are discernible; instead, it seems that policy rationales are being formulated ex-post, leaving large margins for manoeuvre in policy design and ex-post rationalization".

What it seems, is that the SI approach has been the policy response to evolutionary and institutional theories; it is the translation of economic theories into a frame of reference for policy purposes.

In addition, policy-makers saw the evolutionary-institutionalist systems perspective as complementary to the previous market failure rationale, not a substitution for it. Biegelbauer and Borrás state that the lack of 'ready-made solutions' was the best option for rapid adoption of the new ideas by policy makers into various countries with different institutional set-ups, political and regulatory frameworks. They add that "those ideas most likely to foster policy change are those that provide a new understanding of social phenomena (the economics of innovation in this case), suggesting a new way of tackling them, a new policy approach" .

Edquist and Hommen (1999) identified a set of defining principles of the SI approach relevant to policy, which were later re-phrased by as follows:

> The SI approach places innovation and learning processes at the center of the focus.
> The SI approach adopts a holistic and interdisciplinary perspective.
> The SI approach employs historical and evolutionary perspectives.
> The SI approach stresses the differences between systems, rather than the optimality of systems.
> The SI approach emphasizes interdependence and non-linearity.
> The SI approach encompasses product, process, and organizational innovations.
> The SI approach emphasizes the central role of institutions.

Nevertheless, it is important to recognize that even if the systems of innovation approach has been very popular among policy-makers, the concept has been underexploited by governments; and scholars have failed to give practical guidelines. Only recently, some academics have started to formulate specific innovation policy based on the systems approach.

The systems of innovation approach has influenced innovation policy and practice in many ways. Some of the more obvious impacts include:

> The design of policy has to be done in a consistent and coherent manner, i.e. single policies have to aim to a common goal, to improve the country innovation performance. The idea is not to propose stand-alone policies, but to design a portfolio of policy instruments, in order not just to enhance individual elements of the NSI but the system as a whole .
>
> The dichotomy of supply versus demand policies must be bridged, making more emphasis on policies designed to provide effective linkages between the supply and demand sides by attempting to make innovation activities technically and commercially successful.
>
> The systems perspective demands innovation policies be embedded in a broader socio-economic context, an interaction of science, technology, and innovation policy with other areas, such as foreign trade, taxation and macroeconomic policy.
>
> Last, but not least, is the need to work on systems failures and not just on market failures. The most recent contribution of the SI approach to innovation policy-making, still under development, is a new trend labelled 'systemic innovation policies', which could be defined as "the process for identifying the causes of lock-in and eliminating those bottlenecks to enable innovation and economic progress both at the firm and the system level" .

This new wave is trying to synthesize the changes in innovation policy and practice mentioned above. In the words of :

"From a conceptual perspective, embedding STI policies within the context of a systems framework provides a strong argument for the development of 'systemic' policies in addition to 'reinforcement' and 'bridging' policies. It also necessitates an appreciation of weak spots in current policy mixes and the formulation of appropriate steps to rectify these weaknesses".

Thus systemic innovation policies involve building bridges between all nodes and not only between pair of nodes and deal with systemic failures not market failures. The emphasis on the analysis of systemic failures is to shift state intervention from just funding (supply-policy), to attempt that the innovation system performs adequately as a whole. A key role for policy-makers is "bottle-neck analysis", that is to identify and try to rectify structural imperfections . Klein Woolthuis, Lahhuizen and Gilsing (2005) summarize what different scholars have identified as systemic imperfections or failures:

> Infrastructural failures: physical infrastructure.
> Transition failures: failure to adapt to a new technology.
> Lock-in/ path dependency failures: inability to adapt to new technological paradigms.
> Hard institutional failures: related to legal systems and regulations.

Soft institutional failures: related to social institutions such as political and social values.
Strong network failures: "blindness" that evolves if actors have close links and consequently miss new outside developments.
Weak network failures: lack of linkages.
Capabilities failures: lack of learning capabilities.

As a conclusion, the comment by Biegelbauer and Borrás (2003b) on the impact of the SI approach is pertinent:

"In many instances not only policies and policy tools have changed, but also policy aims and even the very conception of what may constitute a problem worth solving"

3. Science, technology and innovation policy in Canada

Some nations have specific ministries of S&T or innovation with formally-stated STIP. Canada does not, but while Canada does not have a single ministry dedicated to science and technology policy, this does not imply that there is no policy. Several trends can be identified, which taken together are Canada's unwritten science, technology and innovation policy (see box below). The federal government has, over the past two decades, cut back on its support for innovation both in terms of funding (primarily for research) and in terms of making innovation a national policy priority. There have been limited efforts at the development of national policy strategies (e.g. the Innovation Strategy of 2003) but for a number of reasons external to the innovation file itself, these initiatives have not seized the attention of Canadian decision-makers.

<u>Canada's Unwritten Science, Technology and Innovation Policy</u>

Direct support of basic and early stage applied research in the university sector.
Creation of specialized, decentralized, stakeholder operated granting agencies for university-based research (e.g. Networks of Centres of Excellence, Genome Canada).
Shift from direct support for industrial S&T and innovation to indirect methods (e.g. Scientific research and experimental development tax credit program)
Reduction of direct R&D spending in government labs.
Active recruitment of S&T highly qualified personnel through repatriation of Canadian emigrants and encouragement of immigrants.
Participation in international consortia for big science projects such as NASA programs, and the Canada-France-Hawaii telescope.

There is a national synergy in basic research: following federal initiatives the university community has accepted nation-wide networking as an approach for carrying out basic research (i.e. the Networks of Centres of Excellence), whereby networks support interaction among individual researchers and enhance their individual research contributions through interaction not only with their immediate peers, but also researchers from other disciplines. In the industrial and government areas these synergies are not as clear. Industrial innovations are often imported and disseminated from a single Canadian office by a foreign-controlled multinational. As for government – even though there are innovation programs within the provincial governments – the federal government is virtually the sole performer of research and innovation in the government sector.

How these policies impact regional innovation systems and clusters? STI policies and programs in Canada produce different results in various cities and provinces. Not all regions can benefit from them, not all can take advantage of them. In the words of Jorge Niosi (2005) :

"Horizontal policies at the national level produce, more often than not, results at the regional level. Even if incentives apply at the entire country, only a few regions are able to take advantage of them. This characteristic of some geographical areas can be called "absorptive capacity" of regions"

Table 1. Canadian Innovation Policy Options

	Direct Interventions in the NSI	Indirect Interventions in the NSI
Direct R&D	Government laboratories	Research grants to universities and firms
General R&D support	Technology-based capital projects	R&D tax credits
Direct S&T activities	Testing, standards data collection	Regulatory activities
General S&T support	Technology outreach	S&T education

4. The Regional Systems of Innovation in Canada

Innovation can demonstrably be described as a property of a system (of innovation). In general, it is additive, not a zero-sum game: innovation in one system does not occur at the expense of innovation in another system. Furthermore it is not simply additive – at least at the global scale it is clear that global innovation is more than the sum of national systems of innovation. But what about the sub-national level? It is likely that NSI can be greater than the sum of their component RSI only if there is cross-fertilization among the regions. Externalities are important and the successful RSI capture them.

Studies of innovation are usually tied to areas where there are significant levels of industrial activity. But what happens in regions where manufacturing is not the predominant sector? For example, the province of British Columbia (BC) is moving from a resource-based economy directly to a services-based economy; outside Vancouver's metropolitan area the key actors are SMEs, federal laboratories and community colleges. Does innovation exist in these non-industrial areas? Studies in BC have suggested that it is equally valid to describe, to measure and to implement innovation policies in non-industrialized areas as in the large urban agglomerations (Holbrook and Hughes, 1998).

In federal states the national system of innovation is usually composed of several regional systems. These regional systems of innovation are often weak because of a need for leadership - the technological future appears to depend more on social and political than on technological processes. Thus regional innovation systems are fragile because they are weakly institutionalized, and not always, the federal innovation system provides the leadership required.

Canada, as a federal state encompasses both a national system of innovation and a number of "semi-autonomous" regional systems of innovation. There is an NSI but there are also several RSI. The issue for policymakers in Canada is whether (or not) the NSI is the simple sum of the RSI or if there is a synergistic effect from the RSI that make the NSI greater than the sum of the RSI. Needless to say, national policymakers argue that there are synergistic effects, but what is the direct evidence for this?

In the Canadian federation, the regional economies (and social structures) vary widely, so that to infer, for example, that each region in Canada is an industrialized economy, based on national statistical indicators, is misleading. Some provinces are highly industrialized, while others are highly dependent on resource extraction. The Ontario/Quebec economy is not the same as the British Columbia (BC) or Prairie regions. National statistics are biased by the Windsor – Quebec corridor. At the local level, Canada is a country of metropolitan islands: Vancouver, Calgary, Toronto, Montreal, etc. Thus studies of the Canadian national system of innovation must be carried out at regional or even lower levels of aggregation.

Studies on the Canadian national system of innovation have been going on for over a decade. In the past five years, much of this work has been channelled through the Innovation Systems Research Network (ISRN). This research program has examined the NSI through a number of studies of individual industrial clusters across the country using a common research protocol; its activities have been described by Holbrook and Wolfe (2005). One of the major findings of these studies is that in the case (as opposed to other OECD nations, particularly the US) most clusters, and in particular all technology-based clusters, are centred on a major public sector research institution. This institution can either be a major research university or a federal laboratory: the choice is usually a result of history (path dependency). In either case the federal government has fostered the development and establishment of the cluster.

In looking at industrial clusters, ISRN researchers used, for a start, the conventional Porterian definition of a cluster, that of a geographic concentration of economic activity that has some competitive advantage, and thus (usually) exports. Focusing on the dynamics of a cluster or group of clusters, the process of change over time is best described by a system of innovation, whether national, regional or local. The pattern of change of a system of innovation can be measured over time as economic growth, or contraction, and are usually closely tied to similar social trends.

In the process of carrying out the ISRN studies, it has become apparent, that in the Canadian federation, the national system of innovation is an aggregation of a number of regional systems of innovation, and that these regional systems are themselves aggregations of local systems of innovation and/or regional clusters.

<u>Selected observations from the ISRN case studies</u>

- Clusters in Canada have a large public-sector institution at the centre.
- High-tech clusters in the west tend to produce IP rather than manufactured products (e.g. biotechnology, wireless).
- Location matters – cities with sticky labour markets are better prospects.
- The role of industrial associations is important – more than just champions.
- The effects of a catastrophic event in the cluster – path dependency.

The emergence of the regional clusters in Canada, has had little to do with direct government intervention. It has been a matter of chance, history, and availability of 'critical mass" just reached in the few large cities. According to Niosi (2005), science-based industries have different organizational attractors or anchor tenants. Certainly the policy environment is also a central attractor, but even national horizontal policies produce different results at the regional level. Niosi identifies the following key attractors for some R&D-intensive clusters:

- Major innovative industrial users are the key attractors of the advanced materials producing firms.
- Major innovative corporate assemblers tend to agglomerate parts and components producers in aerospace, aircraft, and other mass transportation systems.
- Knowledge-producing semi-public institutions such as universities are major attractors and incubators in biotechnology.
- Large R&D-intensive corporations are the key agglomerators and incubators in information and communication technologies.
- Venture capital is another attractor in all knowledge-intensive industries where SMEs are pervasive, such as biotechnology, medical devices and software (Niosi, 2005).

For instance, "a detailed study of Canada's regional clusters in biotechnology shows that both federal NRC labs and provincial labs in biotech played a secondary role in stimulating biotechnology clusters, as most of these labs are situated in remote regions or small metropolitan areas" (Niosi, 2005). The attractors of the three regional clusters in human health biotechnology in Canada have been the local research university (Holbrook et al, 2004, Niosi, 2005). Universities are clearly regional assets, and in most regional high-tech clusters have played a major role, while the location of government labs have been the result of political decisions, having little impact on cluster emergence.

All of this has led to a number of interesting questions about regional systems of innovation in general and clusters in non-industrial areas. These questions include:

Are regional innovation systems scalable? If a set of characteristics can be assigned to an innovation system at one level can they be amplified or reduced to larger or smaller geographic or political boundaries?

What are the necessary and sufficient conditions that support the formation of an industrial cluster in Canada? Are these region-specific?

What are the necessary elements of a cluster: a university, research labs, government agencies, private firms, civic associations, and human capital?

What are the conditions required for the continued existence of a cluster: at least one private firm with a global reach (the Porter model), manufacturing resources, active/interventionist public sector, and access to the global knowledge base.

Can a local system of innovation or cluster survive the catastrophic loss of a node/actor?

5. The Role of Cities[5]

The existing distribution of R&D performers across the country has been established by a mixture of economics, history and politics. The link between R&D funding and the innovativeness of an economy, regional or otherwise, is based on the premise that R&D funding decisions are exogenous. The award of R&D grants by peer review committees is at arm's length, and represents an informed assessment of the quality of R&D proposals. Similarly, industrial R&D decisions, while they are often made within the institution in which the work is performed, usually reflect an assessment of what the overall market served by the enterprise in question is likely to require in the future – not its current product line. By contrast, government R&D expenditures are driven not by local priorities but by national priorities – thus, although there may be exceptions, federal and provincial governments' own research expenditures do not usually fall into the "free market" concept of competition for research funding or generation of ideas.

Since intellectual property is the outcome of R&D activities, highly qualified human resources, the "means of production" of that product, are an essential element in determining the R&D competitiveness of a location. This is closely related to the "receptor capacity" of a region, since not only must the IP be produced, but there must also be a commercial infrastructure that can absorb the IP. This receptor capacity is often closely linked to the number and viability of university spin-off companies.

In a number of articles and books, Richard Florida (see for example Florida, 2002) provides arguments in support of the intuitively attractive notion that cities that are attractive places to live are also attractors of knowledge-based workers, and thus have a competitive advantage over those cities that are not seen in such a favourable light. Gertler *et al.* (2002) have confirmed that this is the case for Canadian cities. In particular

5 This section is based on Holbrook and Clayman, 2004

there is a correlation between the percentage of highly qualified personnel (HQP) and the level of high-tech output (the Milken[6] Techpole index), but an even stronger correlation between the cities' standing in Florida's "Bohemian" index (a measure of factors such as the percentage of the work force who derive their income from artistic activities) and the Techpole index.

A statistic such as annual expenditure on R&D in a given region is difficult to interpret without some national yardstick. Individual regional performances should be compared to the national average, or against each other. To compensate for widely differing conditions – population, economic activity, etc. – the data should be normalized and the result presented as a ratio. For comparing R&D expenditures between nations or states, one traditional measure has been the ratio of R&D expenditures to economic activity, often the gross domestic product (GDP). In line with the arguments in the previous paragraph linking high-tech success to levels of human capital, the denominator should be some measure of human resources in the region. The most obvious measure is population in the region.

Given the work of Florida and Gertler, another normalizing factor is also useful: the ratio of R&D expenditures to numbers of highly qualified personnel (HQP). HQP in a region/city can be viewed as the level of human capital available as an input to the R&D process. Use of this normalization links the level of R&D expenditures to a broad measure of the receptor capacity of the city. This ratio, R&D expenditures over HQP, can be referred to as the "R&D intensity."

A "Region" or a "City"?

As noted above studies of regional systems of innovation and studies of industrial clusters converge on individual cities or metropolitan areas. Industrial clusters can only exist in a limited geographical area – the human capital in each cluster should be able to interact on a face-to-face basis, not only to exchange information but also to build the relationships that will be part of their professional activities. In Canada, given its geography, this means that any cluster, existing or putative, is almost always linked to a single city or metropolitan area. Regardless of the means through which clusters are stimulated (e.g. by granting agency funding) they must be analyzed on a municipal basis. Thus in order to analyze federal research support at the cluster level, data on expenditures must be collected by city and regional municipalities and, where there is more than one university per urban entity, these university activities must also be aggregated.

As previously noted, in order to get a measure of the intensity of knowledge production, data on R&D expenditures in a city should be normalized. Looking at R&D intensity in Figure 2 reveals four situations:

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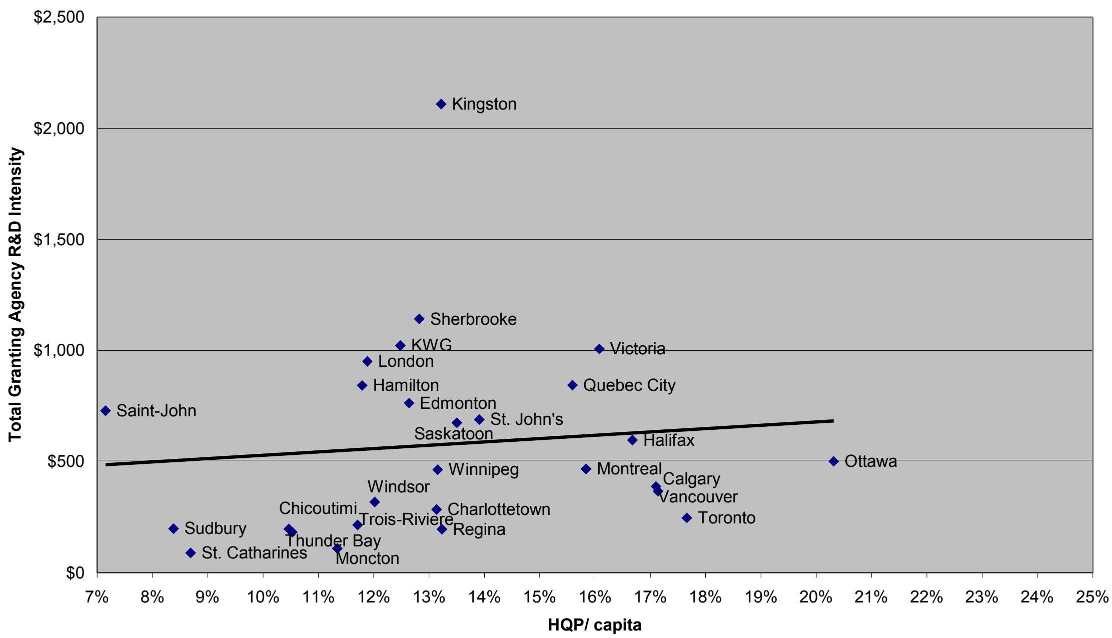
6 The Milken Index was originally developed by the Milken Institute for measuring high-technology output in US cities. It is a measure of factors such as R&D inputs, risk capital, entrepreneurial infrastructure, investment in human capital, and the S&T workforce. Gertler *et al. (op. cit.)* have adapted that index using Canadian data from Statistics Canada.

Large urban centres, such as Toronto and Vancouver, with high levels of absolute R&D expenditures and large numbers of HQP in non-R&D activities yield non-extreme levels of R&D intensity,
"University towns" such as Kingston, where the university is a major factor in the local economy, have high R&D expenditures and low numbers of HQP, resulting in high R&D intensity which may not reflect to true state of the local economy,
Ottawa and some of the provincial capitals which have low levels of granting agency R&D expenditures and large numbers of HQP in non-R&D, public service activities resulting in low R&D intensity, and
Other cities where knowledge-based industries are not a large component of the economy have low R&D expenditures and low numbers of HQP, resulting in non-extreme R&D intensity.

Figure 2: Total Granting Agency R&D Intensity versus HQP/capita - 2002/2003



6. Do network-based policies foster regional industrial clusters?

There are a number of network-based research and innovation programs in Canada[7], and we have already seen that they produce quite different results in the various cities and provinces across the country. Not all regions can benefit from them, nor can all take advantage of them. In the words of Jorge Niosi: "Horizontal policies at the national level produce, more often than not, results at the regional level. Even if incentives apply at the entire country, only a few regions are able to take advantage of them. This characteristic

7 For example: The Networks of Centres of Excellence (NCE), Genome Canada, the Canadian Institutes of Health Research (CIHR), and the Industrial Research Assistance Program (IRAP).

of some geographical areas can be called "absorptive capacity" of regions (Niosi, 2005). However, network-based policies and programs have been able to tap on regional assets, and have a more distributed R&D capacity across the country, not only on Ontario and Quebec.

Thus those institutions and regions which benefit from research networking programs have had a major role in the development of the regional (high-tech) clusters. Access to research funding has been important, but more important has been the possibility to retain and attract. As Holbrook & Clayman (2004) discuss the role of R&D funding in cluster development.:

> *"Creative individuals "cluster" themselves, and as a group, provide the synergy to develop an economic and social entity that is greater than the sum of parts. "If you build it, they will come" should be an approach to building the knowledge capacity of a city, but it does not guarantee that economic and social development will follow the funded research activities. Investment in R&D, in itself, is necessary (but not sufficient) for a city to develop a knowledge-based economy"* .

Harris (2005) proposes two options to improve Canadian investment in R&D and innovation. In his words:

> *"R&D is subject to major agglomeration economies, perhaps due to the knowledge spillovers having a dense network of R&D specialist who can interact with each other. ... From a policy perspective, therefore the Canadian R&D problem (low BERD) is resolvable in two ways. One approach is simply to encourage existing patterns of concentration. A second approach is to focus on raising R&D levels in those regions that are particularly low, but may have some chance of emerging as the location of new clusters*" .

From what we have seen, it seems that Canadian policy-makers have opted for the second option suggested by Harris, that is, to increase R&D funding not in the core provinces, but on those regions that that have potential to "give birth" to industrial clusters. Industrial clusters can only exist in a limited geographical area – the human capital in each cluster should be able to interact on a face-to-face basis, not only to exchange information but also to build social and business relationships that support the cluster network. In Canada, given its geography, this means that any cluster is almost always linked to a single city or metropolitan area.

6. Conclusions

The acceptance and diffusion of the systems of innovation approach on policy making and understanding of innovation processes has been remarkable, although its "real" use as an analytical tool has been disappointing (Edquist, 2005). For policy-making purposes the results are varied. The SI conceptual framework has provided the basis for doing "bottle-neck analysis", that is identification and rectification of structural imperfections. This allows the development of 'systemic' policies in addition to 'reinforcement' and 'bridging' policies, the last two being the bulk of innovation policies in both developed and developing countries. Cluster promotion, a fashionable policy these days, is considered a systemic innovation policy, but without an understanding of the ‘whole’ system of innovation (however it is defined at a national or regional level) those policies may not be very successful.

Klein Woolthuis and colleagues (2005) identified a set of systemic failures (see above), some of which we consider are of major importance for the development of RSI in Canada. Based on the varied results that innovation policies produce at the regional level: soft institutional failures (related to social institutions such as political and social values), and capabilities failures (lack of learning capabilities in certain regions) , are significant shortcomings.

Some authors argue that research policy should be kept under the central government realm, and innovation policy transferred to provincial/state governments, as they should be regionally specific (Cooke, 2003). In Canada, the federal and provincial governments have not evolved completely in the way Cooke envisioned it. As Niosi (2005) argued, regional innovation systems have developed ‘bottom-up”, sometimes against federal decisions of allocation of resources (money and R&D facilities. Besides, just few provinces have active intervention in the area of science, technology and innovation policy.

Rectification of the two major shortcomings will require coordinated effort on the part of both the federal and provincial levels. Neither level of government can afford to renege on its responsibilities in this area – both must establish strong policies and programs and they must do this cooperatively.

Canada is evolving slowly in relation to STI policy, in the way Cooke (2003) envisioned it:

“To some extent multi-level governance hierarchies have evolved, where national governments are mainly responsible for delivering science policy and basic research funding, while regional governance systems (involving public and private actors) deliver innovation programmes”.

Few provinces have active intervention in the area of science, technology and innovation policy. Overcoming structural failures of the Canadian innovation systems will require coordinated effort on the part of both the federal and provincial levels. Neither level of government can afford to renege on its responsibilities in this area – both must establish strong policies and programs, and they must do this cooperatively.

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