Some notes on theories of Technology, Society and Innovation Systems for S&T policy studies

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Introduction

Does technology shape society, or does society influence our technological choices? Is technological determinism a theory of society or a theory of technology? The debate on Science, Technology and Society (STS) studies has been animated by two opposite views on technology: one that affirms that technology shapes society, and the other that society shapes technology. The former, is commonly associated with the notion of technological determinism; while the latter could be labeled 'social shaping of technology' which covers various approaches, such as social constructivism and actor-network theory. Neither provides an overall view: one looks at the forest and the other at the trees, but both have failed to give us a comprehensive view of technological change and the major forces driving social change.

What follows is an examination of technological determinism – the shaping of society by technology - and the influence of society on the evolution of technology . It does not pretend to be exhaustive or representative of the most recent scholarship on the subject. A good, recent, compendium on the subject is *the Handbook of Science and Technology Studies* by Hackett et.al. (2008)

The discussion includes:

The history and foundation of STS
- Technological determinism
- Social Constructivism
- Critical theories of technology

Innovation studies as a bridging of the STS/STP divide
- evolutionary theories of technical change,
- systems of innovation (SI) approaches,
- cluster studies

Some Definitions: Knowledge, Research, and Technology: What is innovation?

What we understand for science and technology is very important: how we define the concepts, taking into account linguistic differences, and how to deal with these concepts, whether as a single concept or as distinct terms. For example, 'Technology' can be defined as knowledge, artefacts, or skills. The word 'Science' can refer just to 'hard' natural sciences (as in English), or to both the 'soft' social sciences and basic sciences (as in German and Spanish). Depending on the definition, the policy and focus changes. The treatment of the concepts should depend on the purposes, for instance, if it is for policy design or for understanding knowledge creation. For policy purposes it makes sense talking about 'science and technology' as a single concept, because from the government's point of view it wants to make the best of its investments on these activities, therefore to look for a 'combined' policy keeps in mind the bridges and connections that have to be built or kept between the two to create synergies. How should policy-makers visualize science, technology, and innovation from a policy perspective?

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

R&D as defined by the Organization for Economic Cooperation and Development (OECD) "Frascati Manual" is a very narrow concept based on the concept of the "creation of new knowledge". The Frascati Manual also defines a number of "related science activities" that themselves do not contribute directly to the creation of new knowledge in the national systems of innovation (NSI), but which are necessary for the operation of the NSI. UNESCO has noted that "S&T comprise….such activities as R&D, S&T education and training and S&T services"

In the late 1980s a new stream within innovation studies emerged, the systems of innovation approach, championed by Christopher Freeman, Bengt-Ake Lundvall, and Richard Nelson. The approach was developed from historical-empirical analyses, and was based on evolutionary theories of technical change, institutional economics, and the chain-link model of innovation. It emerged thanks to findings in different areas. On the one hand, researchers and policy-makers saw how firms in different countries performed differently, recognizing that national capabilities affect firm's performance and competitiveness. On the other hand, it was also recognized that firms do not innovate alone; they rely on various supporting organizations and institutions.

Needless to say, governments are keenly interested in innovation. In general, the objectives of innovation policy are:

- To identify who are the innovators and what are the innovations

- To differentiate between inventors, innovators, and implementers
- To establish public sector infrastructure to support innovation

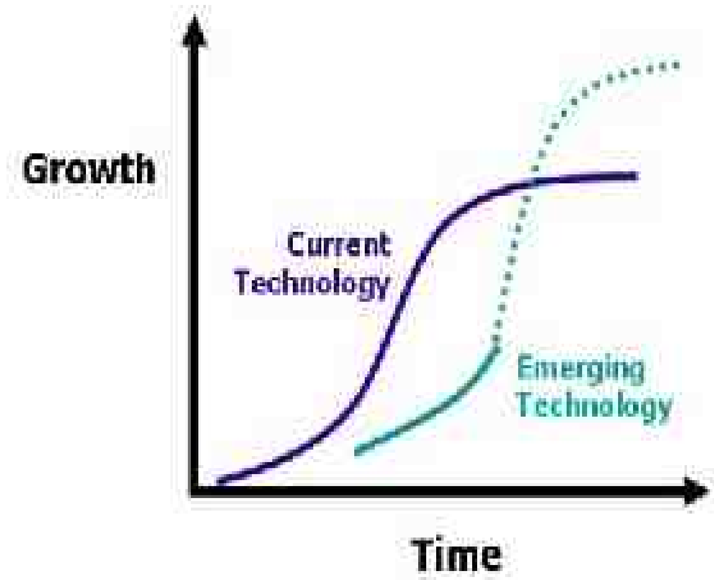
According to Metcalfe (2000), technology involves much more than science, and innovation involves much more than technology.

"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" (Metcalfe, 1995).

Not always do innovations involve the application of technology: organizational and service innovation. Technology by itself is of no significance unless it is translated into innovations. 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. Dodgson and Bessant noted that:

"*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" (Dodgson & Bessant, 1996)*.

There are two views – a economic view and a social view. The conventional view is economic, – that first proposed by Josef Schumpeter in his book "The Theory of Economic Development". In it he argued that there are five forms of innovation: new products, new processes, new markets, new resources, and new organizations. The social view looks at how innovations are adopted and adapted. They follow an "S" curve (see below) where there are early adopters and late adopters. This approach has been discussed by Everett M. Rogers in his landmark book "*Diffusion of Innovation*".



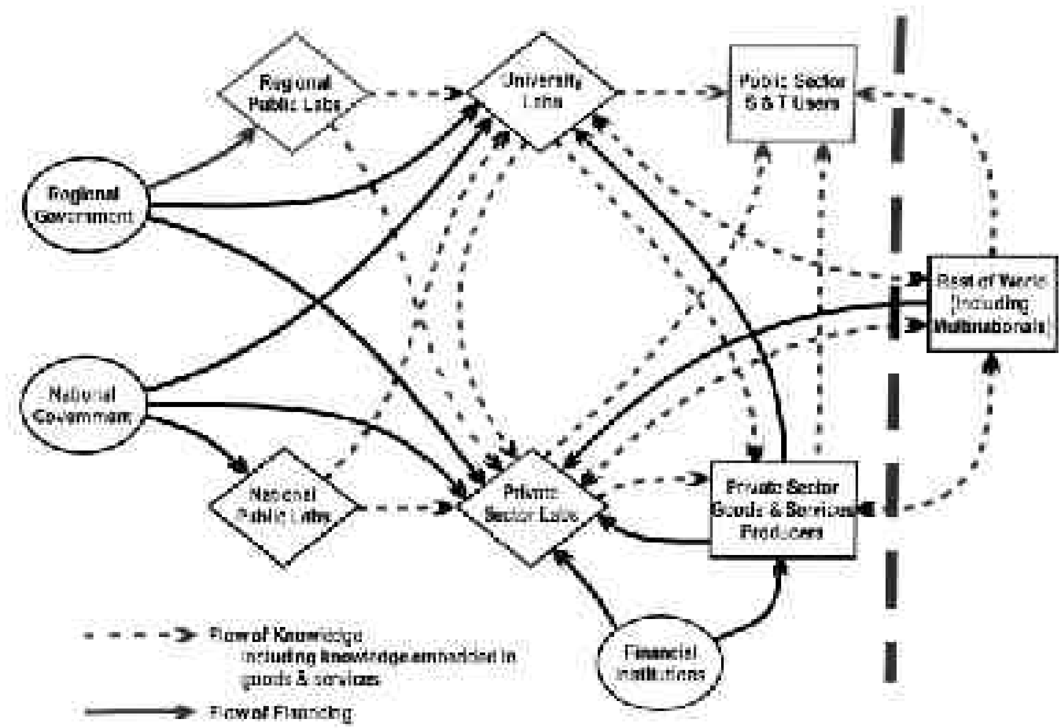
The OECD has noted that the study of national systems of innovation offers new rationales for government technology policies. Previously government S&T policies focussed on market failures. Studies of innovation systems can identify systemic failures. A national system of innovation describes the relationships among institutions, both public and private. These relationships are usually traced and measured through financial flows or movements of people.

In federal states the national system of innovation is the sum of several regional systems. The whole of the NSI should be more than the aggregation of its parts. In general, an NSI in a federal nation is much more than the sum of its regional (provincial or state) systems of innovation.

The emphasis on the analysis of systemic failures is an attempt to shift state intervention from simple subsidies (supply-side policies), to measures that ensure 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.

The OECD defines "innovations", as opposed to "innovation" in terms of technological innovations:

"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, Oslo Manual, sec. 15.)



Ref Holbrook and Hughes (1998)

Science and Technology Policy studies

Science and technology policy (STP) was established as an area of government interest and intervention 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, and in the 1980s, there was a shift to innovation policy.

The linear model is, today, generally regarded as too simplistic. STP has been traditionally divided between promotion and control. From a disciplinary perspective, S&T promotion has had influence from economics and management. S&T control has evolved in a highly practical manner, with no influence from the social sciences. STP studies have moved between two different models of science and technology relationships, the linear model and the chain-link or interactive model of innovation and two major economic theories[1] (neoclassical economics and evolutionary economics of technical change). Both models and theories have quite opposite views on how innovation occurs, and the policy instruments needed to foster it. At present, within STP studies, and more precisely innovation studies, evolutionary theories are the predominant paradigm.

[1] There are also organization and management theories that have informed STP, especially looking at how innovation occurs within the firm.

The chain-link model, developed by Kline and Rosenberg in 1986, emphasizes the need for learning feedbacks (inter-relations) between marketing, production and development as a basis for the wider process of innovation. Neo-classical economics have likewise been rejected if for no other reason than the social destruction that has occurred as a result of these theories. The evolutionary approach is less precise, but to use Richard Nelson words:

"technical change clearly is an evolutionary process; the innovation generator keeps on producing entities superior to those earlier in existence, and adjustment forces work slowly. The technologies that are developed are only superior in a relative sense, not optimal in an absolute sense, and the system never reaches a state of equilibrium. Technological change is an open-ended and path-dependent process where no optimal solution to a technical problem can be identified" (cited by Edquist, 1997: 6).

The Divide between S&T Policy and Science, Technology and Society

STS is a contested acronym: some understand it as 'science and technology studies', while others see it as 'science, technology and society' (studies) or 'social studies of science and technology'. For this paper STS stands for Science, Technology and Society, emphasizing the societal aspects of scientific and technological development. Concerns about S&T were born of World War II, when people recognized the complex and problematic, and sometimes undesirable, relationships between power and science. STS emerged clearly in the late 1960s as a social movement, besides other social upheavals that appeared then (e.g. environmental and feminist groups). Because of its origins, STS studies have often been critical of S&T developments and often try to propose ways to control S&T. Later on, in the 1980s, STS was reinvented and turned into an academic field, focused mainly on knowledge creation, rather than policy and control issues.

Some authors (Spiegel-Rosing, 1977; Teich, 2001) argue there is a divide between STS studies and policy-making. Others (Williams & Edge, 1996) affirm that some streams of STS studies (e.g. especially social shaping of technology) have been concerned with technology policy. It can be argued that these academic communities are quite differentiated, with very little overlap. This does not mean that STS scholars have not influenced policy-making, as it is not their main concern, while STP researchers do seek to affect policy directly.

STS started as a movement, with a critical view of scientific and technological development and its impact upon society, proposing alternatives to control S&T. STS later turned into an academic field, more interested in knowledge creation, having a strong disciplinary focus (sociological, philosophical, or historical). STP, according to some authors, grew out of the 'control' approach to STS.

Arie Rip(1994) states that STS is a curious field of study, encompassing many disciplines (history, philosophy, sociology, political science, economics, innovation and management studies, psychology, literary and textual analysis, cultural studies, anthropology) under one research interest: science and technology and their roles in society, with “a certain looseness of method (which) may well go with such an open-ended approach” (Rip, 1994). Williams and Edge (1996) in their article about social shaping of technology analyse the economics of technological change and its contributions to STS studies. Nevertheless they affirm that few of those writers would recognize themselves as part of any STS school. In general, economics, innovation and management studies are not included as part of STS.

Perhaps because STS has strong roots in its original disciplines, the disciplinary divide is still there; interdisciplinarity is still to be achieved. Susan Cozzens has written:

“while disciplines are still very much in evidence in this research community, there is no one-to-one correspondence between the topics studied and the traditional disciplines. Nonetheless, the disciplines continue to play a strong role in STS. Most people who study S&T still do so within a single discipline” (Cozzens, 2001: 57).

The debate on STS has been animated by two opposite views on technology: one that affirms that technology shapes society, and the other that society shapes technology. The former, is commonly associated with the notion of technological determinism[2]. There is no ‘accepted’ definition of technological determinism, and there are also various denominations (e.g. soft vs hard). Andrew Feenberg (2002)states that technological determinism is based on two theses:

- The pattern of technological progress is fixed, moving along one and the same track in all societies.
- Social organization must adapt to technical progress at each stage of development according to ‘imperative’ requirements of technology (Feenberg, 2002).

The main ideas behind social shaping are that technology:

- is seen as a dimension of society rather than as an external force acting on it from a metaphysical beyond

[2] There is a strong techno-determinist literature: see for example:

Heilbroner, Robert. “Do Machines Make History?” In Controlling Technology: Contemporary Issues, 2nd ed., E. Katz, A. Light, and W. Thompson (eds.) New York: Prometheus Books, 2003

Mumford, L. “Authoritarian and Democratic Technics.” In Controlling Technology: Contemporary Issues, 2nd ed., E. Katz, A. Light, and W. Thompson (eds.) New York: Prometheus Books, 2003

Bimber, Bruce. “Three Faces of Technological Determinism.” In Does Technology Drive History? The Dilemma of Technological Determinism, M.R. Smith and L. Marx (eds.) Cambridge, MA: MIT Press, 1998, 79-100.

Williams, R. “The Political and Feminist Dimensions of Technological Determinism.” In Does Technology Drive History? The Dilemma of Technological Determinism, M.R. Smith and L. Marx (eds.) Cambridge, MA: MIT Press, 1998.

- does not follow its own momentum but is instead shaped by social factors, and,
- is open to negotiation and change, while it is designed.

One of the goals of scholars supporting these theses was to open the ‘black box’ of technology, to show how technological artefacts are developed, showing the technical alternatives and paths. Scholars of this tradition demonstrate that technological artefacts are culturally constructed and interpreted. These two approaches are like the two ends of the spectrum, and scholarly work moves like a pendulum in between those ends.

Ina Spiegel-Rosing argued that STS studies and SPS (science policy studies) have been traditionally divided for several reasons: their disciplinary origin, their sources of research questions, the consequent emphasis on cognitive or operational problems, and their focus on science or technology (Spiegel-Rosing, 1977: 17). Thirty years later this view is still valid. She stated STS has strong roots in its founding disciplines - all social sciences, being the big three: history, sociology and philosophy - implying that they have different intellectual traditions. STP, on the other hand, evolved from political science and economics, and is therefore less fragmented.

STS in its early years was mainly concerned with the study of science, neglecting technology. Even today, technology is considered as a ‘minor’ subject of inquiry. The split between science and technology has characterized academic research; and in a lesser extent has been maintained in government circles. When STS became an academic field, its research problems focused on understanding how science functions. Meanwhile STP became more concerned with governance, direction and promotion of S&T in the real world of S&T. Perhaps, as a result, STS and STP have completely different approaches to science and technology.

There is no general agreement on how to treat science and technology, whether as a single concept or distinct spheres. The categorization depends highly on the purpose; for instance, if we are trying to understand how knowledge is created (the STS focus) it is better to keep them as two distinct terms. Science and technology are distinct branches of knowledge and distinct communities, located in different institutional contexts, with different research problems and methods, responding to different incentives. From a policy point of view (the STP focus) it makes sense to talk about ‘science and technology’ as a single concept, because governments want to make the best of their investments on these activities, and look for a single policy to build bridges and connections between science and technology to create synergies between the two. When the focus of policy analysis turned to innovation, it became clear that innovation included was much more than just R&D or technology, but that it includes organizational and managerial factors affecting the S&T enterprise.

Does Society shape Technology?

In the early 1980s social shaping of technology approaches emerged as a major stream within STS. Under 'social shaping[3]' there are find different approaches, such as social constructivism developed by Trevor Pinch and Wiebe Bijker, actor-network theory[4] developed principally by Bruno Latour and Michel Callon, and the systems model developed by Thomas Hughes[5]. "Social shaping models stress that technology does not follow its own momentum nor a rational goal-directed-problem-solving path but is instead shaped by social factors" (Bijker, 2001: 26). These studies are the result of combining sociology of scientific knowledge and history of technology (Pinch, 1996).

What are the main ideas behind social shaping of technology?:

- Technology is seen as a dimension of society rather than as an external force acting on it from an 'epistemological or metaphysical' beyond.
- Technology does not follow its own pace but is instead shaped by social factors.
- Technology is open to external forces, negotiation and change, while it is designed.
- One of their goals was to open the 'black box' of technology, to show how technological artefacts are developed, showing technical alternatives and paths.
- These scholars show how technological artefacts are changed by the users.
- They demonstrate how technological artefacts are culturally constructed and interpreted, although focused on the actors (i.e. agency-centered).

The study of the social construction of the bicycle by Trevor Pinch and Wiebe Bijker (1989) has become a classic, as has the volume in which it appeared, which Pinch and Bijker edited with Thomas Hughes (Bijker, Hughes, & Pinch, 1989). All subsequent work by both exponents and the critics of the social construction of technology approach has taken this volume as its benchmark. Nevertheless, the idea that technology is socially shaped is not entirely new, Mumford talked about it in some of his books and articles. Social constructivism is considered the current view or the core concept of technology within STS studies[6] (Cutcliffe, 2000: 52). Briefly its conceptual framework consists of four related components:

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[3] Other authors make reference to social constructivism as the concept 'umbrella' that covers these different models, but I would rather use social shaping which is a more encompassing concept.

[4] Cutcliffe has a short and clear definition of this approach:

"The key concept is "actor network" – a group of entities that includes not only people but also theories, technical devices, political institutions and policies, even the natural environment. Together this network of animate 'actors' and inanimate 'actants' constitutes a seamless web. These heterogeneous elements are all equally important and must be considered 'symmetrically', that is, as equally important" (Cutcliffe, 2000: 31).

[5] "The systems approach analyzes technology as heterogeneous systems that in the course of their development acquire a technological momentum that seems to drive them in a specific direction with certain autonomy. Hughes explicitly makes the argument against a priori distinction between the social, the technical, the scientific, and so on. The concept of technological momentum nicely captures the seemingly autonomous nature of technological systems, while at the same time showing that it is not an intrinsic property but is slowly built up during the systems development" (Bijker, 1995: 250). Thomas Hughes is usually situated within social constructivism, although he positioned himself in between technological determinism and social constructivism.

[6] Other authors considered ANT as the most successful theoretical achievement within STS so far (Sismondo, 2004).

- Relevant social groups: are identifiable groups participating in the construction/development of the technology, their ‘imprint’ their meanings to the artefacts being developed.

- Interpretive flexibility: neither an artefact identity, nor its technical success or failure, are intrinsic properties of the artefact but subject to social variables (Bijker, 2001). It is mainly during the design process that different social groups give different meanings to the artefacts being developed. However, final users can define what the technology is for and may have a distinctive use from the one planned.

- Closure and stabilization: the process of design and construction of a technological artefact is not endless, it always comes to a closure and consensus between the relevant social groups.

- Technological frame (similar to scientific paradigm): structures the interactions between the actors of a relevant social group (Bijker, 2001).

There are many authors highly critical of social constructivism, such as Langdon Winner and Andrew Feenberg. Some of the most common criticisms to social construction of technology, and generally to social shaping approaches, are:

- These approaches are agency centered, leaving aside structural factors and issues related to culture and power. As Klein and Kleinman put it: “Following the actors, however, risks falling into a crude empiricism that raises problems of its own” (Klein & Kleinman, 2002: 32).

- They assume that all groups are equal and all relevant groups are present in the design process.

- They got lost in single historical case-studies. In Feenberg’s words: “Constructivism’s narrow empiricism goes along with a purely academic conception of the history of technology” (Feenberg, 1999: 11).

- They study finished artifacts, when there is no room for changing or negotiating any possible change. As Winner puts it: “True the new methods are useful for historical study –reconstructing choices that have already been made, speculating about how outcomes might have been different” (Winner, 2001: 15).

- They got concentrated too much on how technology was developed disregarding the impacts and effects of those technological choices.

- Social constructivists assume technology as neutral and they do not take political positions in this sense; they concentrates on how technology works, on the form of that technology, and not on the social implications (Williams & Edge, 1996).

Regarding the last criticism, Pinch responds: “what the social constructivists work point to, is that the design and adaption of technology should be part of the political agenda. There is no one inevitable logic of development. There is choice” (Pinch, 1996: 34). However, scholars within this tradition have never made recommendations on how to incorporate technology in the political agenda, in contrast to constructive technology assessment for example.

Does technology shape society? - Technological determinism

The idea of technological determinism as a theory of technology implies that technologies are autonomous, they develop at their own pace without human intervention, they have quasi magical powers, and they acquire a life of its own once introduced into society. Simply put, this thesis gives agency to technology (Marx & Smith, 1994). This is hardly sustainable from any perspective, and it really does not explain how technologies develop. It is based on the consequences rather than the genesis of technological innovations. As a theory of technology, technological determinism does not seem very useful or sound in explaining how technical change occurs.

There is no ‘accepted’ definition of technological determinism. Bijker wrote that:

“Technological determinism comprises two ideas: technological development is autonomous, and societal development is determined by technology. […] It seems wise for analytical purposes to reserve the term technological determinism only for the second idea, a theory of society, [keeping it] separate from the idea of an autonomous technology, a theory of technology” (Bijker, 1995: 238).

There are various views on technological determinism and how to classify it; the most common labels being hard and soft determinism. According to Marx and Smith (1994), on the one hand, hard technological determinists impute agency (the power to produce change) to technology, and imply that technological development is inescapable, inevitable. On the other hand, soft determinists recognize human agency, and that changes in history are due to various and complex social, economic and cultural factors. However, “agency, as conceived by soft technological determinist, is deeply embedded in the larger social structure and culture –so deeply, indeed, as to divest technology of its presumed power as an independent agent initiating change” (Marx & Smith, 1994: xiv).

Bimber distinguishes three different versions of technological determinism:

- Normative: based in Habermas, suggests that technology can be considered autonomous and deterministic when the norms by which it is advanced are removed from political and ethical discourse. Jacques Ellul is a good exponent of this version.

- Unintended consequences: derives from observations of the uncertainty and uncontrollability of the results of technological development. Langdon Winner is an advocate of this thesis.

- Nomological:

"implicit in this account are two claims: that technological development occur according to some naturally given logic, which is not culturally or socially determined, and that these developments force social adaptation and changes" (Bimber, 1994: 84).

Bimber maintains that the only truly determinist explanation is the nomological. He makes a very good point explaining what the concept should stand for:

"Technological determinism should hold that history is determined by laws or by physical and biological conditions rather than by human will; this makes it deterministic. ... Technological determinism should be truly technological in meaning. That is, technology should play a necessary part in the way that preceding events or states of the world determine the future. ... Technology is the medium through which physical laws, some of which we can learn through science, shape the course of human events" (Bimber, 1994: 87).

Andrew Feenberg says that technological determinism is based on two theses:

- The pattern of technological progress is fixed, moving along one and the same track in all societies.
- Social organization must adapt to technical progress at each stage of development according to 'imperative' requirements of technology (Feenberg, 2002: 138-139).

A discussion of technological determinism

There are some similarities between these approaches: societies can be ordered along a simple and unique continuum, and culture does not play a role in shaping technology. What is meant by the term "technology" is very important. To fit technological determinist approaches, technology has to be understood as an artefact. When a broader definition is used, encompassing knowledge about artefacts and process and systems of organization and control, it becomes problematic.

Heilbroner (1967, reprinted 1994) has an interesting intake on technological determinism. He affirms that "the technology of a society imposes a determinate pattern of social relations on that society" (Heilbroner, 1994: 59). The question he was attracted to was whether technology determines socioeconomic order: If medieval technology brought feudalism and if industrial technology was the necessary condition for capitalism to emerge. In his words, that "places technological change in the position of prime mover of social history". Then he asks: "Can we then explain the 'laws of motion' of technology itself? Can we explain why technology evolves in the sequence it does?" (Heilbroner, 1994: 54 - 55). To answer the first question he develops the idea of path dependence (something not explored by then, neither empirically nor theoretically). He says that there is a 'fixed' sequence to technological development, and works on three ideas to explain it: the simultaneity of invention (technological clustering); the absence of technological leaps (technological advances appear essentially incremental, evolutionary); and the predictability of technology. On reading Heilbroner today, he looks more like an evolutionist[7] rather than a determinist. He further explains two ways on how technology influences social relations: the composition of labour force (division of labour between skilled, semi-skilled and unskilled) and the hierarchical organization of work (supervision, coordination, centralization).

To refute technological determinism positions, we have to escape the trivial level of observation that technology is man-made, and hence subject to many societal influences. It is clear that culture play a role in shaping the history of technological development, and that societies do not develop along a unique, fixed path. Though, what is interesting to explore is if technology determines social change or not, if it is a major (or 'the') driving force behind major societal changes, and if social organizations must adapt to technical progress. In this sense, Cutcliffe notes that "the obduracy of technology must be recognized in terms of its ability to form enduring practices, theories and social institutions, with the very real resulting ability to then determine social development" (Cutcliffe, 2000: 51). Like it or not, a chosen technology will affect how people live, work, have pleasure, etc. However, this does not mean that we cannot change the direction of technological development and 'control' the possible impacts that specific technologies have upon society. It may be that technological determinism is a poor choice of words for explaining certain phenomena. Unfortunately, the concept has a negative connotation, and as Bimber notes "the term is used in a muddy and imprecise way" (Bimber, 1994: 81).

There are many academics that will argue that technology is (at present) the most important force driving social change. This does not mean that social, cultural, political, and economic factors do not shape technology. It is not that technology shapes itself, but technologies complement each other, or depend upon one another, especially when we are dealing with general purpose technologies (GPTs)[8], which are highly pervasive of the whole economy and society.

It is easy to fall into 'quasi' technological determinist stand-points when looking at major changes experienced by a society or a group of countries during long periods of time. These types of studies provide a big picture, an economic historical perspective, overlooking the 'people' behind the creation of specific technologies. In these cases, it is common to encounter terms such as technological trajectories, techno-economic

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[7] It is worth noting that evolutionary theories of technical change started to emerge late 1970s and early 1980s.

[8] These are technologies that are employed throughout the economy, and the society in general, they help to produce a wide range of products, and are used in a wide array of processes and services (e.g. information and communication technologies).

paradigms[9], technological regimes[10], and technology systems, which give the erroneous idea of being technological determinist. What they mean is that technologies build one upon the other, they form 'clusters' of technologies, and each regime or paradigm characterize an economic era, and is dominated by one or more GPTs or enabling technologies. The replacement of an all pervasive GPT alters the paradigm. These analyses, based on economic and historical accounts, are much better at explaining how technologies develop and produce changes in societies, and as such, they are more adequate and robust theories of technology.

Besides this phenomenon, it is important to acknowledge that when a new technological paradigm emerge, it is accompanied by structural changes and the co-evolution of economic and social movements, with all these changes following a pattern, the cyclical nature of capitalist development (long 'Kondratiev' waves) (Freeman & Louca, 2001)[11]. Freeman and Louca affirm that the evolution of societies follows recognizable patterns, which depend in the relationships between five semi-autonomous subsystems: science, technology, economy, politics, and general culture. They do not give precedence to any one of them, despite recognizing that at particular times a subsystem could be the primary driving force of change or have a predominant influence.

Why are these approaches not technological determinist, even if they acknowledge the great importance of technological change as a determinant of long-term economic growth? Lipsey, Carlaw and Bekar[12] present three propositions to challenge this:

> *"First, major new technologies, particularly transforming GPTs, have important effects on the socio-economic system of any country into which they are introduced. Second, the same technology introduced into different places, and/or different times, will have different effects because the rest of the political, social, economic and institutional structures will differ between the two situations. Third, because knowledge builds on previous knowledge in an uncertain, path dependent and sometimes discrete process, the introduction of a new technology cannot have unique predetermined results".*

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[9] A techno-economic paradigm, concept developed by Perez and Freeman, refers to an economy's set of interrelated technologies, with the supporting and facilitating policy and infrastructure.

[10] A technology regime is a coherent set of techniques that characterize a specific historical period of time.

[11]. "This book is about how societies and economies evolve through time. It argues that their evolution has recognizable patterns, depending in the relationships between technological innovation, social structure, economic development, institutional framework, and cultural standards. In particular it discusses modern industrial capitalist economies -how they change, how they structure their change, and how these patterns of change configure long-term fluctuation, known to economics as long waves or Kondratiev waves" (Freeman & Louca, 2001: 5)

[12] I would like to thanks Dr. Ricard Lipsey, who made available the first chapter of this forthcoming book, wrote with Kenneth Carlaw and Clifford Bekar, titled *"Economic Transformations: General Purpose Technologies and Long Term Economic Growth".*

Shaping versus determinism

Many authors have criticized approaches based on the social shaping of technology, as well as technological determinist positions. Both approaches could be seen as the two blades of a pair of scissors: neither has more importance or prevalence upon the other. This analogy (i.e. the scissors) is commonly used among economists when talking about the main force behind innovation: technology-push or demand-pull.

These dilemmas or debates are useless, because the two forces are needed. Let's say that the streams reviewed are the two ends of the spectrum, macro perspectives versus micro case-studies. What is in between? There must be something, a meso (or meta?) level methodology or approach that recognize the co-evolution of technology and society. There are recent developments in STS that could be named middle ground approaches, which attempt to avoid either end of the spectrum; such as constructive technology assessment and critical theory of technology. Constructive technology assessment is a promising approach within STS studies.

Building bridges – Constructive Technology Assessment

By integrating different bodies of literature, combining sociological-philosophical approaches with economic-management perspectives, one can start to build a bridge between STP and STS. We need to bring into the STS debate a set of concepts from political economy and organizational analysis, and suggest how pulling these concepts together can provide a cogent approach to analyzing technology development (Klein & Kleinman, 2002).

STS approaches have focused mainly on individual technologies or technological systems but not on innovation systems and networks. However, technology usually develops in larger structures and networks, with the participation of an array of actors such as firms, public organizations, and social and legal institutions. Innovation occurs in institutional, political and social contexts, it is embedded in social relationships. Consequently, STS and STP studies, if combined, could provide a more cogent view of technological development.

As noted above both STS and STP studies have methodological problems, both areas of studies have various strands that focus either on micro case studies or macro analysis, neglecting the meso level. By combining them with the systems of innovation approach and the principles of constructive technology assessment (CTA) the "bridge" may be achieved. Starting in STS, CTA can be situated between micro and meso levels of analysis. On the other hand, within STP there have some recent developments that can be situated at the meso level, such as studies on regional systems of innovation, sectoral innovation systems, technology systems, and innovation networks.

Technology assessment (TA), as traditionally understood has evolved over time. Initially TA was done at the end of the 'tube', when the technology was already in use and deployed. “From an STS perspective the emphasis shifted several years ago from ‘impact assessment’ to design, social shaping and the management of technology in society” (Rohracher, 2004). Today, technology assessment can be categorized in many ways: awareness TA, strategic TA, and constructive TA. *Constructive technology assessment* (CTA)[13] is also referred by different authors as interactive TA or participatory TA. According to Schot & Rip (1996), technology assessment philosophy is to reduce the costs of societal learning in the use of new technologies, and to do so by anticipating potential impacts and feeding these insights into decision making (Schot & Rip, 1996).

CTA redefines technology assessment as an active contribution to the process of design as opposed to an “independent program of technology impact analysis” (Gow, 2003: 42). He adds that “CTA redefines technology assessment as an active contribution to the process of design as opposed to an independent program of technology impact analysis” (Gow, 2003: 42). The shift in focus within TA responds to the need to recognize that empirical studies of actual impacts are not enough, that the analysis of possible impacts in plausible scenarios is necessary. Rip emphasized this shift:

> *“New developments in TA are linked to better understanding of the dynamics of technology and society (co-evolution and co-production of impacts) and to shifts in how we want our societies to go about shaping themselves (devolution, distributed modes of governance, some participation). These must be indicators of further evolution of our society” (Rip, 2001: 210).*

Gow (2003) explains the main differences between TA and CTA, based in two distinct models of technology development. In his words:

- Exogenous model: anticipates a finished technology that enters into and creates effects in a society.
- Endogenous model: recognizes that a technology and its effects are not necessary dropped ‘stork-like’ into a society but are produced, womb-like, by various interested parties within society.

The shift in focus within TA recognizes that empirical studies of actual impacts are not enough, and that the analysis of possible impacts in plausible scenarios is necessary.

CTA attempts to develop technologies with desired positive impacts and with few (or at least manageable) negative impacts. The moment of intervention is crucial, and should be during the design phase. That does not mean that it is a simple and straightforward task. CTA has its own methodological problems, in particular what is known as the ‘Collingridge dilemma’, the knowledge vs control dilemma. When control of technological change is still possible, during the early stages of design and development, knowledge of possible impacts is limited, because the outcomes are difficult to anticipate. Yet once the technology is deployed it may be insuperably difficult to introduce substantial change to it because of investments made in its development and deployment, so it can hardly be controlled (Gow, 2003; Rip, 2001; Rip, Misa, & Schot, 1995).

[13] It is important to note that CTA originated in the Netherlands; following Denmark, Norway, and Germany.

Some authors believe that this is a major obstacle for CTA, being impossible to anticipate impacts, and if intervention occurs, being right. However, Rip affirms that "anticipations need not to be correct to be useful in guiding action productively". We need visions of the future in order to orient our actions: this is what recent TA activities attempt to provide. One could call this the agenda-building function of TA, in contrast to the forecasting and assessment function which is also there, and was its main function in the 1960s (Rip, 2001: 197). This also implies that experimentation and societal learning must be an integral part of management of technology in society (Rip et al., 1995: 4).

Innovation studies are dominated by various paradigms, however complementary between them, such as evolutionary theories of technical change, systems of innovation (SI) approaches, and theories about interactive learning[14]. The *systems of innovation approach*, provides a conceptual framework to understand the complexities of the innovation process and the institutional arrangements that affect it. It seems 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.

Knowing that firms do not innovate alone and that the environment affects their innovative capabilities, the systems of innovation approach helps to decipher that environment. Within the systems of innovation approach we find different levels of analysis: national, regional, sectoral[15], and technological[16]. With the exception of the national system of innovation approach, where the unit of analysis and the boundaries of the system are clearly established, that is the nation-state, other levels of analysis have difficulty defining these boundaries. While most literature and empirical studies available deal with national and regional systems of innovation, only a handful of scholars have studied sectoral innovation systems and technology systems. There is no unique definition of national systems of innovation (NSI); in addition, if compared to definitions of regional systems of innovation, the only difference is the limited spatial dimension of the latter. Nelson and Rosenberg (1993) define a NIS as the interaction of innovative capabilities of firms with a set of institutions that determine the firm's capacity to innovate. Holbrook and Wolfe have summarized the key characteristics of an NIS:

- 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.

[14] Purposely, I am leaving aside management theories related to innovation, which are not relevant for this discussion.

[15] "A sectoral system of innovation is a set of products and the set of agents, carrying out market and non-market interactions for the creation, production and sale of those products" (Malerba, 2002: 247).

[16] A technological system is a network of agents interacting in a specific economic/industrial (technological) area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion and utilization of technology (Carlsson & Stankiewitz, 1995 cited by Edquist: 8). It is focused on generic technologies with general applications over many industries.

- Analysis of NSI emphasizes learning as a key economic resource and that geography and location matters (Holbrook & Wolfe, 2000).

Although, both STS and STP have developed separately, building to date little or nothing on one another, these two areas converge: both recognize that technological development and innovation are embedded in social relationships and that uncertainties and unintended consequences are associated with them. There is a common area of interest, the need to develop the meso level of analysis, which has potential in both STS and STP studies. The connections between the meso level and the macro level of analysis have to be worked out. It seems easier to go downward (micro and meso linkages, or local and regional systems of innovation) than upward (meso and macro connections – regional and national systems of innovation). Scholars within the TA tradition propose that visions of the future to orient our actions, what they refer to as the agenda-building function of TA. Similarly, innovation scholars have been doing (technology) foresight exercises for some time now. It would be very interesting to explore how each field can contribute to understand the dynamics of technology, how to reduce uncertainties about impacts, how to orient its future developments, and how to create a 'history of the future' (to use Rip's terminology).

The systems of innovation approach is a good tool for determining the main actors involved in the innovation process, as well as the -local or national- capabilities needed to foster innovation. However, scholars within this approach have not been very successful at explaining communication and interaction patterns, and how networks function. Certain STS approaches (e.g. actor-network theory) could possible contribute to the unfolding of these issues. In the same way, empirical studies about systems of innovation provide a detailed picture of the organizations and institutions involved in innovation. However, these studies likely have had little influence on CTA studies as such, helping to identify the main stakeholders that could participate in technology assessment exercises, doing institutional and organizational mapping and tracking knowledge flows. Future work should explore in more depth technology systems (Bo Carlsson & Jacobsson, 1997; Kash & Rycroft, 1998), sectoral innovation systems (Breschi & Malerba, 1997; Malerba, 2005), and socio-technical systems (Geels, 2004), in order to see how they can relate to CTA.

The systems of innovation) approach

The innovation systems approach spread quickly and has gained acceptance by policy makers. Why? How has the innovation systems approach changed policy design and practice? How has the systems of innovation approach led to a better understanding of innovation processes?

Innovation studies moved away from the linear model since the 1980s, when the chain-link model and the innovation systems approaches emerged, which in turn were based on evolutionary and learning theories. A growing number of scholars working outside the dominant neo-classical economy paradigm[17] were doing research on the new innovation paradigm, and worked closely with a small number of international organizations (OECD, EU, ECLAC, UNCTAD) (Mytelka & Smith, 2002).

The systems of innovation approach emerged in the late 1980s. Christopher Freeman, Bengt-Ake Lundvall, and Richard Nelson. Freeman introduced[18] the concept of 'National Systems of Innovation' (NSI) in a case study of Japan, in 1987[19]. Lundvall further developed the theoretical and conceptual foundations of NSI, using Denmark as an example (Lundvall, 1992). In 1993 Nelson edited a book with 15 studies of NSIs (Nelson, 1993). Since then, many books and articles have been written about the concept; but there is still not a 'formal' theory of NSI, as many researchers have pointed out (see Edquist, 1997; Holbrook & Wolfe, 2000; Nelson & Rosenberg, 1993). Nevertheless, theories of interactive learning together with evolutionary theories of technical change are considered to be the theoretical foundations of the systems of innovation approach (Edquist, 1997).

Lundvall and colleagues affirm 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" (Lundvall et al., 2002: 214). Biegelbauer and Borrás are even more specific, they point out 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" (Biegelbauer & Borrás, 2003b: 9). 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 as substituting it. Biegelbauer and Borrás affirm 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 added that:

"*those ideas most likely to foster policy change are those that provide a new understanding of social phenomena (the economics of innovation process in that case), suggesting a new way of tackling them, a new policy approac"* (Biegelbauer & Borrás, 2003a: 290).

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[17] Such as Bengt-Ake Lundvall, Richard Nelson, Christopher Freeman, Luc Soete, Michael Storper, and Nathan Rosenberg.

[18] Freeman affirms 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.

[19] Freeman, C. (1987). *Technology policy and economic performance: lessons from Japan*. London; New York: Pinter Publishers.

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. Recently, some academics have started to formulate innovation policy based on the systems approach.

Castellacci *et al* affirm that there are two traditions within innovation systems: a historical-empirical approach (NSI approach, e.g. Nelson's book), and an interactive learning-based approach (the Aalborg school) (Castellacci, Grodal, Mendonca, & Wibe, 2004). The former is the more established and developed strand of the two. The historical-empirical approach emerged because researchers and policy-makers started to recognize that firms perform differently in various countries, and also that firms do not innovate alone. In that sense, the SI approach attempt to understand and "decipher" the environment that surrounds firms. However, this version of the NSI approach focuses on the institutional set-up that support and promote innovation activities.

In contrast, the Aalborg school started from two basic assumptions: i) knowledge is the most fundamental resource in the modern economy, making learning the most important process; and, ii) learning is interactive. This orientation emphasized the concept of knowledge-based (or learning) economy (Castellacci et al., 2004: 11). These scholars say that their "version of the NSI concept may be seen as a combination of four elements: the neo-Schumpeterian reinterpretation of national production systems, empirical work based on the home-market theory of international trade, the microeconomic approach to innovation as an interactive process inspired by research at SPRU, and, finally, insights in the role of institutions in shaping innovative activities" (Lundvall, Johnson, Anderson, & Dalum, 2002: 216-217).

Within the systems of innovation approach we find different levels of analysis, national, regional, sectoral,[20] and technological[21]. From here onward I make reference to national and regional systems of innovation, taking into account that most of the conceptual and empirical studies available focus on these two levels. For reasons that are not at all clear few scholars study of sectoral innovation systems and technology systems. Some authors affirm that both approaches, national and regional, developed in parallel, hence the regional systems of innovation (RSI) approach is not an 'off-spring' or a 'downsizing' of the national strand, but a different perspective. The RSI approach comes from two streams: SI literature as such, and regional studies of science and technology. .

With the exception of national systems of innovation, where the unit of analysis and the boundaries of the system are clearly established, i.e. the nation-state, the rest of levels of analysis have difficulty defining these issues. For instance, regarding what is a region, 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

[20] "A sectoral system of innovation is a set of products and the set of agents, carrying out market and non-market interactions for the creation, production and sale of those products" (Malerba, 2002: 247).

[21] A technological system is a network of agents interacting in a specific economic/industrial (technological) area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion and utilization of technology. (Carlsson & Stankiewitz, 1995 cited by Edquist: 8). It is focused on generic technologies with general applications over many industries.

agglomeration of cities, a city, a metropolitan area, or a locale (part of a city)? A technology system could make reference to an specific technology in the sense of 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) (B. Carlsson, Jacobsson, Holmen, & Rickne, 2002).

In terms of the regional dimension of systems of innovation:

"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" (Oughton, Landabaso, & Morgan, 2002: 99).

Regional or local systems of innovation shift the focus on spatial aspects, which:

"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" (Holbrook & Salazar, 2004: 51).

In moving from national to regional innovation systems, the institutional framework becomes paradoxically, less clear, at least in terms of government, despite the smaller and apparently more manageable nature of the system. "[R]egions are neither autonomous nor sovereign in terms of relations with the nation-state or supranational institutions. The regional institutional arrangement is linked with elements of super-ordinate governance" (Braczyk & Heidenreich, 1998). In this sense, regional policy-making becomes problematic.

Edquist identified a list of characteristics of SI approaches in his book in 1997, which were later re-phrased by Edquist and Hommen (1999), as follows:

- They place innovation and learning processes at the center of the focus.
- They adopt a holistic and interdisciplinary perspective.
- They employ historical perspectives.
- They stress the differences between systems, rather than the optimality of systems.
- They emphasize interdependence and non-linearity.
- They encompass product technologies and organizational innovations.
- They emphasize the central role of institutions.
- They are still associated with conceptual diffuseness.
- They are conceptual frameworks rather than formal theories.

Diffusion of the system of innovation approach

In the case of innovation studies a number of international organizations, (e.g. OECD, EU)[22] played an important role in the diffusion of the new 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 (Mytelka & Smith, 2002).

The systems of innovation approach diffused quickly and became very popular among researchers and policy makers, although it is neither a theory nor a policy manuscript. Maybe one of the reasons for 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.

Philip Cooke proposed a taxonomy of national and regional innovation systems: they can be differentiated in the "governance" dimension; by how technology is transferred (*Grassroots*, *Networked*, and *Dirigiste*) and in the business innovation dimension: by the posture of firms in the regional economy (*Localized, Interactive*, *Globalized).* The ntire paradigm is explained in detail in Cooke in Braczyk, Cooke & Heidenreich (Eds.), "*Regional Innovation Systems - The Role of Governances in a Globalized World*", 1998.

Table 2: THE GOVERNANCE DIMENSION

Issue or variable	***Grassroots RIS***	***Networked RIS***	***Dirigiste RIS***
Initiation	Locally organized	Multi-level: local, regional, federal and supranational levels	Product of central government policies Animated from outside
Funding	Diffuse Local banking and government, chambers of commerce	Guided by agreement among banks, firms, and government agencies	Largely centrally determined
Research	Highly applied or near market	Mixed: pure and applied research and near market activities	Basic or fundamental
Technical Specialization	Low, generic problem solving	Flexible	High
Coordination	Low degree of supra-local coordination	High, many stakeholders, presence of associations, forums,	Very high at least potentially

[22] Mytelka and Smith affirm, that "more hierarchical organizations, such as the World Bank and the IMF, retained the macro-economic perspective and neo-classical approaches with which they were more familiar.

		industry clubs	

Source: Based on Cooke, 1998.

Table 3: THE BUSINESS INNOVATION DIMENSION

Characteristics	***Localist RIS***	***Interactive RIS***	***Globalized RIS***
Domination	Few or no large enterprises or large branches of externally controlled firms Dominated by SME	Balance between large and small firms, whether indigenous or FDI in origin	Global corporations, sometimes clustered supply chains of rather dependent SME
Research reach	Not very great	Access of regional research resources to foreign innovation	Internal
Public vs. private R&D	Few major public innovation or R&D resources, and small private ones	Mixed of public and private research institutes	Private mainly, but could be public research infrastructure to help SME
Associationalism	High degree of association among entrepreneurs and between them with local or regional policy-makers	Higher than average, expressed in local and regional industry networks, forums and clubs	Influenced by larger firms and conducted on their terms

Source: Based on Cooke, 1998.

Cooke then provided some examples:

Governance structure→ Business innovation dimension↓	***Grassroots***	***Networked***	***Dirigiste***
Localist	Tuscany (northern Italian industrial districts)	Tampere (Denmark)	Tohoku (Japan)
Interactive	Catalonia	Baden-Wurtemberg	Québec
Globalized	Ontario California	North Rhine–Westphalia	Singapore Midi-Pyrenées

What are the boundaries of a regional system of innovation and what determines its viability? How small or large is a region? The Canadian national system of innovation is made up of a number of regional systems of innovation, and industrial innovation policy needs to be tailored to fit specific regional needs. The Ontario/Quebec economy is not the same as the BC or Prairie regions. National statistics are biased by the Windsor – Quebec corridor.

Table 4: CANADIAN PROVINCIAL INNOVATION SYSTEMS

Governance structure/ Business innovation dimension	***Grassroots***	***Network***	***Dirigiste***
Localist	Prince Edward Island	Nova Scotia Newfoundland	New Brunswick
Interactive	Saskatchewan Manitoba	British Columbia Alberta	Québec
Globalized	Ontario		

Source: Holbrook (2006) , based on Cooke, 1998

Arguably, in Canada, some provincial boundaries, such as those between Saskatchewan and Manitoba, or among the Maritime provinces (the localist business innovation provinces), are artificial in terms of innovation systems. Canadian RIS can extend beyond provincial boundaries, as in the Maritime provinces, or in some cases, such as the Ottawa and greater Toronto RIS, be contained within one province. Canada is a country of metropolitan "islands": Vancouver, Calgary, Toronto, Montreal, etc. Indeed in the more successful regions, from the point of view of innovativeness the RIS can be subdivided into local systems of innovation (LIS), which are usually based in individual cities[23]. Table 5 gives a possible distribution of local systems of innovation.

Table 5: CANADIAN LOCAL/METROPOLITAN INNOVATION SYSTEMS

Governance structure→ Business innovation dimension↓	***Grassroots***	***Network***	***Dirigiste***
Localist	St. John NB St. John's NL	Halifax	Québec City
Interactive	Saskatoon Winnipeg	Calgary Edmonton Victoria	

[23] The obvious exception is the Greater Toronto Area (GTA), where the LIS extends over the entire conurbation. Indeed one of the major issues surrounding the analysis of the GTA LIS is determining its effective boundaries.

Globalized	Ottawa	Toronto Vancouver	Montréal

Source: Based on Cooke, 1998

Innovation in emerging economies

Many developing nations have a well established national system of science and technology from a legal and institutional point of view. It is important to introduce an important distinction between developed and developing countries. NSI is an *ex-post* concept for developed countries, built upon empirical studies, which showed similar patterns. The institutions already existed, and worked together with firms; there were innovation networks in place. What the NSI approach did, was to explain how those networks functioned and to emphasize their importance, and to highlight the role of national governments and public policy. For developing countries, the NSI is an *ex-ante* concept, in the sense that governments have created technology-related institutions, and have been trying to build networks to promote innovation at the firm level, based upon the NSI model (Arocena & Sutz, 1999).

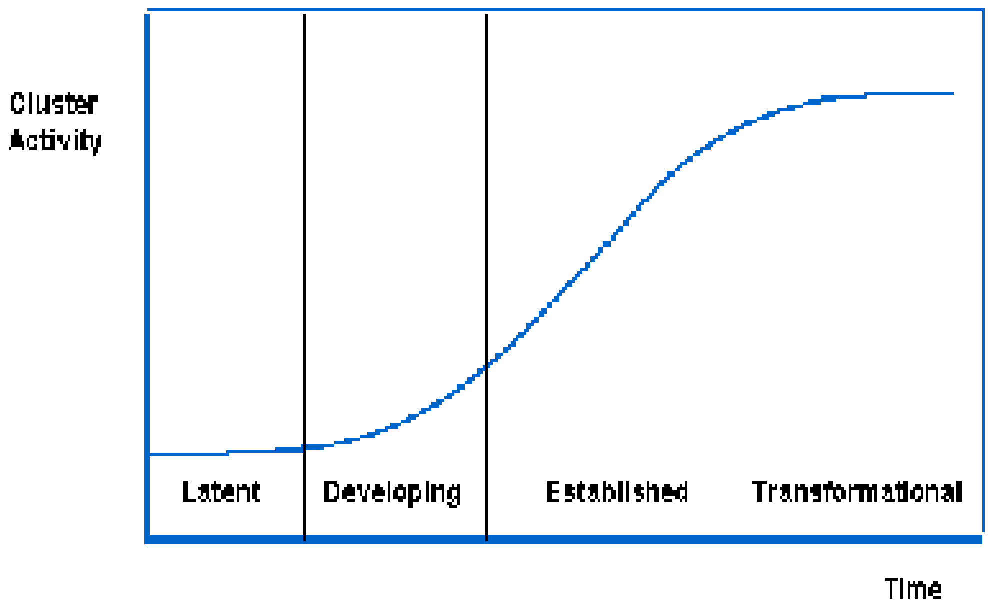
In developing countries the definition of innovation policies should be broader than in developed countries, encompassing not just technological innovation, but also organizational innovation and service innovation, and making more emphasis on diffusion and technology transfer than creation of knowledge. In this context, Mowery's classification of 'technology policies' (as he labelled them in his 1995 article) is relevant:

- supply policies (creation of technology)
- adoption policies, and
- competition policies[24] (e.g. trade policies, industrial regulations, intellectual property regulations)

Clusters and innovation

Industrial clusters (according to Michael Porter) are geographic concentrations of economic activity that have some competitive advantage, and thus (usually) exports. The change, over time, of a cluster, or group of clusters is best measured using a system of innovation model. The changes over time of a system of innovation, can be measured as economic growth , or contraction. Similarly, social trends can be used to describe changes to the system of innovation.

[24] According to Mowery, competition policies are usually not considered to be part of technology policy, but because they have an important influence on national innovative performance he includes them in his taxonomy.



Andersson *et.al* (2004) have noted that clusters have a life cycle/development cycle. In the diagram above:

- Latent (or “seed”) – There are a number of firms and other actors that begin to cooperate around a core activity and realize common opportunities through their linkages.
- Developing – As new actors in the same or related activities emerge or are attracted to the region, new linkages develop. Formal or informal institutions for collaboration may appear, as may a label and common promotional activities for this industry in the region.
- Established – A certain critical mass is reached. Relations outside of the cluster are strengthened. There is an internal dynamic of new firm creation through start-ups, joint ventures, and spin-offs.
- Transformational – Clusters change with their markets, technologies, and processes. In order to survive, the cluster must avoid stagnation and decay. Transformation may be through changes in the products and methods, or into new clusters focused on other activities. These may be spin-offs within the region which start next-generation clusters (this is the real test of the continuity of a cluster).

This model can be used for predicting the likelihood of success of a cluster

	Low economic potential	*High economic potential*
Have critical mass	Transformational	Established
Do not have critical mass	Latent	Developing

The Innovation Systems Research Network (ISRN) *(Holbrook and Wolfe, 2005)*

ISRN was set up to bring together researchers from a number of disciplines (ranging from chemistry to economic geography) to study industrial clusters and their role in regional systems of innovation. The Canadian national system of innovation is made up of a number of regional systems of innovation, and industrial innovation policy needs to be tailored to fit specific regional needs.

The program started with the Michael Porter definition of a cluster, but expected to find variances from this model across the country. Issues included "critical mass", "critical density", "champions of innovation" and the role of government in providing infrastructure. ISRN is now a two-stage, ten-year project with over $5M SSHRC funding and matching amounts from other sources. There are subnetworks in ISRN: covering the Maritimes, Quebec, Ontario and the West.

Researchers from all subnetworks carried out studies on specific industrial clusters. Some were unique to a single region (e.g. automotive), while others were carried out in all, or several regions (biotech and multimedia). Each cluster was studied to examine the factors affecting innovation in that cluster, and the relationships among the various components of each structure.

The research questions included: "What are the necessary and sufficient conditions that support the formation of a cluster in Canada? Are these region specific?" The program found that necessary conditions (i.e. common features)included university, labs, government agencies, private firms, human capital (?). The sufficient (conditions for continued existence) included at least one private firm with a global reach, manufacturing resources, and an active/interventionist public sector There is a potential test for the existence of a cluster: in the event of a catastrophic loss of a node/actor, can a cluster survive? Cluster development does appear to be very dependent on history (or "path dependency"?)

It appears that clusters in Canada have a large public-sector institution at the centre. High-tech clusters in the west often produce intellectual property (IP) rather than manufactured products: biotech, new media; Vancouver has a higher number of biotech "stars" than Montreal or Toronto. Location matters – cities with sticky labour markets are better prospects. Entrepreneurship vs. government intervention is a factor. The role of industrial associations is important – more than just champions.

ISRN evidence suggests that successful clusters are an outcome based as much on social factors as on economic (e.g. strong industrial associations). Regional governments need to understand where they are located in relation to the Cooke taxonomy (p. 24-25). Policy makers need to understand the relative stickiness of labour markets . Regional policy makers need to identify local competitive advantages that are based on social structures: culture, history, and language. At the local level, in local systems of innovation (LSI) – who are the actors? What are the key interactions between industry and other actors: government labs, educational institutions, industry associations, and local governments.

Richard Florida ("*Rise of the Creative Class*", 2002) argues that highly skilled professionals determine first where they want to live and then seek employment in that area. In Canada, Florida and Gertler (2002) have followed up on this in a series of reports "*Competing on Creativity".* They propose four measures for Canada: percentage of population with post-secondary education (*talent*), percentage of population employed in the arts (*tolerance*), percentage of population who are immigrants (*diversity*) and an index of the degree to which the economy is dependent on high-tech industry (*technology*)

Innovation policy and practice and the systems of innovation approach

The role of the systems of innovation (SI) in changing innovation policy and practice is quite different depending on the nations studied, that is to say: is the nation developed or developing (see Arocena & Sutz, 1999)? Most of the literature on SI has been produced in relation to developed countries. Different levels or areas of influence can be appreciated in reference to innovation policy and practice and the systems of innovation approach:

Arguably the most of important impact that the SI approach has upon innovation policy is that the design of policy has to be done in a consistent and coherent manner, i.e. single policies have to aim toward 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 to just to enhance individual elements of the NSI but the system as a whole (Guy & Nauwelaers, 2003).

Overcoming the dichotomy of supply vs demand policies has been crucial, 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 demand innovation policies to 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.

The diversity of levels of analysis within the SI approach is one of its strengths. The national level will be useful as long as nation states exist, even with increasing globalization of world economies. The other analytical levels are not only legitimate, but necessary, because they broaden and deepen our understanding of NSI, and point to the limitations of national policies (Lundvall et al., 2002).

Last, but not least, was the need to work on systems failures and not just on market failure. The most recent contribution of the SI approach to innovation policy-making, still under development, is a new trend labelled 'systemic innovation policies'. Klein Woolthuis and colleagues affirm that "SI-based innovation policy could be redefined 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 system level" (Klein Woolthuis, Lankhuizen, & Gilsing, 2005: 612).

This new wave is trying to synthesize the changes in innovation policy and practice mentioned above. "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" (Guy & Nauwelaers, 2003). Following these authors, systemic innovation policies:

- Involve building bridges between all nodes and not only between pair of nodes[25].
- Attempt to blur the frontiers between knowledge creators and users, and between private and public actors.
- Deal with systemic failures not market failures.

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 the 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 they miss new outside developments.
- Weak network failures: lack of linkages.
- Capabilities failures: lack of learning capabilities.

The emphasis on systemic failure 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", which identifies and tries to rectify structural imperfections (Arnold, 2004).

Various authors affirm that the SI approach has been useful as a benchmarking tool for economic and policy analysis. These benchmarking exercises can be done for different purposes. Although international comparative exercises are important, the SI approach is more useful to do bottleneck analysis. At an international level, it is always important to keep in mind that there is no ideal model to achieve, since the concept of optimality is absent from the SI approach, as Edquist points out:

> *"We cannot define an optimal system of innovation because evolutionary learning processes are important in such systems and they are subject to continuous*

[25] For instance, cluster policies are considered systemic policies.

> *change. The system never achieves an equilibrium since the evolutionary processes are open ended and path dependent" (Edquist, 1997: 20).*

In summary, the comment by Biegelbauer and Borrás 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" (Biegelbauer & Borrás, 2003b: 2).

Contributions of the SI to the understanding of innovation processes

Without doubt the SI approach has provided useful insights to a better understanding of innovation process. Listed below are some of the conceptual underpinnings of this approach:

- 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.

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 notes that "a country innovation performance will depend not only on how it performs on each individual element of the NIS, but how these separate elements interact" (OECD, 2003: 6). Or as Maureen MacKelvey explains it: "the concept of NSI encompasses an idea of systematic interactions, which cannot be reduced simply to the actions of specific firms, or to existing R&D system, or to competitions among firms or institutions" (McKelvey, 1991: 136-137).

Intellectual property and quanta of innovation

We can think of knowledge as the "fluid" that courses through a national system of innovation. But we can also think of an NSI as being similar to the Internet, with the digital packets of the Internet replaced by codified packets of knowledge, which can be defined in terms of specific intellectual property rights (IPRs). IPRs are "packets" of codified knowledge, or "quanta "of knowledge. These quanta vary in economic and social value.

As well as IPRs the packets can be the knowledge embedded in human capital: in other words people, as they move from one institution to another. IP that is in the public domain, and thus accessible by anyone. It could be characterized in terms of an IPR, but there is no unique owner. This type of knowledge can be tacit such as a skill, in which case the possessor of the skill owns the IPR.

IP that is not in the public domain – for example, a patent - can be traded for money or other value. IP that is contained in a product or service that is traded is also traded. A piece of electronic equipment may contain several IPRs, and by buying the equipment or service, the purchaser is, in effect, buying a licence, a licence whose use is limited to the use of the equipment (or service).

IPRs that are traded are (usually) well defined, such as patents or licences. However, the vendor still remembers the quantum of knowledge sold even if he/she cannot use it. More importantly the producer of that quantum of knowledge remembers what did not work. An IPR can retain its value even if it is not new. Most studies reflect on innovations created within a specific NSI – little is done on innovations imported from outside that system. But transfers of IPRs into a system of innovation are innovations in most regions and countries, particularly developing economies.

Studies of NSI identify bottlenecks some of which restrict the flow of the quanta of knowledge. What are these bottlenecks? Are they social, legal, bureaucratic or inherent to the technologies that the quanta carry? The flow of these quanta can be affected by a number of variables: economic and social values over time, over regions, and among the various actors in the national system of innovation. Studies of IPRs need to look at least these three dimensions (time, space, social actors).

Academic papers contain IPRs, in that the author(s) is/are claiming priority of discovery or creation of a particular piece (quantum) of knowledge. They are individual units of IPR (although they may contain more than one individual piece of IP). These IPRs are in the public domain, but they still have the property of a "right", even if it is only a "moral" right. These IPRs have value, as for example in determining hiring and promotion. They are easy to quantify: the ISI Citation Index is a useful method of measuring output by individual, by subject, by university, etc. The science of bibliometrics is based on the analysis of publications and citations, and forms a rich field of data for looking at inter-relationships in the NSI.

Patents are a formal declaration of IPRs, with the state granting exclusive privileges in return for disclosure, to stimulate innovation (as opposed to licences). Patents with citations can also be analyzed statistically: see the work of Francis Narin and CHI on patent bibliometrics. Some patents (US, and others with citations to previous patents) and some industries (chemicals, biotech, pharma) can be analyzed through bibliometrics.

Those industries that rely on speed of development or trade secrets do not patent and hence cannot be analyzed. There are “key” patents and “patenting trees” that identify major new IP; these can be measured bibliometrically

Technology Policy and Science Policy

Technology policy and science policy are best presented as aspects of a broader innovation policy. What is innovation policy? Dodgson and Bessant say that innovation policies aim at improving the capacity 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 (Dodgson & Bessant, 1996: 4).

What should an innovation policy include? Most of taxonomies refer to technology policy, few to innovation policy. Dodgson and Bessant (1996) organize 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)
- regulation (patents, environment control)
- public enterprise (innovation by public-owned industries)
- political (regional policies, awards and honours for innovation)
- public services (telecom, transport), trade (trade agreements, tariffs)

This classification show us the variety of measures that could be implemented, both direct and indirect. Within this range of tools some are supply-oriented, others demand-oriented, and others aiming to facilitate linkages between supply and demand. As an example, Guy and Nauwelaers (2003), as part of a benchmarking exercise of Science, Technology and Innovation Policies (STIP) in Europe, organized innovation policies into a matrix divided by reinforcement or bridging policies, and directed to knowledge users or creators, and public or private sector.

Their conclusions were:

- the same types of instruments are used in many EU member countries, with slight differences in emphasis and orientation to suit local contexts

- similar combination of policies are mainly due to imitation, rather than the result of deeply considered reflection on the appropriateness of particular mixes
- 'systemic policies, those directed to bridging initiatives between public and private sector knowledge users and creators, are the less developed
- the more varied and extensive are the bridging initiatives between public and private sector knowledge creators (Guy & Nauwelaers, 2003).

Arguably, resource-based economies should invest less in supply policies and more on adoption or diffusion-oriented policies and competition policies. Considering that technology is fundamentally knowledge, technology transfer is really a complex learning process, as Dodgson and Bessant note. If a country orients its innovation policy to diffusion and technology transfer, that does not imply that is a simpler task, it simply means that the focus changes. In the words of these authors:

"Two important policy lessons can be learned from a broader understanding of technology transfer and its contribution to innovation: i) the importance of creating and increasing the effectiveness of intermediaries, and ii) the development of innovative capabilities within firms" (to absorb the knowledge being transferred) (Dodgson & Bessant, 1996: 44).

For many years technology policy was under the "umbrella" of industrial policy or research 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 on 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.

It is important to note that even if within the innovation academic community the linear model of innovation is highly discredited - and was refuted by the chain-link model - many innovation policies are still based on the linear model (Mowery, 1995; Mytelka & Smith, 2002). The systems approach although widely accepted has had limited impact on policy-making. Slowly, various countries are moving towards a systemic approach, especially in the European Union, but from the wide array of policies implemented, few can be considered truly systemic (Guy & Nauwelaers, 2003). The systems of innovation approach is currently the best tool for innovation policy design, despite still being insufficiently developed and used.

Science, Technology and Innovation Policy

In designing a technology policy for a nation, what are the influences, both from theory and policy? How does one design the policy and what sorts of policy processes should be put in place to ensure that the policy evolves and adapts to changing circumstances?

There has been some evolution in the way practitioners and academics have dealt with Science, Technology and Innovation Policies (STIP). As noted previously, 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 S&T on the overall economy and society. In the early 1980s, there was a shift to innovation policy. The evolution of STIP can be explained mainly by political and economic factors, directly related to the world economy. Biegelbauer and Borrás (2003) also argue that changes in STIP are due to acceleration of the innovation processes and the changing nature of the state. However, social and environmental concerns have also played a role in shifting emphases.

Several authors have provided different periodizations of S&T policy (Elzinga & Jamison, 1995; Gibbons, 2001; Jamison, 1989), although there is similarity between them all. The ones that I will use to illustrate my point are Gibbon's and Freeman's. Gibbons affirms that there have been three phases on STIP:

- Phase 1 'Policy for science' (40s to 60s): the principal concern was the support of scientific research per se, especially big science.

- Phase 2 'Science in policy' (the 70s): the intention was that science played a key role in supporting diverse policy objectives, in particular social and economic development. This was a period dominate by social priorities.

- Phase 3 'Policy for technological innovation (the 80s)': Policies shifted to technology as a more effective base from which to support national industry.

Gibbons noted that if this latter policy (e.g. Phase 3) is to be efficient, it should supplant the older science and technology thinking, based on a broader understanding of the innovation process, of the constitutive role of knowledge producers, and "that people in their fungibility, multi-competence and capacity to connect with others are the crucial resource" (Gibbons, 2001: 34-35).

Christopher Freeman[26] classifies policies from an economic perspective. He defines also 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.

It is worth asking if we are facing a new wave of STIP. Even if it has not been clearly exposed, it is emerging and being demanded by policy-makers. This new phase is focused

[26] Cited by Elzinga and Jamison (1995).

on the knowledge-based society – or economy. For instance, the European Commission is talking about the third generation of innovation policies, despite recognizing that the second generation of policies are not fully developed and adopted. Their classification is as follows:

- First generation: based on the linear model of innovation.
- Second generation: emerged late 1980s early 1990s: its underpinning model is the innovation system approach -and also issues related to clusters and networks.
- Third generation: implies having innovation at the centre of all policies, and the knowledge-based economy is the guideline of these policies (European Commission, 2002: 49-50).

Canada's unwritten S&T policy

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)
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 HQP through repatriation of Canadian emigrants and encouragement of immigrants
participation in international consortia for big science projects such as NASA programs, the Canada-France-Hawaii telescope, etc.

From:. Salazar and Holbrook, 2007

Where We Are Today: Research on Knowledge and Research Networks

Highlighting the role of knowledge and research networks is a major contribution of the SI approach in understanding innovation processes. Innovation has become a highly uncertain, risky and complex activity, but also technologies as such are becoming more complex; all this has important implications for innovation policies. According to Kash and Rycroft:

"complex means that a technological process or product cannot be understood in full detail by an individual expert sufficiently to communicate all the detail of the product or process across time and distance to other experts" (Kash & Rycroft, 1998: 70).

The authors argue that policy must be based on the substance of the innovation process itself, and they add that at the heart of complex innovation processes is the network." (Kash & Rycroft, 1998: 73). Innovation networks have emerged as a new form of organisation within knowledge production, and have acquired greater importance within literature in organizational change, management of technology, and innovation studies. Kuppers and Pyka (2003) define an innovation network as:

"an interaction processes between a set of heterogeneous actors producing innovations at any possible aggregation level (regional, national, supranational). As such, an innovation network is a self-maintaining social structure created in an unstable situation" (Kuppers & Pyka, 2003: 7).

Despite all the contributions of the SI approach to a better understanding of innovation process not everything is studied and understood. Little is known about innovation networks, what is different and new from other forms of social organisation, what are their elements, what are their interactions, what are their coordination mechanisms, etc. Some of the most recent studies about innovation networks are based on theories of complexity and self- organization and generally, empirical research uses complex, mathematical constructs (see for instance Deroian, 2002; Pyka & Kuppers, 2003). The role of networks in innovation process can also be studied from a social network perspective, a field highly developed (see for example Agapitova, 2003). By contrast, networks and their role in knowledge diffusion and clustering of firms is a promising area of research. Ref: Wixted &, Holbrook (2008)

As with any policy, innovation policies should be evaluated on a regular basis, to review their efficiency and effectiveness, and also to change focus in case the circumstances have changed. However, stability, consistency and financial commitment are also needed. Innovation policies do not, usually, produce results in the short term, so any revision has to bear that in mind.

It would be interesting to study if the application of the NSI model to developing countries has been successful, considering that networks and intermediaries have been created by 'government-push' or 'action', trying to facilitate interactions and linkages between different agents. But we believe innovation networks to be self-organizing systems, hence government's role should be to facilitate their creation and to provide policy tools for their development. As Dodgson and Bessant point out: "manufactured (innovation) networks, set up from the top down, may often be less effective than those which emerge naturally from the bottom up" (Dodgson & Bessant, 1996).

Bibiography

Wixted, B., &, Holbrook, J.A.D. (2008) "*A Taxonomy for the evaluation of research networks*" , in preparation; see the CPROST website