# Contributions from the Sociology of Technology to the Study of Innovation Systems

*Naubahar Sharif*

Literature in the area of innovation systems (IS) has been growing in importance and the IS approach has become well established. It is widely used in North America, Western Europe and Scandinavia, both in academic contexts and also as a framework or tool for policymaking. This paper examines work by sociologists, historians and others who have attempted to provide new insights into the nature of technology, in order to determine how the new sociology of technology literature—particularly social construction of technology methodologies—can contribute to, and unpack the study of innovation system.

Technology is one of the most pervasive features of modern society, yet the sociological analysis of technology from the "inside" is still in its infancy.[1] In the last decade a new wave of scholarship has arisen in which scholars have, once again, started to get inside the black box of technology to show how technological artifacts may embody important social assumptions.[2] Such arguments are important because they challenge one version of technological determinism—that there is some innate logic to technology. It opens the way to ask questions such as: is technological development shaped by society and if so how? Can technology be understood with the same conceptual tools as developed for other areas (e.g. science or culture at large)?

Literature in the area of innovation systems (IS)[3] has been growing in importance and, like the literature in the sociology of technology field has existed for just over a decade. The innovation systems approach has become well established in a short period of time. It is widely used in North America, Western Europe and Scandinavia—particularly in academic contexts—and also as a framework for policymaking.

The purpose of this paper is to examine work by sociologists, historians and others who have attempted to provide new insights into the nature of technology, in order to determine how the new sociology of technology can contribute to the similarly recent study of innovation systems. In particular,

Naubahar Sharif is a Ph.D. candidate in the Department of Science and Technology Studies at Cornell University. He may be reached at <ns89@cornell.edu>.

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the paper attempts to unpack the innovation system concept by applying social construction of technology (SCOT) methodologies to it.[4] The first section of the paper details some of the salient aspects of the IS approach. In the second section, main concepts from the field of sociology of technology are outlined and their relationship to the IS literature explored. The final section of the paper concludes with generalizations about the ways in which the sociology of technology contributes to the study of innovation systems.

## Background to the National Innovations System Concept

The market and non-market institutions in a country that influence the direction and speed of innovation and technology diffusion constitute a national system of innovation (NSI). The national system of innovation is taken to be the totality of institutions and practices that interact to produce and diffuse new technology.[5] The Organisation for Economic Co-operation and Development's (OECD's) definition of NSI is the set of institutions that (jointly and individually) contribute to the development and diffusion of new technologies. These institutions provide the framework within which governments form and implement policies to influence the innovation process. As such, it is a system of interconnected institutions to create, store, and transfer the knowledge, skills, and artifacts, which define new technologies.

From the above perspective, the innovative performance of an economy depends not only on how the individual institutions (e.g. organizations, research institutions, universities) perform in isolation, but on, "how they interact with each other as elements of a *collective system of knowledge creation* and use, and on their *interplay* with social institutions (e.g., values, norms, legal frameworks)."[6]

The concept of an NIS provides a tool for analyzing country specificities in the innovation process in a globalized economy, as well as a guide for policy formulation. It highlights interactions between various actors and the workings of the holistic system rather than the performance of its individual components.[7] The characteristics of the innovation processes differ among countries depending on industrial specialization, specific institutional setting, policy priorities, and so on (see section on "sources of diversity between countries." for more on this). Historical experience shows that such differences persist even when countries deal with the same technological and economic developments. History matters, therefore, as countries have a tendency to develop along certain technological trajectories, shaped by past and present patterns of knowledge accumulation and use.[8]

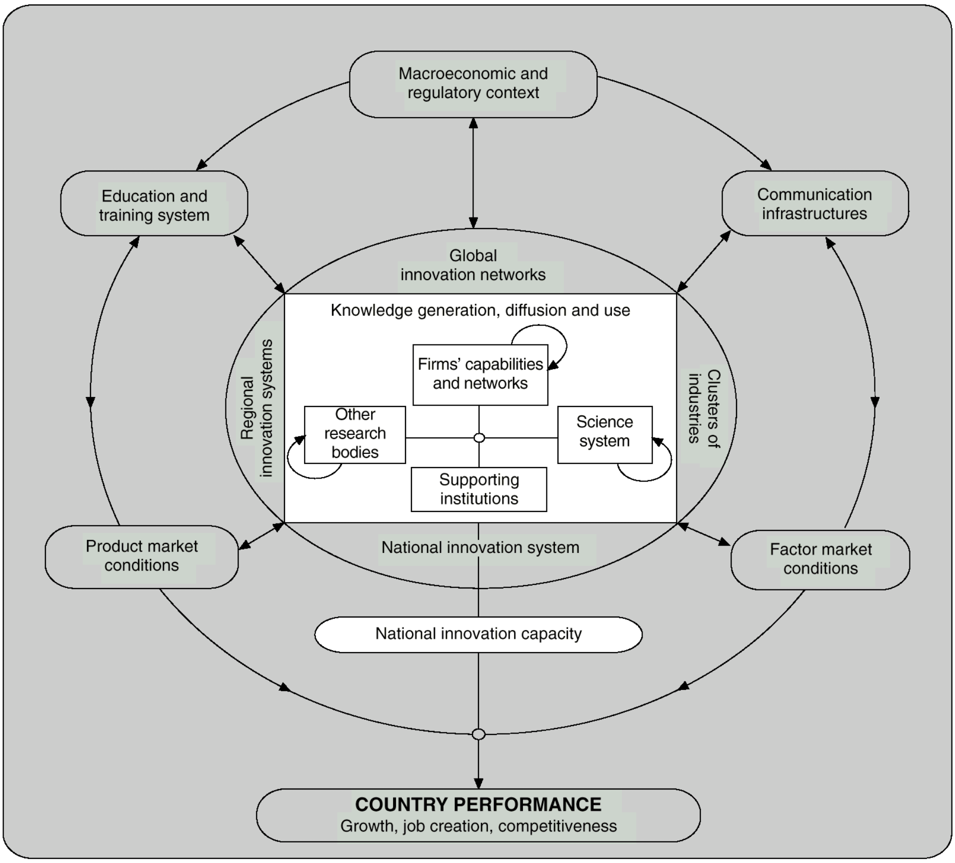
A systematic analysis of technological development and innovation helps define the tasks of governments in promoting innovation-led growth by emphasizing that competitive markets are a necessary but insufficient condition for stimulating accelerated rate of technical innovation and deriving the benefits from knowledge accumulation at the level of organizations and individuals. Firms are learning organizations as well as profit maximizers, and their efficiency depends on numerous and often country-specific institutional, infrastructural, and cultural conditions with respect to relationships among the science, education and business sectors, accounting practices, corporate governance structures, and labor relations.

In the innovation systems literature, governments are seen to have a responsibility for improving the institutional framework for knowledge exchange among organizations and between market and non-market organizations in addition to correcting market failures (e.g., providing public goods, intellectual property rights, subsidizing R&D).

The innovation systems approach is not only a tool for the analysis of social reality, but also comprises a prescriptive dimension that aims at modifying reality to conform to the social organization model it endorses. An important aspect of innovation systems literature then, is its aim to identify deficiencies in a society and prescribe correctives. The social organization model endorsed by innovation systems literature is shown in Figure 1. It refers to the system-

**FIGURE 1**

**Main Actors and Linkages in the Innovation System**




*Source*: Organisation for Economic Co-operation and Development. *Managing National Innovation Systems*. Paris: Organisation for Economic Co-operation and Development, 1999, 23.

atization (presented in the form of a model) of the social components participating in innovation. This model is obtained from official OECD literature for the study of the components of innovation. Based on the general model, the research literature aims to evaluate the extent to which the various components perform their role and the possibilities for improving operations to further facilitate the innovation process.

### *Origins of the (N)IS Framework*

The concept "national systems of innovation" goes as far back as 1841 to Friedrich List. His concept "national systems of production" took into account a wide set of national institutions including those engaged in education and training as well as infrastructures such as networks for the transport of people and commodities. It focused on the development of productive forces rather than on allocation of given scarce resources. The concept pointed to the need to build national infrastructure and institutions.

The modern version of the innovation system concept was not based upon any direct inspiration from List. Rather, it emerged from within the discipline of evolutionary economics. It was only after the concept had become generally accepted that Christopher Freeman and others went back and brought List forward as the intellectual ancestor. The idea of a national system of innovation was inherent in the work of the IKE-group in Aalborg in the first half of the 1980s. A standard phrase found in publications from this period was the "innovation capability of the national system of production." The "innovation system" concept was introduced by Lundvall but then still without the adjective "national" added to it.[9] But the concept was also present in the international comparisons between national styles of management of innovation pursued at SPRU and it was Chris Freeman who brought the concept into the literature in 1987 in his book on innovation in Japan.[10] And it was certainly inherent in the work of Richard Nelson and other U.S.-scholars engaged in comparing the U.S. system of science and technology with other national systems. Others who worked in parallel along similar lines of thought but with less emphasis on innovation were Michael Porter[11] and Richard Whitley.[12] Whitley's concept of national business system is complementary to the innovation system approach in its emphasis on culturally embedded business practices.[13]

### *Advantages (N)IS Framework*

There are four primary advantages of using the innovation systems framework. First, the system of innovation concept goes beyond research and development (R&D) in an effort to explain innovation dynamics. The concept assumes that the rate of technical change depends on both the scale of R&D in various countries and on inter-organizational learning processes. Second, these learning processes are very much influenced by institutional set-ups that foster competition and co-operation. The concept encompasses not only stock of knowledge (R&D stock or technology capital) but also institutional elements, which strongly influence growth dynamics.[14] The third advantage is that the framework allows emphasis to shift away from the organization as the sole vector of technological innovation in a society to the role of government policy, legal institutions, education and training institutions, and even norms and regimes. That the interactive processes and feedback loops between these institutions are emphasized is a strong point of the framework. Finally, the NIS approach is particularly well suited to analyses of technology policy. By drawing attention to the systematic features of the innovation process and their variation across countries, the NIS approach cautions against simple policy prescriptions that do not take into account cross-national differences among competing systems.[15]

### *Sources of Diversity between Countries*

Just as the characteristics of innovation processes differ among countries depending on various factors, countries also vary widely with regard to innovation. There are three chief sources of diversity. A first source of diversity is country size and level of development. Large and highly developed countries e.g., the United States, offer markets with advanced customers and opportunities to reap economies of scale while maintaining diversity in R&D activities. Innovators in smaller high-income countries such as Hong Kong, generally have to internationalize more rapidly and concentrate on a narrower range of fields and niches that are not attractive to larger countries / multinational enterprises (MNEs) to reap these benefits. They will profit most from free flows of technology across borders and their innovation systems are often focused on capturing the benefits of inflows of technology. Hong Kong also faces proportionally higher costs for maintaining institutions that cover a broader range of subjects than can be taken up by their industries. On the other hand, technological change in information and communication technologies, combined with deregulation and globalization, may reduce the scale advantages of large countries. The second source of diversity relates to the respective roles of the main actors in innovation processes (organizations, public and private research organizations, and government and other public institutions), and the forms quality and intensity of their interactions. The main actors are shown in Figure 1. The actors are influenced by a variety of factors that exhibit some degree of country specificity manifested in the financial system and corporate governance; legal and regulatory frameworks; the level of education and skills; the degree of personnel mobility; labor relations; prevailing management practices; and a nation's system of political governance (such as neo-liberal / free market democracies—United Kingdom, the United States—to social democracies such as Sweden to advanced communist nations like North Korea to fundamentalist communist nations like Cuba to various forms of autocracies, and so on).

## The Sociology of Technology

The sociology of technology evolved as an extension of the application of theories and models of sociology of science to technology. This was a reflection of the sociology of scientific knowledge (SSK) that emerged out of Edinburgh being the dominant paradigm in the sociology of science.[16] The Edinburgh program treated science as any other cultural artifact or belief system, and it states that science enjoys its high status because of its success in solving many of society's problems through various practical applications—not because science has a monopoly on truth claims about nature and natural processes. The Strong Program gave the greatest theoretical support to SSK by claming that, in matters of assessing truth claims about scientific theories, symmetry must be attained. In other words, the same sociological tools must be used regardless of the (degree of) truth of falsity or a claim or the same method of analysis must be used to explain a true scientific theory from a false one.[17] Harry Collins operationalized the tenets of the Strong Program in his Empirical Program of Relativism (EPOR).[18]

Closely following these developments in the social studies of science was the social studies of technology. In sociology of technology, as in sociology of science, the concept of symmetry should be upheld to explain successful technological innovations as well as failed ones. Technological developments should be interpreted according to the particular contextual situations of the community of its users and developers. The success of a technological innovation must be analyzed in the same analytical framework as a failed innovation. Furthermore, the success or failure of a technology cannot be simply reduced to a functionalist account of its workings or its internal structures, but its achievements and problems have to be explained in terms of social factors also.

In this section the empirically-based theories and models of social construction of technology that have the potential to contribute to the study of innovation systems are analyzed. The three constructivist theories analyzed that have the greatest potential to make such contributions are: the original social construction of technology (SCOT) model of Pinch and Bijker; actor-network model and heterogeneous engineering (Law and Callon); and the systems model (Hughes). Each of these approaches attempts to understand how a variety of social, political, and economic considerations shape technological development.[19] These approaches and concepts are, further, analyzed with specific respect to the innovation systems framework in an attempt to establish their usefulness, applicability and validity (to the study of innovation systems).

*Social Construction of Technology*

Trevor Pinch and Wiebe Bijker[20] were among the early founders of the field of the sociology of technology.[21] In their form of sociology of technology, they treat "technological knowledge in the same symmetric, impartial manner that scientific facts are treated within the sociology of scientific knowledge."[22] In the case of science, scientific facts are interpreted with respect to nature: in the case of technology, technological artifacts are interpreted with respect to culture. Pinch and Bijker's social construction of technology (SCOT) model is built based on a detailed historical case study of the development of safety bicycles of the 1890s that evolved from the unstable high-wheeler of the 1860s. The four theoretical anchors of the model are: (1) the *relevant social groups* who exercise; (2) *interpretive flexibility*; (3) *closure*; which means (4) "*stabilization* of the artifact and the 'disappearance' of problems"[23] so that the "final" technological product (the safety bicycle) emerges as the culmination of the entire process of technological change. There are two types of closure. The first is rhetorical whereby the concerned social group(s) are convinced that their problem is solved, which is effected through rhetorical means, such as facile advertisements and other rhetorical tactics (in order to solve the technological controversy). In other words, "technical" solutions are not required. The idea is to convince the concerned social group(s) that there exists no critical problem for the bicycle's acceptance. The second type of closure is closure by redefinition of the problem. Closure and stabilization are achieved by redefining the original problem and finding a solution to another related problem. The idea is to identify the key social group(s) first and "enroll" them in the new scheme that would encourage others to follow the enrolled groups.[24] Pinch and Bijker conclude that the content of an artifact is described by the "meaning" ascribed to it by the social groups, and the meanings themselves are influenced by the wider society.[25]

Perhaps the most important concept of Pinch and Bijker's SCOT model is the idea of "interpretive flexibility" of artifacts. This assumption holds that there is more than one interpretation for the "sociological facts" behind the "social construction" of artifacts. Thus, the focus of the explanation moves from the strictly internal technological realm of the artifact to the external social milieu. This property of the artifacts is used to explain the process of "closure" through which the artifacts are "stabilized" by the "interests" and "actions" of the relevant social groups.[26] To summarize, the focus of SCOT is that social factors and the interests of the actors determine the innovation process. Technological artifacts are explained and their construction interpreted with respect to the culture of the community of technology practitioners and the users / consumers of a technology. Finally, in interpreting technological change, both failed and successful innovations should be analyzed symmetrically using the same analytical devices.[27]

The issue of how SCOT can contribute to the study of innovation systems is now considered. The innovation system framework is not a "traditional" technology of a tangible artifact—it is a social technology. Therefore, to even consider innovation systems a technology, a broader definition of technology has to be adopted. Such a definition must incorporate a knowledge and skill component. To begin with, therefore, the definition of technology is one where technology has three parts. First are artifacts, systems, and networks. This is the material aspect of technology, and this is the traditional definition of technology associated with tangible products. Second are knowledge, skills and techniques. This is the component of technology into which the innovation systems idea can fit. Innovation systems are a way of analyzing an economy to determine how innovations can be promoted (for the purposes of economic growth). The third component of technology is related social practices and social relations (e.g. organization of work). This aspect of technology can sometimes be difficult to distinguish from the (second) knowledge, skill, and technique component. Finally, while the last two components of technology (knowledge and social relations) may *seem* at first to be "lo-tech," usually it is these components of technology that are more important. Given this, it is now possible to determine the usefulness of SCOT to innovation systems.

The central argument of SCOT would be that innovation systems can be understood by analyzing a variety of social, political, cultural, environmental, and economic issues surrounding the development of the concept as an *analytical tool*. This is true for the innovation systems framework. The concept of innovation systems first emerged from the work of a network of scholars based at the Science Policy Research Unit (SPRU) at the University of Sussex, notably Chris Freeman's studies of Japan's system of innovation[28] and in related work by Bengt-Åke Lundvall and his colleagues at the University of Åalborg in Denmark. Because the original studies focused on specific countries, *national* innovation systems (*N*IS) was the favored and most commonly used terminology. Innovation systems can also be conceptualized at other levels though—for example at the regional level or at the level of industries (sectoral or technological level). These systems may or may not be confined within a country's borders, but national characteristics and frameworks always play a role in shaping them (more on this point a little later, with respect to the idea of closure). Now, more than a decade and a half later, the concept has become well established as a leading paradigm for analyzing innovation processes.

In addition to the time and place from where this concept originated, it is important to take into account the socioeconomic context in which this approach developed. The approach did not emerge at just any moment in history, but precisely when economic globalization was accelerating during the 1980s and when international competition between companies intensified. In particular, Japan was quickly emerging as the new global economic powerhouse, dominating a variety of industrial sectors and threatening to lead the world economy in terms of gross national product. In this newly emerging economic context, companies' competitiveness became more dependent upon the ability to apply new knowledge and technology to products and production processes. Companies had to adapt to rapidly changing market conditions or take the lead by innovating their products and processes in a world where technological developments were taking (and continue to take) place at an ever-increasing rate. It became increasingly difficult for individual companies to produce all the relevant knowledge themselves and for them to translate new knowledge into innovative products or production processes. Consequently, to succeed in the innovation process, companies became more dependent upon complementary knowledge and expertise developed by other companies, universities, private, and public laboratories. In other words, the acceleration of the rate of production of knowledge that accompanied economic globalization required companies to intensify their participation in knowledge production networks to sustain their competitiveness.[29]

In terms of SCOT's theoretical anchors, parallels can be drawn with respect to the (early) development of the technological analytical tool that is the innovation systems framework. For one, there are a number of *relevant social* *groups* that contribute to innovations in a country, that the innovation system attempts to enroll. These groups include, firms, the government, research institutions and universities. Furthermore, there is a large amount of *interpretive flexibility* as regards what constitutes "innovation" between each of the social groups. For example, in a study of four Hong Kong small- to medium-sized service-oriented firms, I have found that the term innovation is highly problematic and requires substantial clarification, depending on who uses the term.[30] Government officials, and government policy may perceive of innovative activity from firms at the "ground level" who (need to) engage in innovative activity to ensure their competitiveness. Similarly, what is innovation in a university setting is more like what innovation is in an independent research institution. The point of *closure* is an interesting one for the innovation systems concept, because it does not seem to have been achieved thus far in one key respect. Partly because the innovation systems approach is currently more of a conceptual framework rather than a formal theory, there is much debate as to whether it is even appropriate to speak of "national" innovation systems, when different categorizations such as technological, regional or sectoral or transnational may be more suitable. As a result, over the past several years there have been several new concepts emphasizing the systemic characteristics of innovation but with focus on other levels of the economy than the nation state. Indeed, the literature on "regional systems of innovation" has grown rapidly since the beginning of the 1990s.[31] Bo Carlsson with colleagues from Sweden developed the concept "technological systems"[32] while Franco Malerba developed the concept of "sectoral systems of innovation," alluded to above. These concepts have been presented as alternatives to the national system approach. It has been argued that many interesting interactions in the context of modern innovation tend to cross national borders.[33] This is particularly the case given the rise to prominence of multinational companies as the dominant global form of business organization. Therefore, there is no a priori reason why the national level should be taken as a given for the analysis. This indicates that while parts of the concept have *stabilized*, other parts or problems are still open for debate.[34]

The above analysis shows that the innovation system framework, as an analytical tool, can indeed benefit from a social construction of technology (SCOT) analysis. One of the main reasons for this is that the IS concept (as a social technology) is open to interpretive flexibility. The workability of the IS concept is subject to radically different interpretations which are coextensive with social groups. Different social groups apply this IS concept different. Depending on which social group uses the IS framework (government, policymaking / influencing bodies, firms), different outcomes can accrue (depending on how they apply it). SCOT is valuable as it focuses attention on what counts as a viable working technology. The actual working of the innovation systems framework is embedded in social choices and negotiations as regards what counts as innovation, what is the appropriate delimiting criterion (national or other), and what the borders of the system are to be. These social choices and negotiations are made each time the IS concept is used, or developed upon.

*Actor-Network Model and Heterogeneous Engineering*

Using the galley, which is primarily a war vessel, as empirical focus, John Law provides a full-fledged actor network explanation of technological change by staying within the SCOT frame.[35] In this example, Law looks at the process which led to the domination of the ocean trade route between Africa and the Middle East and later the monopoly over the spice trade with the Malabar Coast of southwestern India by the Portuguese sailors during the late fifteenth and early sixteenth centuries. Based on the concept of "heterogeneous engineering," Law uses the process of the social construction of the galley to show how the Portuguese, who apparently began their exploration in trade in spices, eventually ended up dominating the Indian Ocean and colonizing many Asian and African countries. Law argues that because of the "heterogeneity" of the technological activity, a purely sociological or technological (systems) approach might lead to reductionism in explaining the technological change. The essential theoretical point is to understand how stability can be maintained in the construction of the heterogeneous network when hostile and contingent forces threaten the stability of the system. It follows that "the structure of the networks (or systems) in question reflects not only a concern to achieve a workable solution but also the relationship between the forces that they can muster and those deployed by their opponents."[36] In Law's network approach, neither nature nor society has a direct effect unless they "impinge" on the network builder. Therefore, adhering to the symmetry principle of the Strong Program, Law argues that the same type of analysis should be attributed to all components—humans and nonhumans. The second rule of network analysis is that actors are those entities that have detectable reciprocal influence on each other.

Like Law, Michel Callon also does not invoke a division between nature and society in his actor-network model of the social construction of technology.[37] Arguing that the study of the process of technological change itself is a process of "society in the making," Callon argues that the very claim that one can clearly demarcate social aspects of technological innovation from, say, scientific or technical aspects of it is false. He argues that social, economic, or political considerations are not added to the scientific and technical factors in the process of technological change as an afterthought. All these factors are present, right from the beginning. The most important theoretical component of Callon's model is that the *relationship* between the heterogeneous actors is what makes an actor network, which in turn cannot be whittled down to one singe actor or to a single network.[38] According to Callon:

> The actor-network can thus be distinguished form the traditional actors of sociology, a category generally excluding any nonhuman component and whose internal structure is rarely assimilated to that of a network. But the actor-network should not, on the other hand, but confused with a network linking in some predictable fashion elements that are perfectly well-defined and stable, for the entities it is composed of, whether natural or social, could at any moment redefine their identity and mutual relationships in some new way and bring new elements into the network. An actor-network is simultaneously

> an actor whose activity is networking heterogeneous elements and a network that is able to redefine and transform what it is made of.[39]

The basic premise of both the heterogeneous-engineering and actor-network models is to build a system in which the elements, both animate and inanimate, are linked together to bring “closure” and foster “stability.” In terms of explaining technological change, Law contends that “no change in vocabulary is necessary; from the standpoint of the network those elements that are human or social do not necessarily differ in kind from those that are natural or technological.”[40] While Law’s central characters are heterogeneous engineers, engineer-sociologists are the main agents of change in Callon’s model. Both Law and Callon adhere to the symmetry concept for explaining social, cultural, technical, and other existing factors by the same vocabulary.

Up to this point, Law’s and Callon’s analysis can be applied to innovation systems (as an analytical tool and social technology). By its very title, the innovation system concept attempts to present a unified and holistic view of the set of institutions that contribute to the development of new technologies. If we look at Figure 1 (page 3), we see that innovation system model depicts three levels. At the center are organizations and the factors of innovation to which it must allocate resources—e.g., research and development, technology, scientific and technical personnel. The second level concerns institutions in the immediate environment of the company—e.g., universities, governmental research centers, and other companies. These institutions provide the company with the supplementary resources necessary to support its innovation capacity. The third level is concerned with the global environment—the general conditions of the social, political, and cultural orders that define the environment in which the company develops and that determine whether or not the environment is favorable for innovation. At the heart of the innovation systems literature is the organization, above all, the firm. The objective of many innovation system studies is not only to understand the process of knowledge production, but also to evaluate the extent to which each of the elements participating in this production adequately performs their role (and this is generally determined via comparisons among countries) and thereby favors an expansion of the country’s national innovation capacity (which in turn leads to heightened country performance).

Unlike in the actor-network model where there is only a cluster of actants[41] with no overall structure or order as to how they were brought together, the innovation systems framework, as an analytical tool / social technology, strives to provide such structure and order. The precise reason for providing this order forms the basis of the whole IS concept. In the actor-network model, it is not apparent, how, where, or when a new actant is to be included or excluded.[42] This can be said to only partly be true for the IS model, as there is a unifying and defining criteria of including those actors that can do contribute to a nation’s innovation (system) and excluding those actors that do not contribute to innovative activity. The actant, therefore, is “innovation.” This is neither a human nor human, but rather a concept.

There are a number of actants in the IS and all of these relate to society. These social, political, or economic considerations are present right from the beginning of the process of innovation. However, because the social technology of the IS concept is a macro level framework, the natural or human actors are considered at the aggregate level. At this combined level of analysis, these actors are considered to become non-human. Therefore, firms (as a whole) are viewed as a (vital) social group that is the locus of innovation. The government (as a dominant social group in society) is another important social group. Research and development institutions are a third such group, and so forth. The human element disappears in these analyses, and the institutional component takes over. However, there is a variant to the non-human actants in the innovation system framework. Concepts and ideas have a large part to play in the IS conceptual framework. Therefore, the macroeconomic and regulatory context, factor market conditions, the corporate governance structure, labor relations, prevailing managing practices are ideologies that influence the innovation system. These actants influence and are influenced by a variety of factors that exhibit some degree of country specificity (in bringing about innovations). What is debatable is discussion of the "important" actors (to a nation's innovation system) and the actants that can be proven to be not so important.[43]

The actor-network model is intended to breakdown the barrier between micro and macro level concepts and events by linking them together. In the innovation system framework, the actors are linked systematically so that complex and dynamic processes like the development of research capacity, the transfer of knowledge, the sustenance of innovative firms can be isolated, empirically studied and changed according to pre-conceived goals. This is the main difference between the IS concept as a social technology and the actor-network model. In the former, there is a definite structure, hierarchy and understanding of importance of the various actors and actants. In the latter, there is no overall structure with actors and actants all being equally privileged. Other than this difference, the main underlying idea of the actor-network model fits well with the IS concept.

*Systems Model*

The third and final sociology of technology model that is applicable to the study of innovation systems is the systems model. The promoter of such an approach is Thomas Hughes.[44] In his pioneering study, Hughes follows the process of electrification in America during the period of 1880-1930. Hughes' description of electrical power systems embodies the physical, intellectual, and symbolic resources of the society that constructs them, and he charts the changes in configuration of the electrical power system by examining the changing resources and aspirations of organizations, groups, and individuals. The power system both causes social change and is affected by it—there is a co-production between the power system and social change.

What signifies a system is the "interconnectedness" of its components or interacting parts.[45] The goal of any system, technological, social, or sociotechnical as is the case in most instances, is to transform certain inputs into outputs under given constraints and contingencies. Therefore, the goal is to understand the system components and the overall system dynamics to stabilize and optimize its performance. Since the components are interconnected, a single component can change the system behavior and thus the system dynamics. Thus, it is of the utmost importance to find the most efficient system configuration—the way to interconnect the system components, which are arranged either in a vertical mode or in a horizontal mode.[46] Those parts of the system that are not under the system's control are called the environment—a sort of backdrop. However, a component of the system can easily incorporate the environment if there is a need. In this way, there is fluidity with regards to the borders of the system. A system that brings in the environment and is subject to environmental influence is called an open system.[47] The system, in Hughes' model, does not include the environment (although the environment influences the system).

Hughes provides a model for system evolution that incorporates elements of business and economic history as well as science and technology studies themes. In phase one of the model, invention and development is considered and inventor-entrepreneurs predominate.[48] Technology transfer characterizes phase two of the system, and the main actors are inventor, entrepreneur, organizer of enterprises and financiers. Growth is the third phase of the system in which the actors involved in the development attempt to solve critical problems that are obvious weak points or weak components (reverse salients).[49] Phase four of the system is when momentum is developed. Finally, phase five of the system is distinguished by qualitative changes in the nature of reverse salients and by the rise of financiers and consulting engineers to preeminence as problem solvers.

Hughes' work integrates elements of the firm yet is also sensitive to changes over time. After introducing the widely accepted system's metaphor or model, Hughes' second main contribution is perhaps the idea that even individuals and firms are constrained by their larger geo-political environment (including patents law, regulations and government restrictions). This point is highlighted in the way the electrical power system failed to take off in England the same way it was about to grow in the United States. Furthermore, Hughes' business and economic history is concerned with how the macro economic climate and the more firm-specific business climate affected the system (not the economy or the firm). By adopting a dynamic five-stage model, Hughes' systems analysis crafts a balance between various fields by being sensitive to contributions that different forms of analysis can have (aggregate, firm-level and micro, detailed case study approach). During different stages of the model of system development, emphasis can be placed on the most relevant aspects of the system, using the most applicable form of analysis (economic, business or S&TS).

Hughes claims that all technological systems are social constructions that are made out of a "seamless web" of science, economics, and social forces. Hughes' claim is that since technological systems "are invented and developed by system builders and their associates, the components of technological systems are socially constructed artifacts."[50] Hughes, however, differs from the actor-network theory of Callon in such a way that he includes only the animate (reflexive) actors, such as inventors, industrial scientists, engineers, financiers, and managers in his network. Despite this, Hughes claims that his systems model of technological change and the actor-network and social constructivist models have several things in common. In the five stages described above, according to Hughes, one may find all the standard structural components of technological change—invention, development, innovation, transfer, diffusion, growth, competition, and consolidation—though not necessarily in that order. The way Hughes conceptualizes of these individual components is the difference between Hughes' systems model and the other sociology of technology models.

Can innovation systems be analyzed using the system metaphor? Yes and no. As far as the *systems metaphor* is concerned, it is very appropriate for the study of innovation systems as an analytical tool. In innovation systems, what signifies the system is the interconnectedness of its components and interacting parts. The social technology of the innovation system aims to transform the efforts and innovative activity of various societal institutions into country performance (measured in terms of economic growth, job creation, and competitiveness). In any country, there are constraints and contingencies (e.g. values, norms, and legal frameworks) that have to be considered in making the transformation. Therefore, the objective of the innovation system conceptual framework is to attain a deeper understanding of the system components and the overall system dynamics (the connections/linkages between the system components) in order to optimize country performance. Since the components of an innovation system are interconnected, a single component (such as the education system) can change the system behavior and thus the system dynamics. Government policy is another example of a component that can have especially far-reaching effects on the system dynamics. Thus, what the innovation systems concept attempts to do is to find the most efficient system configuration—the way to interconnect (improve, change or create linkages between the system components). The deviation in applying the systems metaphor arises when the environment (or backdrop) is considered. One of the problems with the innovation systems concept is precisely that the system's boundaries with the environment are not well defined. Therefore, although the innovation system does not include the environment (just as Hughes' conception of a system does not include the environment), exactly what constitutes the environment and what does not constitute the environment is not always clear.

Having said this, Hughes' *model for system evolution* is not quite as applicable in the case of innovation systems (as compared to the applicability of the systems metaphor) as an analytical too, but is more applicable to the innovation systems concept as an *object of analysis*. The main reason is that the system does not comprise a technological artifact at its core. Phases three (growth) and four (momentum) are perhaps the most applicable phases of system evolution. The innovation system is a knowledge-based technology that is used for ordering and organizing society in a certain way. There are, therefore, no entrepreneurs involved with the system's invention and development (stage one). While the concept has been transferred (stage two) across industrialized countries, the various social groups involved with the transfer of the concept are unlike those that characterize the electronic power system in Hughes' model. There are, for instance, no actors such as financiers, organizers of enterprises, or entrepreneurs. The third stage of Hughes' system (growth) is applicable, as the actors involved in the development of the innovation system concept (academics and policymakers) have had to solve critical problems that are obvious weak points or weak components (reverse salients). Such weak points include the most important delimiting criteria for the concept (national, sectoral, regional, technological); defining the boundaries of the system so as to retain its analytical powers; and overcoming the problem related to comparison. The comparison problem arises as the concept so closely studies individual countries, on a "case-by-case" basis; it becomes rather difficult for cross-country comparisons to be carried out with any degree of effectiveness (as the constituent elements of the IS may have little in common across geographic boundaries). There is also the related question of how a country *arrives* at an innovation system that is effective and produces the desired results. While useful, comparisons between countries cannot provide policy prescriptions for nations: one of the main reasons being that each and every country possesses its own unique characteristics that affects its innovation system. System momentum (stage four) can be witnessed with the innovation system concept in that it is receiving greater and greater attention. Academic journals, policy makers and governmental bodies are all giving the innovation systems concept greater attention/utilizing it more widely. Supranational organizations, such as the OECD,[51] the European Commission and UNCTAD[52] have absorbed the concept as an integral part of their analytical perspective. Change also has begun to take place with respect to employing the concept at even the World Bank and International Monetary Fund (IMF). The U.S. Academy of Science too has recently brought the innovation systems concept into its vocabulary and now uses it as a framework for analyzing science and technology policy in the United States. Sweden has given the concept legitimate status in its own particular way by naming a new central government institution (an "*ämbetsverk*") VINNOVA, which stands for "the Systems of Innovation Authority." Finally, stage five of the model for system evolution is not appropriate as there have been no qualitative changes in the nature of reverse salients, nor have there been the rise of financiers and consulting engineers to preeminence as problem solvers.

## Conclusions, Implications, and Directions for Future Research

This paper has attempted to draw the main threads from the field of sociology of technology and apply them to the study of innovation systems. This is not to say, however, that *all* the concepts, theories of ideas from the field have been extracted. Only those that seemed to provide the most fruitful analysis for comparison and insights for the study of innovation systems were chosen. For example, broad themes such as the testing of technology, standardization of technology, gender and technology, and users and technology were not examined in this paper—not because of their unimportance or insignificance, but rather because the models of social construction of technology are the most relevant in providing contributions to the study of innovation systems. The standardization literature, in particular, is an issue because the IS social technology attempts to set standards across countries through its "theory." Therefore, standards have a key role to play. There are many relevant related questions in the context of the IS. These include: what constitutes as a standard; how are standards agreed upon; what causes standards to change; who, or which groups cause standards to be changed? Alder[53] addresses some of these issues relating to standards and standardization. The three social construction of technology models examined in this paper are deemed to have the greatest practical and realistic implications (below) for the IS concept—for the furthering of the concept, and for the furthering of the useful implementation of the concept. Breadth of analysis was consciously sacrificed for depth of understanding.

This leads to another point. It is important to note that this study has examined quite a different type of technology than that which is commonly the subject of analysis in the field of sociology of technology. With the innovation systems concept, there are absolutely *no* physical components of the technology. The entire concept, framework, and system are a form of knowledge used to apply to understanding and organizing society for the purposes of bettering country performance. This is notable simply because most previous sociology of technologies have been conducted where there have been some tangible component to the technology. In this sense, this study may provide the starting point for further and increased studies on knowledge, skills or techniques. Because of this, and also combined with the nature of the knowledge examined (innovation systems) the conclusions drawn are not typical to those found in the sociology of technology field.

What all three approaches examined in this paper have in common are their attempts to understand how a variety of social, political and economic considerations shape technological development. Technology forms part of a seamless web of society, politics and economics. Thus, the development of the innovation systems concept is not merely a technical achievement; embedded within it are societal, political, and economic considerations. All three approaches are concerned, to varying extents, to address the social and technical in equivalent ways.[54]

Applying the SCOT analysis to innovation systems, the focus is on the "design stage" or the early development of the concept. Insufficient attention is paid to the users of the technology—in this case the users of the IS concept. This is consistent with SCOT, and indeed was one of the criticisms leveled against the model.[55] The important point with SCOT, however, is that unlike the other models of social construction of technology, it is at least possible to analyze the developmental stage of the IS concept, in addition to its "usage" stage. This is extremely important in this case because the IS concept emerged from a very specific set of circumstances that were of concern to the Western industrialized countries at the time. This suggests that while SCOT may overemphasize the early design stage and early development of a technology (the IS concept), this emphasis is valuable, and can contribute to understanding the form that the technology ultimately takes. This is apparent with the example of the IS framework.

The actor-network, heterogeneous engineering model of technology can contribute to the study of innovation systems by illuminating the connections between the various actors of the IS. Furthermore, social, economic and political considerations are not added to the innovative capacity of a nation, but are all present right from the beginning. A final insight is that the relationships between the heterogeneous actors (e.g. the science sector, education sector, business sector, government, and the firm) is what makes the innovation system (the actor network), which in turn cannot be whittled down to one single actor or to a single network. All true, but all of this is already assumed, de facto, by the innovation systems concept. The same can be said for the systems metaphor. The very premise for the development of the concept is that a multiplicity of actors comprises the innovation system. No single actor (e.g. a large firm, no matter how large it may be) can constitute the entire actor-network. What current innovation systems studies attempt to do are to examine in detail the connections between the various actors. How can these connections be improved? What constitutes a healthy connection (for the purposes of innovation)? How can the connections / linkages be institutionally cemented? Given that these are the concerns facing present scholarship in innovation systems, it is safe to say that without adopting the same language, IS studies are pointing in the same direction as Law and Callon in terms of their actor-network, heterogeneous engineering model. Unlike Callon, Latour, and others, however, the IS concept does not attribute agency and reflexivity to all elements of the actor-network regardless of their differing roles. Certain institutions (e.g. universities, firms, legal structures) are assumed as natural kinds. Indeed, this is one of the areas in which work by Law and Callon can be of value. By opening up the individual categories and questioning the assumptions behind the composition of the various actors in the innovation systems, it may be possible to better answer some of the questions posed earlier—regarding the connections between the actors of the system. It may be that the answers to the questions posed lie in discrediting the actors as "natural" entities. By gaining a deeper and richer understanding of the actors and their composition, a different viewpoint can be added to the understanding of innovation systems. In this way, the actor-network, heterogeneous engineering model in particular can contribute to the study of innovation systems. This direction offers wide scope for future research.

In conclusion it is safe to state that the innovation systems concept contains many elements and insights—albeit in flashes—that the sociology of technology has to offer. Based on the above conclusions, there are two main directions for future research that this paper has identified that the sociology of technology can contribute to: a. a better understanding of the innovation systems concept itself, and b. the successful implementation of the innovation system concept. First, is to shift the focus back onto the "design stage" of the concept so that there is a greater emphasis on the particular context from which the concept emerged. This strategy is useful for several reasons. The IS framework was a response to certain economic and political conditions. Those conditions have now changed. Japan is no longer a major force nor a threat that it was a decade ago. To study the set of circumstances from which the IS concept emerged would be particularly helpful as it may allow a re-direction of focus, or a re-definition of the problem to occur as a result. Are the same circumstances present in the world today? No—therefore, does the innovation system concept still have value? How? What are the present day economic and political forces in play? How can the innovation system adapt itself so as to be useful giving the present global economic and political situation? In other words the closure of the concept as a *whole* (not just parts of the concept) has to be questioned. In particular, what is suggested is that the stabilization that has resulted should be reversed so that the entire process by which stabilization, closure, and acceptance by the relevant social groups via their different interpretations of the concept is reversed and questioned. The problem needs to be re-defined. The sociology of technology tells us that this re-definition can result in a very different type of closure (not just rhetorical) based on a redefinition of the problem (and finding a solution to a related problem). The content of the of the innovation system concept is described by the "meaning" ascribed to it by social groups, and the meanings themselves are influenced by the wider society—*as it is at present*.

Secondly, a dramatic opening up of the black boxes of the individual actors is necessary. By not privileging any of the actors in the IS model, it is likely that certain new observations can be extracted that can help in the applying the IS concept more usefully and successfully. Currently, all of the important actors are assumed as "givens." This needs to be questioned to examine the social forces that feed into the development of the actors. Such a strategy can provide awareness of the assumptions that each of the actors takes on board that influence their behavior. Do the actors behave as the IS model assumes they do? How does their behavior differ? What implications does the actors' behavior have for the implementation of the IS concept to nations? In other words, what is suggested is a shift in focus from the connections / linkages between actors to the actors *themselves*—to examine how they are socially constructed. Based on this approach, the connections between them can be better understood.

## Notes

1. It is, however, possible to trace a history of the social readings / critiques of technology dating back to the Luddites of the early nineteenth century who organized violent resistance to the introduction of power looms and other automated machinery in the production of yarn and cloth in England. More recently, Lewis Mumford's work on the subject of society and technology has become hugely popular. Mumford, L. (1963). *Technics and Civilization* (New York: Harcourt Brace & World, 3). Another key text: Marx, L. (1964). *The Machine in the Garden; Technology and the Pastoral Ideal in America* (New York: Oxford University Press), explores the tensions and contradictions inherent in the relationship between American culture and society in relation to technology due to its origins as a pastoral/agrarian society but rapid conversion to industrialism.
2. Once again such scholarship, while not completely new, has been reawakened with renewed vigor recently and has a much larger following than it ever did before. To illustrate the history of such

scholarship, once again Mumford, in the 1930s wrote, "When one examines [technology] freshly, however, many of these [traditional ideas] are upset. We find that there are human values in machinery we did not suspect" Mumford, L. (1930). "The Drama of the Machines," *Scribner's* (August 1930), as quoted in Mumford, introduction.

3. The terms of Innovation Systems (IS) and Systems of Innovation (SI) are used interchangeably in this paper and refer to the same concept (as are the terms NSI (national system of innovation) and NIS (nation innovation system)).
4. The analysis is not two-way, as the paper does not attempt to use the innovation system concept to say anything about SCOT methodologies. While useful, this exercise is not undertaken in this particular paper. The directionality of analysis is strictly attempting to examining how SCOT's analysis can be applied and contribute to the understanding of the IS concept.
5. Much of the discussion in this section is drawn from: Organisation for Economic Co-operation and Development. *Managing National Innovation Systems* (Paris: Organisation for Economic Co-operation and Development, 1999).
6. Ibid.
7. Lundvall, B.-Å. 1992. *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (New York: Pinter Publishers: St. Martin's Press).
8. Rosenberg, N. (1982). *Inside the Black Box: Technology and Economics* (Cambridge Cambridgeshire; New York: Cambridge University Press).
9. Lundvall, B.-Å., *Product Innovation and User-Producer Interaction* (Aalborg, Denmark: Aalborg University Press, 1985).
10. Freeman, C. (1987). *Technology, Policy, and Economic Performance: Lessons from Japan* (London; New York: Pinter Publishers).
11. Porter, M.E. (1990). *The Competitive Advantage of Nations* (New York: Free Press).
12. Whitley, R. (1992). *European Business Systems: Firms and Markets in Their National Contexts* (London ; Newbury Park, CA: SAGE Publications).
13. Lundvall, B.-Å., Johnson, B., Andersen, E.S. and Dalum, B. (2001)."National Systems of Production, Innovation and Competence-Building." Paper presented at the Nelson and Winter DRUID Summer Conference, Aalborg Congress Center, Aalborg, Denmark, 12-15 June 2001.
14. Radosevic, S. (1998). "Defining Systems of Innovation: A Methodological Discussion," *Technology in Society,* 20, 75-86.
15. Reppy. J. (2000). "Conceptualizing the Role of Defense Industries in National Systems of Innovation." Paper presented at the The Place of the Defense Industry in National Systems of Innovation, Cornell University, Ithaca, New York.
16. The sociology of scientific knowledge is usually identified by the Strong Program (spearheaded by David Bloor) that emerged out of the Edinburgh Science Studies Unit during the 1970s.
17. The tenets of the Strong Program are that links between society and knowledge is (a.) Causal; that one should study the failures and successes in science, thereby being (b.) Impartial; the same sorts of sociological explanations should be applied, (c.) Symmetrically, for the successes and failures; and that sociologists of scientific knowledge should apply the same tools to themselves as they apply to their study, (d.) Reflexivity.
18. The three stages of the Empirical Program of Relativism (EPOR) are (a.) to demonstrate the *interpretive flexibility* of scientific findings; (b.) to identify *closure mechanisms* whereby interpretive flexibility vanishes (to show where the dispute settled and what social mechanisms lead to closure) and, (c.) to *relate wider social and political structures* to these closure mechanisms (outside of the scientific community) to demonstrate how scientific processes are shaped by society.
19. Some of the work in this section draws on: Parayil, G. (1999). *Conceptualizing Technological Change : Theoretical and Empirical Explorations* (Lanham: Rowman & Littlefield Publishers).
20. Bijker, W.E., Hughes, T.P., and Pinch, T.J. (1987). *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge, MA: MIT Press.
21. Trevor J. Pinch and Wiebe E. Bijker, "The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other." in eds. Bijker, Hughes, and Pinch, 17-50.
22. Pinch and Bijker, 24.
23. Pinch and Bijker, 44.

24. In the case of the bicycle, this took place with the introduction of the air tire first introduced by Dunlop. In the beginning, the tire was dismissed by every concerned group. For the supporters of the air tires, it was intended to solve the vibration problem of the solid tire. However, vibration presented a serious problem to low-wheeled bicycles, and high-wheeled bicycles didn't suffer much from this problem. The situation changed when low-wheeled bicycles began to accept the air tire and as a result, out-pace high-wheelers. In bicycle racing, handicappers (e.g. high wheelers and low wheelers on solid tires) had to be given a considerable start if riders on air tires entered the race. After a while, all social groups, racers, and ordinary users went for speed and stability and thus closure was achieved by redefining the original problem (Pinch and Bijker, 44-45).
25. Bijker attempts to provide a comprehensive "theory of invention" by extending the SCOT program by introducing two new theoretical concepts: "technological frame" and "inclusion" using the case study of the invention of Bakelite (a successful synthetic plastic invented at the beginning of the century). Wiebe E. Bijker, "The Social Construction of Bakelite: Toward a Theory of Invention." in eds. Bijker, Hughes and Pinch, 159-187.
26. Pinch and Bijker, 24.
27. A recent critique of the Pinch and Bijker's SCOT model – and the author's responses can be found in: *Technology and Culture* 43(1), (April 2002): 351-373.
28. Freeman, 1987.
29. Albert, M. (2001). "The System of Innovation Approach." Paper presented at the Society for the Social Studies of Science, Cambridge, Massachusetts, 2 November 2001.
30. Sharif. N. (2002). "The Role of Firms in the National Innovation System Framework: Examples from Hong Kong." Departmental Research Project, Department of Science and Technology Studies, Cornell University.
31. Cooke, P. (1998). "Regional Innovation Systems: An Evolutionary Approach." in Braczyk, H-J., Cooke, Philip, and Heidenreich, M. (1998). *Regional Innovation Systems: The Role of Governances in a Globalized World*, (London ; Bristol, PA: UCL Press).
32. Carlsson, B. and Jacobsson, S. (1997) "Diversity Creation and Technological Systems: A Technology Policy Perspective." in Edquist, C. (ed.). *Systems of Innovation: Technologies, Institutions, and Organizations*. Charles Edquist (London ; Washington: Pinter), 266-294.
33. However, maintaining the policy dimension of the concept at the forefront makes it more sensible to employ the "national" category as opposed to others. As long as nation states exist as political entities with their own agendas related to innovation, it is useful to work with national systems as analytical objects.
34. A special issue of *Research Policy*, 31(2) (February 2002), contains many of the debates regarding the suitable categories to be used for the innovation systems concept.
35. John Law, "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion." in eds. Bijker, Hughes and Pinch, 111-134.
36. Law, 129.
37. Michel Callon, "Society in the Making: The Study of Technology as a Tool for Sociological Analysis." in eds. Bijker, Hughes and Pinch, 86-103.
38. Following the actors, the relevant social groups to understand the process of the construction of facts and artifacts emerged as the most fruitful ethnographic method for the anthropology of science and technology in the social studies of technology. See Latour, B. (1987). *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge, MA: Harvard University Press) and Latour, B. (1996). *Aramis, or, the Love of Technology* (Cambridge, MA: Harvard University Press).
39. Callon, 93.
40. Law, "Society in the Making," 114.
41. Callon, M. (1986). "Some Elements of a Sociology of Translation: Domestication of Scallops and the Fishermen of St. Brieuc Bay." in Law, J. (ed.) *Power, Action, and Belief : A New Sociology of Knowledge?*, (London ; Boston: Routledge & Kegan Paul), 196-229.
42. According to Latour, this determination (of how, where or when a new actant is to included or excluded) should be made by following the actor through the system, and based on the actor's role to decide which other actant deserves inclusion or exclusion (based upon its interactions with the primary actor).
43. Indeed, this point is one of the criticisms leveled at the innovation system framework.

44. Hughes, T.P. (1983). *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press), and Hughes, T.P. "The Evolution of Large Technological Systems." in eds. Bijker, Hughes and Pinch, 51-82.
45. For a technological system (such as the electric power system), controls are imposed to optimize the system's performance.
46. Hughes, *Networks of Power*, 6-7.
47. Hughes, *Networks of Power*, 7.
48. In this case, the inventor-entrepreneur is Thomas Edison. For more on Edison, his life and various inventions see: Israel, P. (1998). *Edison: A Life of Invention* (New York: John Wiley).
49. Reverse salients are obvious weak points or weak components, in a technology that are in need of further development. The concept of a reverse salient refers to an extremely complex situation in which individuals, groups, material forces, historical influences, and other factors have idiosyncratic, causal roles, and in which accidents as well as trends play a part. Reverse salients are defined as a set of "critical problems" (Hughes, *Networks of Power*, ch.4).
50. Hughes, "The Evolution of Large Technological Systems," 52.
51. OECD is an acronym for Organisation for Economic Co-operation and Development. The OECD is a group of 30 countries that share a commitment to democratic government and market economy. The OECD's work covers issues from macroeconomics, trade, education, development and science and innovation governance, identifying policies that work, country surveys, and reviews. (From OECD website: <http://www.oecd.org>).
52. UNCTAD is an acronym for United Nations Conference on Trade and Development. UNCTAD comprises 191 member states and it is the principal organ of the United Nations General Assembly dealing with trade, investment and development issues. Its goals are to maximize trade, investment and development opportunities of developing countries and assist them in their efforts to integrate into the world economy on an equal basis. (From UNCTAD website: <http://www.unctad.org>).
53. Alder, K. (1997). *Engineering the Revolution: Arms and Enlightenment in France, 1763-1815* (Princeton, N.J.: Princeton University Press).
54. Pinch, T. (1996). "The Social Construction of Technology: A Review." in Fox, R. (ed.) *Technological Change: Methods and Themes in the History of Technology*, (Amsterdam: Harwood Academic Publishers, 1996), 23.
55. Pinch, T. (1996). "The Social Construction of Technology: A Review," 27.

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