A SYSTEMIC APPROACH OF THE TECHNOLOGICAL INNOVATION PROCESS IN MEXICO

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ABSTRACT

Schumpeter points out that innovation is a dynamic force that causes the continuous transformation of social, institutional and economic structures which ensures a plausible quality of life of its inhabitants. Innovation is a complex process of interactions between different actors can be understood best as a system where different social and institutional agents interact and promote the innovation and the development of the countries. To try to understand the complexity of this process were studied 41 variables which were related through network analysis and it was found emergent properties that reveal that less than 10 % of the variables are relevant and there are political and social, this result was mainly in developing countries like Mexico which was analyzed from 1980 to 2015. The results also show that these actors found in systemic innovation process have hampered the efficiency of the process.

Keywords: Systemic Approach, Innovation, Networks.

INTRODUCTION

Many sociological aspects of human life are organized like life itself without central authority, resulting in emergent properties characteristics of each social system (Van Gich, 2012, Mitchel, 2009).

Technological innovation is one of the emergent properties that result from relationships in the social context and contribute to adaptation and ensuring survival, which is why several authors suggest studying innovation from system dynamics and complexity (Carayannis y Campbell, 2012, Chang y Chen, 2004, Choi, Kim, y Lee, 2010, Fleming y Sorenson, 2001, Floysand y Jakobsen, 2011, Freeman, 1996, Galanakis, 2006, Goodwin, 1950, 1982, 1990, Hanusch y Pyka, 2007, Hirooka, 2006, Jensen et al., 2007, Kash y Rycroft, 2002, Kok, 2009, Leydesdorff, 2000, Nonaka et al., 2014).

Capacity for technological innovation ensures performance in areas such as primary production, industrial production and provision of services and therefore competitiveness in the economy. In this context, the independent performance of institutions and their interaction with others, formed a collective in which knowledge is created and applied, thus forming feedback loops of the productive system that impact on the competitiveness of each nation (Calia et al., 2007; Rycroft y Kash, 2004).

To understand the phenomenon of technological innovation, the characteristic complexity of innovation processes must be approached from a systemic perspective (Freeman, 1996). In 1972, the term "innovation system" was used to describe innovation as a result of relations between actors and in 2007 a theory of the "National Innovation Systems" (NIS) was published as a macroeconomic alternative that arises in neoliberal economic models. In these NIS the role of different actors (government, academia and the private sector) that articulate innovation activities and economic growth in countries is highlighted (Lundvall, 2007, Dosi, et al., 1988, Kline y Rosenberg, 1986).

This vision of innovation, contemplates the investment of time and energy in enterprises and social organizations for the production of scientific and technological knowledge that is enhanced as a result of interactions between that agents. Thus, this paper identifies those variables or preponderant qualities on technological innovation, by analysing socio-technical actors that make so self-organized Innovation System in Mexico.

COMPETITIVENESS AND INNOVATION

Neoliberal and globalized world behaves as an open system in which the economic and social development are achieved through competitiveness (United Nations, 2012). Understanding competitiveness as the ability to sustain and increase productivity and participation in international markets while improving the life standards of the population (Porter, 1990). From this approach, competitiveness depends on three things: the abundance of natural resources, cost reduction and investment in R & D. This last aspect is closely linked to the emergence of innovation, arising from the interaction between companies and organizations with education, science and technology purposes, whose creative and productive activities are guided by market fluctuations (Abrunhosa, 2003).

Thus, the concept of innovation has undergone several transformations over time due to changing economic models (Rothwell, 1994). After World War II the linear model was generally accepted. In this model, the new technology emerged from basic research and advanced towards the application, invention, market testing and eventually the diffusion process. In these models, innovations are seen as the result of a linear process that involves different steps sequentially ordered, hierarchical and unidirectional manner. However, Kline and Rosenberg discuss the linearity of the innovation process and the relevance of a model of dynamic-systemic behaviour (Kline y Rosenberg, 1986).

On the other hand, even with existent evidence of a direct relationship between investment in science and technology, the generation of technological innovation and causal improving productivity and economic growth, the adoption of a linear model for economic development based on technological innovation would be a mistake given the inherent complexity of the process itself that leads to the emergence of innovation and its impact on competitiveness and welfare indicators, for example, during the 1970s to 1980s, the emergence of new and important technologies was followed by a decrease in productivity in most OECD countries (Pavitt, 1991). The apparent contradiction between these facts became known as the productivity paradox. As mentioned above, the reason is because innovation as an emerging phenomenon is complex and involves the production, dissemination and translation of technological knowledge in new processes or products (Samara et al., 2012)

SYSTEMS OF INNOVATION AS COMPLEX SYSTEMS

The innovation process occurs in a system in which actors interchange tangible and intangible artifacts as knowledge, finance, technology, patents, etc., creating feedback loops between actors and proccesses. The interdependence between the system elements and their interaction with the context and because of the human nature as nuclear part of these systems, allow us to define them as open and dynamic systems.

Complexity in Innovation Systems

From this systemic approach, innovation and competitiveness is the result of complex and dynamic interaction between the government, enterprises, intermediary institutions and organizational capacity of a society or nation (Esser et al., 1994). From this approach several studies on the "innovation systems" have analysed the conditions that determine the behaviour of enterprises and innovation in the field of economics, results and discussion could be found in Lundvall (1992), Porter (1990), Freeman and Soete (1997) and Stoneman (1995), whom stated that in the course of time innovation contributes to economic growth and welfare of nations (Freeman and Soete, 1997; Lundvall, 1992; Porter, 1990; Stoneman, 1995a). Not surprising that governments promote innovation to make progress in addressing and resolving economic and social problems of their countries, even if these attempts are not always entirely successful (OECD, 1997a, b).

Figure 1 shows the basic construct of a SNI in which the subsystems and components generate interdependencies given by the relationships between them, with the aim of generating innovation arising from the formation of relationships and feedback processes, in which exchange flows relate to information and knowledge.

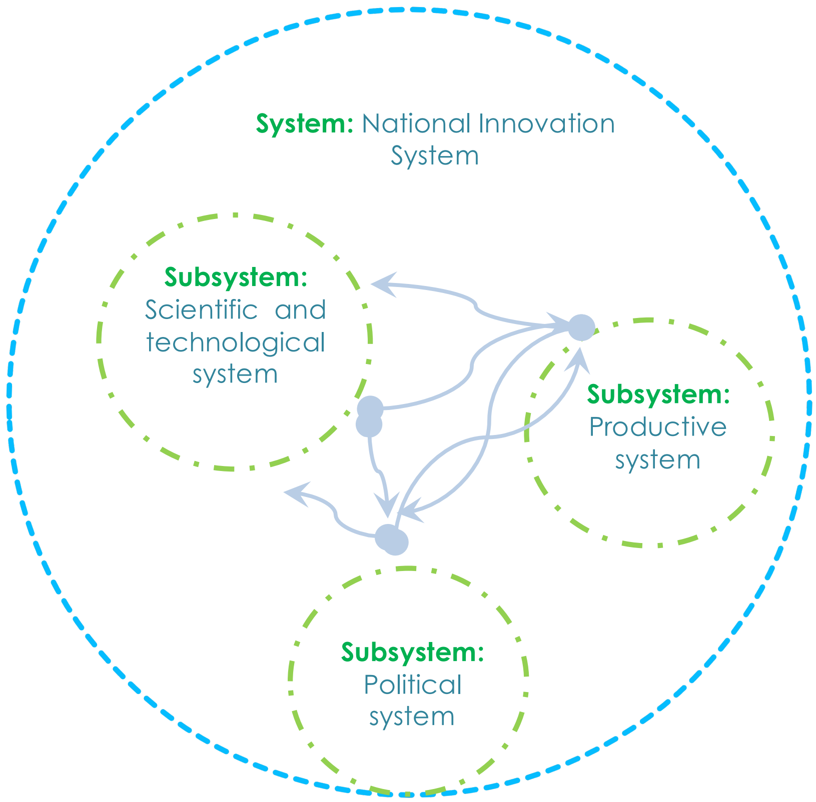

Fig. 1. Subsystems and relationships between them in the context of a National Innovation System.

In the model presented in Figure 1, each subsystem is composed of agents interacting with other agents within the same subsystem and out of the subsystem with the other subsystems agents. An agent is defined as an active element in a multi-elements or network, this implies that each subsystem in itself is a system (Francois, 2004, Lundvall 2007).

This classic construct of a NIS is based on the integration of agents into three subsystems; the scientific and technological system, the political system and the productive system:

- The scientific and technological system is mainly made up of institutions and units engaged in the generation, adaptation, application, processing and dissemination of scientific and technological knowledge, but also the coordination, funding, planning and policy for development of scientific and technological development (Chávez et al., 1974).
- The political system in turn, is defined from the systemic perspective as the government of human organizations in which the set of political interactions, focuses on the authoritative allocation of values (Easton and Armengol, 1969). And from cybernetics is considered as a set of agents capable of self-directed from the

information received from the environment with which it interacts through flows (Francois, 2004, Deutsh, 1966).

- Finally, local production systems are defined as areas where a strong presence of companies, arising primarily from local, specialized in some kind of activity or product that gives personality to the area is recorded. The most characteristic feature is the fragmentation of the production process among these companies, which perform specialized tasks and maintain close relations with each other, either through the market or by establishing cooperation networks (Nájera et al., 2010).

Agents that interact in these subsystems are public and private institutions made up of human beings who work, direct and organize through legislation, norms and social dynamics, so that these institutions or organizations keep different levels of hierarchy in the context of these subsystems. Those subsystems are considered as complex systems because of the amount of parts and interactions inward and outside the system (Simon, 1991).

An important resource for SNI is knowledge, and the most important is the interactive learning process. This means that effective interactions are essential to achieving the goals towards innovation. Therefore, innovation depends largely on the effective transfer of technology and knowledge. This transfer of knowledge is not concerned with the mobilization of technological devices that alone will not generate a benefit to the organization, rather, it is the set of socio-technical among actors interactions transferring tacit and explicit knowledge to increase technological capabilities and generate innovation. Knowledge muts be understood as a process, not as a state, which consists of coherent systems of relationships that connect agents with their world (Gregory, 1993). In the same vein, Foerster (1987) defines knowledge as not residing in the subject or object, but in the dynamic flow between them. The International Encyclopedia of Systems and Cybernetics in turn defines knowledge as that that allows complex systems to support themselves and act (Francois, 2004). In addition you have socio-technical systems that are defined as a combination of the interaction between people and technology (Warfield and Ayiku, 1989). And understood learning as the process of acquiring knowledge and skills through practice, study or information (Francois , 2004). So innovation can be realized if learning is been achieved through an effective process of knowledge transfer, which is itself a process of social interaction that is internal and external to the organization and combines different capacities and organizational resources, constitutes communities of knowledge and articulates different types and forms of knowledge (Cohen y Levinthal, 1990; Nonaka et al, 1999).

From this perspective, innovation is the result of complex processes involving simultaneous, tangible and intangible innovations, and developed through a knowledge network to be operational. In other words, innovation is not generated from the linear formula: basic research + applied research + production + marketing + Marketing = innovation, but rather, innovation is a) a non-linear process that you can not know a priori all the possible exits, b) where the most important resource is knowledge and the most valuable process is learning, c) in which the parts of knowledge is tacit, acquired by interaction, routine and experience, d) in which the skills are distributed unequally among individuals, organizations, regions and nations, and is also a complex, dynamic and multidimensional process (Sauri et al, 2014, Lundvall, 1998; Lundvall and Johnson, 1994). Given the above, it must then innovation besides being a process *per se*, but is also the result of the transformation of a set of components from a less coherent state to a more consistent, unique and dynamic state, ie, has properties as emerging phenomenon which only arises from the interaction between system elements, and only when the components act together, they are likely to emerge innovation, but not when these elements act in isolation. For example, when institutions such as universities generate research products in the form of scientific papers, patents or projects, but these products do not add social value, and they are not introduced to the market, innovation is not concretized. This also means that there must be a dynamic between the elements so that when the system achieves an operational structure in which converge these components only then, the system achieves its goal. This description therefore refers to the property of self-organization, which refers to the ability of a system to build and change their own behavior or internal organization (Varela et al., 1974).

That is why visualize systems as static entities or try to understand them from their results and not from their relations, would not allow understand their structures, which can not be explained by mere aggregation of properties of the elements or organizational types previously achieved by systems, but by the interaction established between system and environment and the elements that constitute them.

From the cybernetic point of view, we must add that the systems have inputs, states and outputs and consequently evolve (Vallée, 1974) and also has feedback, regulations, controls (Wiener, 1948), is endowed with variety (Ashby, 1956), it is autopoiético (Varela et al, 1974) and maintains autonomous relations with their environment or suprasystem (Van Gigch, 1974. Vendryes, 1946).

Innovation Systems as networks

Thus, innovation can be considered as an interactive social process that generates information flows of knowledge for the production, circulation and technological applications that can be useful for organizations but for external agents too (Etzkowitz y Leydesdorff, 2000; Lundvall, 2000; Nonaka et al., 1999; Nowotny et al., 2003; Von Hippel, 2004).

These flows can be observed as network environments for knowledge among the actors involved, whose interactions are facilitated or hindered by three factors: the cognitive proximity, geographical proximity and organizational proximity of innovation agents (Boschma, 2004; Coe y Bunnell, 2003; Ponds et al., 2007).

In this approach of interactivity, multicausality emphasis on the innovation process is done, implying that direct relations between the actors of the system cannot explain by themselves the emergence of innovation as a process or quality. This situation is reinforced by the socially distributed production of information and knowledge in solving problems through the adaptation and application of technological improvements (Gibbons, 2004; Lundvall, 2000; Von Hippel, 2004). In other words, innovation conceived as a process network, focuses its attention on knowledge flows, so that innovation is not a linear concept that is limited to the set of capabilities and production-related artifacts skills (creation technology), but with a heterogeneous body of codified knowledge (explicit) and uncoded (tacit) that combine, apply and distribute in processes of interaction and learning between homogeneous and / or heterogeneous region (companies, universities, technology centers agents , etc.)(Castro et al., 2008). Thus, it is given that innovation refers to a non-deterministic process, and apparently not linear or direct causal link and its parameters do not vary arithmetically, conditions given by the social nature of the agents involved and the socio-technical casually relationships that exist between them. They are adaptive social systems in which humans relate to technological devices to generate adaptive and coevolutionary responses (Banathy, 1995; Bunge, 1993, Francois, 2004).

To analyze these relationships or interactions we used network models (Wasserman & Faust, 1994). A network is a diagrammatic representation of a system (Estrada, 2011) and is in turn a set of nodes (actors, artifacts, agents, etc.) and ties that link all the actors and their attributes (Borgatti and Hangil, 2011; Mitchel, 2009). The positions of nodes and the pattern of links in a network produce a particular structure. Much of the theoretical wealth of network analysis is the characterization of network structures and the positions of the nodes with respect to other nodes (eg, centrality) (Borgatti and Hangil, 2011).

Therefore Theory Network or Network Science is a tool that attempts to describe the behavior of these structures formed by the various relationships that connect them, allowing to state the relevant systemic dimensions (Newman, Barabasi and Watts, 2006).

National Innovation System in Mexico

The methodology of soft systems (SSM: Soft System Methodology), was developed to study complex situations with high human content and can be applied to highly structured systems of human organizations in situations where interaction or systemic structure is unclear or undefined ((Checkland and Poulter 2010).

In the Mexican NIS there are variables of various kinds that can be grouped as: economic, social, infrastructure, policies, education and technology. At the same time, the NIS is immersed in a larger system, consisting of the economic-financial and market policies, determined by the National Development Plan 2012-2018.

It is noteworthy that the variables and factors that are involved in the innovation process between systems arise from relationships between actors and organisations of the same system, but those interactions are kept at an operative distance maybe because the objectives that have each individual actor were not considered or do not match the objectives of a global innovation system.

In these scenario It is possible to assume in advance that in the current situation, the act and the objectives of actors, institutions and organizations that belong to the Mexican NIS not correspond to the objectives which in theory are set for the development of technological innovation in Mexico; however, it is important to clearly define and demonstrate the status of the system to project the changes and improvements needed in the operationalization of an effective Mexican NIS, and that is why the SSM methodology was applied and supplemented with network analysis.

In general terms the current structure of relations in Mexican NIS, appear as relations of conflict between the subsystems and within each of these. The officers involved have fragmented the links and/or collaboration opportunities, in fact, existing relationships within them are due to the forced collaboration between agents in order of the nature for which they were created, for example; government political subsystem, where the link between units is created only for the exchange of information and for reporting statistics, and the same occurs in the system for managing the productive sector. To extend this framework we briefly outlines the background of the formation of NIS in Mexico below.

The history of some agents of the NIS in Mexico dates back to the early twentieth century with the creation of some higher education institutions such as Universidad Nacional Aautónoma de México, the Universidad Michoacana de San Nicolás de Hidalgo and the University of Hidalgo. From 1935 begins a process of institutional building and policy basis for the INS. Later, between 1937 and 1970 the predominant model of economic and social development based on import substitution without including a science and technology policy itself. After 1970 the link between research and development were taken in account, however, the development of scientific and technological activities and the establishment of a minimum base of highly qualified human resources were very limited due to the lack of an overall strategy of science and technology and the allocation of scarce economic resources. With the establishment of more universities like Instituto Politécnico Nacional, the Instituto Tecnológico de Estudios Superiores de Monterrey, among 26 other state universities and other private schools, development of a sector of national public and private companies, as well as the establishment of large transnational corporations, it was constituted a set of critical agents for science and technology. However, this group never acquired systemic features, because as noted, was not the product of a strategic public policy that seeks to turn science and technology into an engine of economic and social development, on the other hand, the impulse to development of these agents was determined by the needs of the industrialization policy associated with the import substitution model that favoured the transfer of technology from developed countries. Thus, the role of agents of science and technology was limited to the training of professionals for the work of business management and development of basic scientific capabilities unrelated to the productive sector. It can be said that in this period, industrial policy defined the characteristics of the agents began to integrate the rising NIS. Thus the SNI in Mexico was born fragmented, without the necessary bridges and canals to allow correspondence and the link between the different agents that comprise (Cimoli, 2000, Dutrenit and Zuñiga, 2003).

On the other hand, in recent years have been implemented or given up some initiatives for the formation, solidification and functionality of the Mexican NIS as the creation of regulatory bodies such as the Consultative Forum on Science and Technology (FCCyT), creation and increase of 0.18% of GDP budget to 0.46% for institutions of science and technology as the National Council of science and technology (CONACYT), the creation of the Special Program of science and technology (PECITI), among others, not yet they have achieved the objectives set in the National development Plan (NDP), which are basically the country to achieve economic and social development for their citizens according to the standards set by international organizations and this is mainly due to the lack of articulation agents that make up the NIS.

More recent data show the consequences of this disarticulated state between agents, which do not ensure efficient functional operation of the subsystems as described below.

The National Innovation Survey (NIE), built by the National Council of Science and Technology (CONACYT), through the National Institute of Statistics and Geography (INEGI) in 2011 shows that Mexican companies mostly seek to innovate to maintain its market share, and own resources are used primarily to make given the difficulty that exists in Mexico to obtain financing, whether public or private, for innovation (Bazdresch and Meza, 2010). According to NIE, the companies that engage in innovation through a research and development department are large production units, no micro survey reported doing some kind of innovation. Another relevant fact is that 2/3 of innovation taking place in the Mexican industrial sector related to the acquisition of machinery and equipment, while only 8% of companies devote part of their resources to research and development of new technologies.

OECD (2011) after analysis of the determinants of successful innovation, has discovered two major barriers affecting Mexico, on the one hand the lack of qualified human resources and secondly, the lack of communication with agents generating knowledge (universities and research institutes).

It is clear that there are many areas of opportunity for science, technology and innovation to contribute to economic development and social welfare in Mexico. International evidence shows that sustained policies from government institutions are needed to strengthen other institutions responsible for these tasks, as usually; directly or by delegation manner, they are ones who carry on the monitoring of innovative processes, and as basic purpose have a fundamental play to design and evaluation of policies on science and technology base. Scientific and technological research is a powerful tool of transformation of a society and is an important factor for the social welfare and development of economy.

Conceptual model of the Mexican Innovation System

The system in question is conceptually constructed as a human activity system which consists of the scientific and technological subsystems, government and productive. These subsystems operate in turn as systems by itself, which are comprised of variables that reflect the dynamic behaviour of innovation as an emergent property resulting from interactions in the system.

When analysed from these three subsystems the conditions and variables that modulate and operate in the context of Mexican innovation system, six relevant systems were identified: a) scientific and technological system, b) Productive system, c) governmental system, d) social system, e) infrastructure system, and f) technological and innovation system. This set of relevant systems also circles on a microeconomic environment governed by the national dynamics and at the same time is influenced by the macroeconomic environment worldwide, both environments have impacts on the final result of the interaction of all variables within each system relevant and relations between them.

Conceptually, each of the relevant systems consists of a number of agents and defined by several variables that result from the interactions within each to generate internal dynamics that add value to the dynamics of the global system. By tracing the interactions, variables associated with these agents need to address the conflict relations found was reflected as these relations of conflict limited the scope of the processes of Mexican NIS, basically is the dismantling of agents within subsystems and between the subsystems.

Because the indicators are different for each relevant system, each scale were assigned because of the particular context, either; geographical, economic, social, political, cultural or technological. Statistical and history, but the measuring instrument, institution or agency responsible, the target indicator, etc. is also considered That is why first, the relevant indicators for each system were identified; subsequently, these indicators were evaluated according to the relevant context to locate the scale; and finally, the level of performance of the systemic dimension was located previously established for each relevant system.

Because the NIS is a socio-technical system that consists of social and artefacts as actors, heterogeneous networks were used due to the combination of agents and studied with mode 2 analysis because each variable has different attributes (Wasserman & Faust, 1994). An analysis of centrality and mediation was applied to find the central nodes on the entire network and point out the centrality of the preponderant nodes. The network density that arises from cohesion given by the effective relationships between actors and between variables also was evaluated and finally, the corresponding interpretations for each system were made.

Conclusions

In the study of innovation systems it is essential to consider that each actor has defined its own goals and interests because the sector to which it belongs or the nature of their activities and no matter whether the scope of each of the actors is bounded to institutional, regional, national or global context. Just as there is diversity in nature and objective of the actors in each subsystem, each subsystem articulated inward as a system generates specific and different from those that may come to be defined for the national innovation system in its entirety goals. Thus, the universe of actors involved in each organization and each subsystem has its own cultural frameworks, values, and philosophical statements. However, it is amazing how this diversity is self-organizing and fed back to be harmonized through the institutionalization of learning and continuous flow of knowledge between stakeholders, whether it done consciously or not.

The methodology used for the operationalization of relevant systems, made possible for us to define the following subsystems: the scientific and technological system, the production system, the government's political system, the social system, infrastructure and technological capabilities and innovation. Including two types of similarities, the first referring to the existence of one or two hubs nodes interrelationships and the second high network connectivity were observed, implying a high density, i.e., high cohesion and synergy between the network elements.

Each actor and system possesses characteristics and objectives, so the network analysis for each subsystem was necessary. For the government political system, the concentrator variable was the Corruption Perceptions Index, which is conceptually terminus antagonizing the process variable. This same variable showed an extremely low intermediation, compared to other nodes, which means that the degree of influence for that system is high, which directly affects performance. In this same subsystem can also be noted that statistically was not possible to establish relationship between the variable of corruption and the index of democracy and freedom to vote, considered important, in this regard, network analysis contributed to the understanding of the dynamics subsystem, the possibility to observe new relationships that arise as emergent properties between variables that showed high connectivity and cohesion.

On the other hand, the revised systemic competitiveness literature highlights the importance of additional factors traditionally considered in competitiveness, such as socio-cultural, political for infrastructure, technology policy, scales of values, etc., all key performance for competitiveness, which varies in each country and is particularly affected by own heterogeneous factors in each region. In this case, it was observed that for Mexico, patterns of socio-political-cultural organization are as important as the technological and budget.

All this allows to verify that the relations of conflict found in the relevant systems are indeed those nonexistent relationships between agents of the subsystems, disruption and progress at different speeds for each system creates disparities that hinder the synergy between actors and artefacts in the Mexican NIS.

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