Rethinking the National Innovation System Functions Based on Viable System Model: A Theoretical Discussion and a Comparative Analysis

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Abstract: National Innovation System theory and framework is an emerging discipline based on systemic approach to innovation which has privileged through last two decades in innovation economics. This approach as any other systemic approach is inevitable to employ a functional view on system in-focus and pursuing goals of the system through functional perspectives. However, this field of study has not gained a consensus on its fundamental concepts such as “Functions” and “Activities” in an innovation system. This is obvious in context of different researches concerning activities in the national innovation system framework. This paper, is a theoretical attempt to make a convergence point for activities underpinning a national innovation system. So, it could be a reference model of NIS’s activities. For this aim, employing the Viable System Model, we have made a taxonomy of NIS activities in three level of granularity: Roles, Functions and Activities respectively. Indeed, a comparative study of previous research on NIS functions have been done.

Key words: National Innovation System • Functions • Roles • Activities • Viable System Model

INTRODUCTION

Innovation study literature in recent years has come to this point that the innovation rather than an isolated activity is a more complex and interactive process has to be studied as a part of a larger system, an “innovation system” [1, 2]. Through these years, a number of system approaches have emerged, including the technological systems approaches (e.g. Lundgren [3], Carlsson and Stankiewicz [4]), the national systems of innovation approach (e.g. Lundvall [5] Edquist and Johnson [6], Freeman and Christopher [7]), the sociotechnical systems approach (e.g. Trist [8]) and the network approach e.g. Håkansson [9]. These approaches as any other systemic approach are inevitable to employ a functional view on system in-focus and pursuing the goals of the system through functional perspectives.

Inherent in a system view is a notion that all system components contribute to the goal of the system or they would not be considered part of that system. The contribution of a component or a set of components to the goal is what here is called a function. The question is that whether there is an agreement on the functions that are served by components in an innovation system in that System(IS) literature or if there are differences between them also in this respect.

However, it seems that this field of study has not gained a consensus on its fundamental concepts such as “Functions” and “Activities” in an innovation system. This is obvious in context of different researches concerning activities in the innovation system framework.

The purpose of this paper is threefold: (1) to find out if existing innovation system literature share an understanding of the functions that are served in an innovation system and (2) to make a convergence among different apprehension of functions of an National Innovation System (NIS) through exploiting system theory especially Viable System Model (3) to elaborate on a taxonomy of the different activities in an NIS.
The structure of this paper is as follows: In section two, a brief definition and theoretical background of two pillars of our research (NIS and Viable System Model) will be described. In section three, the research method will be explained step by step and the different studies’ views of the functions served in innovation systems will be compared. In section four, the resultant taxonomy of NIS’s activities will be presented and in section five, they will be discussed. Finally, section six concludes the paper.

Concepts and Theories

National Innovation System: As it was mentioned before, it is believed that innovation is a complex process which requires interaction amongst many actors. This complex process has some inputs and outputs which can be defined through ‘system approach’. According to innovation system theory, innovation and technology development are results of a complex set of relationships among actors in the system, which includes firms, universities and government research institutes as well as many other actors [10].

System approach to innovation has not a long history starting since the last three decades. Although there are some historical antecedents to the NIS concept, its main background could be traced in academic and policy making organizations as well [11]. According to Freeman [12], following World War II, a linear model of science and technology, push, was often dominant in the new science councils that advised governments. It seemed so obvious that the Atomic Bomb was the outcome of a chain reaction in which basic physics led to a large-scale development in large laboratories and consequently it led to the applications and innovations. While this linear perspective was going to be pervasive as a principle for policy-makers, it proved to be unable to account for different rates of technological innovation and economic development experienced by industrialized countries. Despite similarities among various industrialized and semi-industrialized countries in investing on R&D starting in the 1950’s and 60’s, evidence showed that the rate of technical change and of economic growth depended more on efficient diffusion than on radical innovations and as much on social innovations as on technical innovations [12].

Although there is not a common consensus in the roots of National Innovation Systems, it seems that this concept first appeared in the 1980s in the context of debates over industrial policy in Europe. Since then, there were growing trend of applying this concept in academic as well as in practice so that many countries started to use NIS as an innovation policy framework. Freeman, Lundval and Nelson were the first scholars who dealt with this concept. Freeman (1995) defines the NIS as “a network of institutions in the public and private sectors whose activities and interactions produce, import, modify and diffuse new technologies” [12]. Similar concept could be found in Nelson’s definition that defines NIS as a set of institutions whose interactions determine the innovative performance of national firms [13]. These elements include firms, public laboratories and universities, financial institutions and government regulatory bodies and others who interact together. For Lundvall, it is “constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge” [14]. One account of NIS 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 [15]. Patel and Pavitt believe that NIS consists of national institutions, their incentive structures and their competencies that determine the rate and direction of technological learning in a country [16].

Depending on the geographical borders of the system, we can define other variations of innovations systems as ‘Regional’ Innovation Systems (e.g., many innovative companies are concentrated in Silicon Valley), ‘Sectoral’ Innovation Systems, (e.g., Automobile-related industries); and ‘Technological’ Innovation Systems (e.g., Electronics with applications in a different industries).

There exist both empirical and practical reasons for focusing on the nation as the primary unit of analysis [17]. Many gaps in development adhere to national boundaries and strong correlations have been observed between poverty and geography. Since the NIS perspective is primarily concerned with the flow of knowledge and its impact on economic growth, it makes sense to concentrate on the level that seems most centrally implicated in governing these flows [17].

Based on the NIS literature, there are two main tenets about NIS: one defines it in a broad scope which includes everything which is playing a role in the socio-economic environment. While it seems that this type of definition has a minimum practical use in policy analysis; the other one defines NIS in a narrow context. Since the socio-economic system cannot be considered to
be included in the innovation system, the question is then: Which parts should be included? [10]. A way to answer this question is to identify the “functional boundaries” of an NIS, beyond the “overall function of producing, diffusing and using innovations”.

According to Organization for Economic Co-operation and Development (OECD), NIS institutions, defined in the narrow context, can be divided into five main categories [18].

- Governments that make policy directions;
- Bridging institutions, such as research councils and research associations, which act as intermediaries between governments and the performers of research;
- Private enterprises and the research institutions;
- Financial institutions which provide financial support of innovation and
- Universities and Educational institutions.

The broad definition of NIS includes, in addition to the components within the narrow definition of NIS, all economic, political and other social institutions influencing learning, searching and exploring activities, e.g. a nation’s financial system; its monetary policies; the internal organization of private firms; the educational system; labor markets; and regulatory policies and institutions [19]. Conceptually, the narrow definition is embedded within the broader definition of NIS (Figure 1).

**Functions of an NIS:** There are two key attributes for any innovation system. It is both social and dynamic [20]. These features come from the nature of the institutions that form the system, as well as the linkages and flows that connect them to one another. It is social in the sense that it relies on “an institutional context constituted by laws, social rules, cultural norms, routines, habits, technical standards, etc.” [21]. It is dynamic due to the “financial flows between government and private organizations, human flows between universities, firms and government laboratories, regulation flows emanating from government agencies towards innovation organizations and knowledge flows (spillovers) among these institutions” [21]. Therefore we can identify four basic interactions in a given NIS as follows:

- Interactions among enterprises, primarily joint research activities and other technical collaborations;
- Interactions among enterprises, universities and public research institutes, including joint research, co-patenting, co-publications and more informal linkages;
- Diffusion of knowledge and technology to enterprises and diffusion through machinery and equipment;
- Personnel mobility, focusing on the movement of technical personnel within and between the public and private sectors.
To perform efficiently, innovation systems should function in a way that smooth these interactions towards the goal of innovation systems which are to develop, apply and diffuse new innovations. In literature, the activities that contribute to the goal of innovation systems (both positive and negative), are called functions of innovation systems [22]. Although several different activities take place in innovation systems, it is necessary to only focus on the relevant activities.

Interactive Learning, is one of the primary functions has been mentioned in innovation system literature [5]. Edquist and Johnson [6] mention three functions of institutions in innovation systems: institutions reduce uncertainty by providing information, manage conflicts and cooperation and provide incentives for innovation. McKinley [23] differentiates three functions of innovation systems: (I) retention and transmission of information, (ii) generation of novelty leading to diversity and (iii) selection among alternatives. Galli and Teubal [24] focus on linkages as they explain the transition of innovation systems. They distinguish between hard and soft functions. Hard functions require hard institutions (i.e., performing R&D), while soft functions may be operated by soft institutions (for instance regulatory entities) and involve catalytic and interface roles only. Hard functions are: (i) R&D activities (public) and (ii) the supply of scientific and technical services to third parties. Soft functions include: (i) diffusion of information, knowledge and technology; (ii) policy making; (iii) design and implementation of institutions concerning patents, laws, standards, etc.; (iv) diffusion of scientific culture and (v) professional coordination.

Jacobsson and Johnson [25] outline eight primary functions for an NIS as follows:

- Guide the direction of the search process;
- Supply resources, i.e. capital and competence;
- Supply incentives for companies to engage in innovative work;
- Recognize the potential for growth (identifying technological possibilities and economic viability);
- Facilitate the exchange of information and knowledge and Create ‘new’ knowledge;
- Stimulate/create markets;
- Reduce social uncertainty (i.e., uncertainty about how others will act and react);
- Counteract the resistance to change (provide legitimacy for the innovation).

Liu and White (2001) have developed a different way of defining the functional boundaries of an NIS, identifying five fundamental activities as the core of a framework that can be thought of as nation-specific. These are (1) research (basic, developmental, engineering), (2) implementation (manufacturing), (3) end-use (customers of the product or process outputs), (4) linkage (bringing together complementary knowledge) and (5) education [26].

Another attempt have been made by Hekkert et al (2007) to identify the innovation systems functions by introducing seven functions as follows: (1) entrepreneurial activities (2) knowledge development (learning) (3) knowledge diffusion through networks. (4) guidance of the Search (5) market formation (6) Resource mobilization (both financial and human) (7) creation of legitimacy/counteract resistance to change [27].

From a policy perspective, Smits and Kuhlmann [28] conclude that present-day innovation processes ask for instruments that support the following functions:

- Manage interfaces; cut across subsystem borders and supersede tunnel visions and dead-locks of narrow negotiation arenas; stimulate the debate.
- Build and organize (innovation) systems; facilitate construction and deconstruction (creative destruction) of (sub)systems; initiate discourse, alignment, consensus.
- Prevent lock-in; identify and facilitate prime movers, ensure that all relevant actors are involved.
- Provide a platform for learning and experimenting; create conditions for various forms of learning such as: learning by doing, learning by using and learning by interacting.
- Provide an infrastructure for strategic intelligence; identify sources (Technology Assessment, Foresight, Evaluation, Bench Marking); build links between sources; improve accessibility for all relevant actors (Clearing house); stimulate the development of the capacity to produce strategic information tailored to the needs of actors involved.
- Stimulate demand articulation, strategy and vision development.
- Stimulate and facilitate the search for possible applications; develop instruments that support discourse, vision and strategy development.
As we showed above, several classifications of functions are made by many scholars in the field; however there are some inconsistencies among these classifications as follows:

- Imbalanced granularity: some proposed activities so tiny as long as Meta functions.
- Confused terminology: lack of clear distinctions among “goal”, “function” and “activity”
- Incompleteness: almost all of the proposed functions are not comprehensive to the activities of an NIS.
- Overlaps: there is not a precise logic for arranging the functions in most of these classifications

Therefore, we are going to apply justifiable logic to get taxonomy of NIS functions in the next sections.

**Cybernetics and Viable System Model:** Cybernetics claims that there are underlying laws which apply equally to the manner in which the nervous system of an animal maintains control over its actions, to the way in which a species maintains itself within its ecosystem and to how a corporation maintains its existence in its marketplace [29]. Stafford Beer developed the VSM over a period of over thirty years as an aid to the practical process of diagnosing problems in human organizations and helping to improve their functioning [30]. He believes that the science of cybernetics can be used to design organizations which fulfill these objectives. The VSM is intended to act as an aid to the process of diagnosis of organizational problems and the subsequent process of organizational re-design.

The Viable System Model (VSM) is a blueprint for designing sociotechnical systems that are able to survive and thrive in complex, shifting landscapes [31]. The model comprises five main functions or systems: Policy, Intelligence, Control, Co-ordination and Operations. Beer labeled these management functions Systems 5 to 1 respectively. A sixth function, Audit, is labeled 3* to indicate that it is a sub-system of System 3. These six functions are linked through a series of communication channels or information flows. The six functions of the VSM together with their interconnecting links are depicted in Figure 2 [1].

**System 1:** Operations. System 1 is the collection of embedded operational units that performs the activities necessary to achieve the purpose of the system-in-focus. System 1 units are viable systems in their own right.

**System 2:** Coordination. As each operational unit seeks to maximize its performance, it may adversely impact other operational units (e.g., competing for the same customer). System 2 provides the operational units with a mechanism for coordinating coupled interactions through mutual self-adjustment.
**System 3**: Control (Cohesion). System 3 is responsible for the overall control of System 1 elements. As part of its control function, System 3 must integrate the operational elements into a cohesive whole such that the total system performs better than the sum of its parts acting independently.

**System 3**: Audit (Monitor). System 3’s scrutiny of operations is severely constrained by the highly filtered information transmitted by System 1 (e.g., Summarized performance reports). System 3 provides System 3 with assurance that the information received from operational management accurately reflects the true state of operations.

**System 4**: Intelligence. Whereas, System 3 regulates the internal operations of the organization (i.e., managing “inside-and-now”), System 4 enables the organization to adapt to shifts in the external environment (i.e., managing “outside-and-then”).

**System 5**: Policy. Systems 3 and 4 are dedicated to functions that are concerned with different environments (internal vs. external) and different times (present vs. future). System 5 arbitrates in the debates between Systems 3 and 4 and ultimately determines “which of the various futures for the organization will be enacted” [32].

Beer [1] defined a viable system as one that is capable of maintaining separate existence; of surviving on its own. However, “survival” should not be interpreted in the limited sense of merely existing. … In an increasingly competitive, complex world, survival can only be continuously realized through the processes of learning, adapting and growing. Beer ([33] p.239) asserted that an organization(Socio technical system) based on the VSM has the “mechanisms and opportunities to grow and to learn, to evolve and to adapt – to become more and more potent in its environment”. In this definition, an Innovation System could be considered as a Viable System whose survival involves learning, adapting and growing.

**MATERIALS AND METHODS**

The method we used for investigating the NIS functions primarily relies on theoretical thinking based on literature comparative analysis and Cluster analysis as a complementary method to shape taxonomy. Following, we discuss each step separately.

**Comparative Analysis**: As it is shown, several functions and activities have been mentioned in literature, however it seems that there were not any integrated classification about functions and activities among these studies. Therefore, by incorporating all these activities and functions, we made a comparative Matrix, showing different activities in columns and different authors in the rows. It shows that the frequency of each items presented in the literature.

**Cluster Analysis**: The resulted list from previous step was a rough list of NIS activities included several items which were not in the same granularity and classified. Hence, we needed to arrange these items to get a taxonomy. For this aim, a cluster analysis was conducted. Cluster analysis or clustering is the task of grouping a set of objects in such a way that objects in the same group (called cluster) are more similar (in some sense or another)
to each other than to those in other groups (clusters) [34]. The clustering criteria, was the degree of dependency of each item to every roles (systems in VSM terminology) in a hierarchical order.

We applied a hierarchical definition of activities around the granularity of actions involved in an innovation system. In this definition, “Roles” imply to the higher level functions of a system which are directly act as an enabler for targeting system goals. “Functions” are the underpinned activities of each roles which make a role in action. Activities are the detailed level which refer to actions included in each function. Figure 4, depicts this definition.

A Taxonomy of NIS Functions: As it previously mentioned, to arrange different activities identified in a national innovation systems we exploited two dimensions: first, granularity of activities from Meta activities to more tiny as Roles, Functions and Activities respectively. Second, viable system model’s functions which should be satisfied by designed taxonomy. The resultant taxonomy is as follows:

2-1. **Role 1**: Directing and Regulating
2-2-1. Generating required policies: policies in the fields of science, technology, industry, education and other related policies.
2-2-2. Making regulations, rules and laws: rule setting to support the policies e.g. patent system
2-2-3. Standardization of the products and the processes to reduce costs and improve quality
2-2-4. Legitimization of the technology and firms: through socio-economic policies
2-2-5. Fore sighting: Monitoring current and future trends

2-2. **Role 2**: Knowledge Creation and innovation
2-2-1. Research and Development: performing research and development in technology
2-2-2. Technology transfer: technology transfer from the external sources
2-2-3. Enhancing networking: promoting networking among different entities

2-3. **Role 3**: Diffusion of Innovations (Idea/ Knowledge/ Product/ Process)
2-3-1. Informing: about technologies, knowledge, demand and supplies and opportunities
2-3-2. Advertising of innovations and technologies
2-3-3. Brokerage: bringing together complementary knowledge and resources
2-3-4. Incubation: for new innovations and new entrances
2-3-5. Other Supports for diffusion

2-4. **Role 4**: Facilitation of Market Generation and Infrastructures
2-3-6. Creating a labor market that can be utilized to promote personnel mobility
2-3-7. Creating a product market
2-3-8. Enlarging the market through protective or stimulating policies
2-3-9. Enhancing market access
2-3-10. Providing infrastructures

2-5. **Role 5**: Human Resources Development and Training
2-3-11. Public training and education
2-3-12. Professional education

2-6. **Role 6**: Production
2-3-13. Commercialization of Innovation
2-3-14. Manufacture products or provide services

2-7. **Role 7**: Providing financial support
2-7-1. Providing venture capitals
2-7-2. Providing other financial supports (e.g. loans, investments).
DISCUSSION

The functions identified for innovations systems should be (1) comprehensive, means that no activity required for NIS performance is neglected (2) consistent, means that there would be order among the classification of activities without any redundancy and overlap (3) satisfactory for viability, means that these functions totally satisfy the required functions in VSM.

The early two conditions may be ensured because of the comparative study of several activities of NIS as well as functional decomposition of innovation systems.

The third one which is critical to our clustering attempt needs to be explored deeper for two aspects: first for legitimacy of predication of “Viable system” label to NIS and second for the functional adequacy of designed taxonomy for viability of NIS.

On legitimacy of predication of “Viable system” label to NIS, some researchers have been done indirectly. For example, studies in the Complex adaptive system theory (CAS). CAS is the other term nearly employed instead of viable system. For instance, Rogers and et al[35] in their research employed the diffusion of innovations model (DIM) and complex adaptive systems theory together to construct a predictive or applied hybrid models of induced change in population behavior. In their belief, innovation is occurred in a complex system which adaptability of innovation. Cooke [36] in his book titled “Complex adaptive innovation systems” argue about the complex and adaptive nature of innovation systems. As it is obvious, the viable systems features as adaptability and complexity could be precisely refer to an innovation system hence, it is not so irrelevant if we consider the innovation system as a viable system.

On the functional adequacy of designed taxonomy for viability of NIS, we can show among functional mapping of taxonomy to viable systems Function that the designed taxonomy covers all functions of VSM. The system 1 in VSM indicates the operations. In the IS domain it refers to main value chain of NIS include roles 2, 3 and 6. In the term of Porters value chain Model[37] these are the main series of activities in an NIS.

The system 2 in VSM, indicates the Coordination where in IS domain several functions in different roles deliver that function. Regulation Function (F222) and standardization (F223) from first role (Directing and Regulating) play as system 2 in VSM [38].

The system 3 in VSM stands for control and audit, where in NIS the function 225 resides on monitoring and 223 for auditing and control.

The system 4 in VSM deals with Intelligence where in NIS the function 225 resides on intelligence of NIS through fore sighting future and forecasting trends [39].

Table 1: Functional Mapping of VSM to IS functions

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<th>Functions</th>
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<td>System 1 functions:</td>
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<td></td>
<td>Operation</td>
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<td>Generating required policies</td>
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<td>Making regulations, rules and laws</td>
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<td>Standardization</td>
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<td>Legitimization of the technology and firms</td>
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<td>Professional education</td>
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<td>Commercialization of Innovation</td>
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<td>Manufacture products or provide services</td>
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<td>Providing venture capitals</td>
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<td>Providing other financial supports (e.g. loans, investments)</td>
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The system 5 in VSM stands for policy where in NIS, the first functions dedicate to these one totally and amongst the underlined functions, the first one is dedicated to this one [40].

As well as these higher level functions, there are several activities underlined in those functions that serve as viable systems functions to National Innovation System. Table 1, shows a mapping matrix of our Taxonomy to VSM functions.

CONCLUSION

National Innovation systems could be treated as Viable Systems which their effectiveness (or survival) relies on learning, adapting and growing in a turbulent environment. To be viable, innovation systems need to develop the requisite systems inside in terms of Viable System Model. These interior systems called “Functions” in the Innovation System literature. However there is not a consensus about the number and roles of these functions among Innovation System literature. If we apply the VSM model in Innovation System domain and through a comparative analysis we can get to a well-defined classification of Innovation System functions arranging in three levels of granularity as Roles, Functions, Activities respectively. This is what has been done throughout this paper and eventually resulted to a taxonomy of NIS functions. This taxonomy consists of 7 institutional Roles, 25 related functions and more than 63 detailed activities.

This taxonomy follows a justifiable logic to classify NIS functions which could ensure completeness and consistency among the items and would play as a convergent point of all related studies undertaking functions of NIS as a part of their research.

REFERENCES