A Science and Technology Policy Model to Support Regional Innovation Systems*

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Resumen

Los modelos que se desarrollan desde la perspectiva de la dinámica de sistemas se han convertido en un enfoque importante para desarrollar nuevas teorías en las ciencias sociales. Cuando se evalúa la política de ciencia y tecnología, este enfoque permite analizar esta política dentro de la estructura donde se genera la ciencia y la tecnología. El modelo que se discute en esta investigación busca demostrar cómo se pueden generar un conjunto de indicadores de ciencia y tecnología con el objeto de dar soporte al diseño de una política adecuada de ciencia y tecnología a fin de desarrollar actividades innovadoras a un nivel regional. El análisis de la política de ciencia y tecnología desde la perspectiva de los sistemas de innovación provee marco conceptual adecuado para integrar en el mismo análisis instituciones claves encargadas de generar resultados en relación a la ciencia y la tecnología con propósitos de alcanzar mayores niveles de desarrollo económico.

Palabras Clave: sistemas regionales de innovación; política de ciencia y tecnología; dinámica de sistemas.

Abstract

System dynamics models have become an important approach to develop new theories in social sciences. When evaluating science and technology policy, this approach allows analyzing this policy within the structure where science and technology are generated. The model discussed in this research seeks to demonstrate how

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a set of science and technology indicators can be generated to support the design of an appropriate science and technology policy that foster innovation activities at regional level. The analysis of science and technology policy from the perspective of the innovation systems, however, provides an adequate conceptual framework to integrate in the same analysis key institutions in charge of generating science and technology outcomes with economic development purposes.

Keywords: regional innovation systems; science and technology policy; system dynamics.

JEL: O31; O38; C39.

1. Introduction

Simulation models in social sciences are developed to understand the real world (Sawyer, 2004). However, real world phenomena are characterized to be highly complex, and thus system dynamics (SD) models have become an important mechanism to develop new theories in social science (Schwaninger and Grosser, 2008). In relation to science and technology, the value of a simulation model lies in the generation of a structure that combines science and technology within the same process. This idea takes into account the importance of the structure characterizing a system when determining the behavior and relationships where the system operates (relationships between variables) (Morecroft, 2007; Sterman, 2000, Wolstenholme, 1990).

Yet, reliable statistic indicators of science and technology are not always available when defining a science and technology policy. Nevertheless, such policies are needed for science and technology developments and innovation purposes given that the impact they have on economic and social development in a region. At this level of analysis, major limitations are imposed by the availability of timely information when designing an adequate policy for science, technology and innovation. In this paper a simulation model that allows the generation of this type of indicators from the perspective of innovation systems and making use of SD methods. The objective of this paper is twofold. First, it discusses SD modeling as an alternative technique for evaluating science and technology policy to sustain a regional innovation strategy. Second, it shows how SD modeling may allow determining anticipated behavior trends in science and technology indicators under alternative scenarios. Both objectives are achieved simultaneously through defining a set of adequate parameter values that define the behavior of the system model.

The discussion from these objectives is exemplified with a SD simulation model developed in the case of the province of Michoacán in Mexico. The model seeks to capture the structure of innovation that characterizes the production and use of science and technology at the regional level in this province, taking into account the actors involved in this process. However, this research includes in the same analysis several factors that influence and determine the competitive capabilities of local firms through generating and using scientific and technological knowledge that contribute to developing a regional system of innovation. Thus, the analysis of science and technology policy from this perspective provides an adequate framework to integrate into the same analysis key institutions in charge of generating science and technology outcomes that regionally support economic development. On the other hand, this approach allows highlighting the role played by the articulation of competencies and skills as attributes of the research institutions, government agencies, and firms within the system.

The innovation systems approach allows analyzing the behavior of the actors participating in the system, taking into account their strategic direction and underlying mechanisms that individually drive their actions, and govern their interactions with other actors within the system. One of the most important results emerging from this research is that it generates a set of indicators that may contribute to design a science, technology and innovation that increases the competitiveness of firms in a region. In addition to this introduction, this paper contains five sections. Section two discusses some theoretical aspects of regional innovation systems to facilitate the introduction and development of the simulation model in this research. Section three discusses the links between innovation systems and system dynamics. Section four presents the methods derived from the dynamics of systems approach in relation to innovation systems, and the possibility to generate and use science and technology inputs to support regional innovation systems developments. Particularly, the case of the province of Michoacán in discussed in this section. Section five shows the main contributions emerging from the simulation model developed in this research. Finally, section six presents some general conclusions.

2. Innovation Systems

The concept of innovation systems is useful to describe the institutions and links between actors involved in the process of innovation. However, there are many definitions seeking to define more precisely what an innovation system is. However, it would be possible to say that an innovation system comprises the institutions responsible or related to innovation processes that underlie in a production system (Edquist, 1997). In this sense, an innovation system comprises a set of institutions and links that produce, disseminate, and adapt technical knowledge (Edquist, 1997). Indeed, innovation systems companies many actors such as universities, government agencies, and firms where the interrelationships among theme include flows of technological, financial and human resources, as well as tacit knowledge, know-how and regulatory and trade relations (Niosi, 2002). It is worth saying that the institutions making up an innovation system include the set of habits, routines, rules, regulations, and governing relations that shape social interactions (Johnson, 1992). These institutions may include firms, universities, governments and other government agencies responsible for managing and disseminating scientific and technological knowledge flowing within a system of innovation. On the other hand, the flows and links established between the different actors that comprise a system of innovation may include flows between government and private organizations, human flows between universities, companies and public agencies governmental regulations emanating from these agencies with a view to foster innovation processes in organizations, as well as flows of scientific and technological knowledge (externalities) generated from these institutions (Niosi, 2002). Also, the systems of innovation can be seen on an industrial scale, local, regional, national or international. It is also important to say that not only the creation of knowledge is important to define a system of innovtion, but the flow of this knowledge among firms, and the aptitude to absorb and transfer this knowledge (Feria and Hidalgo, 2011). In this sense, it is very important to stress the importance of knowledge production and knowledge diffusion to define systems of innovation (Lundvall, 1992; Nelson, 1993; Etzkowitz and Leydesdorff, 1997).

Nowadays, there is a great interest and acceptance among academics and public policy makers to analyze systems of innovation from a systemic perspective (Niosi, 2008; Solleiro and Castanon, 2005; Stamboulis, 2007). This systemic approach of innovation systems allows including as part of the same analysis several factors that influence and determine the competitive capabilities of firms in a region. Actually, the generation and use of scientific and technological knowledge involves different actors and established networks that shape and help to determine a system of innovation. In practice, these actors may or may not be geographically close, allowing this fact to acquire stronger or weaker networks. The point to stress here is that the systemic approach is seen as an appropriate theoretical framework in the analysis of the characteristics that define an innovation system.

Finally, it is worth saying that the concept of innovation systems has evolved as a tool to analyze the process of regional economic development. In this sense, the analysis of systems of innovation has shifted from national to regional and sector levels. At different levels of analysis, innovation systems as an important tool study economic development allows characterizing the economic structure of a country or a region in that only a few sectors are really innovative (Niosi, 2008).

3. Innovation Systems and System Dynamics

Simulation models are developed in the social sciences based on the idea that they contribute to understand the real world (Sawyer, 2004). Indeed, the construction and development of models based on system dynamics principles has become a mechanism to developing new theories (Schwaninger and Grosser, 2008). The model discussed in this paper aims to combining the generation and use of science and technology within the structure where these processes are carried out in order to develop innovations. This idea is widely accepted by several authors that point out the importance of the structure of a system when determining the behavior and relationships among the actors of the system (Morecroft, 2007; Sterman, 2000; Wolstenholme, 1990).

Modeling system dynamics models may allow establishing the causes and effects between variables that define their behavior (Gilbert, 2008). The main idea underlying modeling under the perspective of system dynamics methods is based on the simultaneous evaluation of a set of differential equations that estimate the values of a variable at any time (Gilbert, 2008). The models built under the system dynamics approach, it is assumed that they are characterized by a series of feedback loops and delays featuring the system. Under this approach, it is important to understand the basic concepts that make up a system (Pidd, 2009): 1) resources and information, and 2) levels and rates. The difference between resources and information is essential when building a model from the perspective of system dynamics. Resources should be understood as "physical objects" that become part of the processes in a system. In turn, these resources can be classified as consumable resources and non-consumable resources. On the other hand, the levels (stocks) and rates (flows) are two concepts focusing on the dynamics of systems (Pidd, 2009).

In this research, we assume as a regional innovation system the actors and their interrelationships within the province of Michoacán as they may contribute to the activities within the same system of innovation. In this sense, from a general perspective, the methods derived from the systems dynamics approach provide insights on the underlying structure that characterizes this system of innovation. Moreover, this approach allows distinguishing the different possibilities that may exist in terms of the strategic direction and underlying mechanisms that drive from alternative actions that govern the interactions between agents in the system (Stamboulis, 2007). Thus, a simulation model that is built from the perspective of system dynamics methods should contain a set of feedback loops that relate causes and effects to explain how actors are interrelated, as well as the nature of these interrelationships.

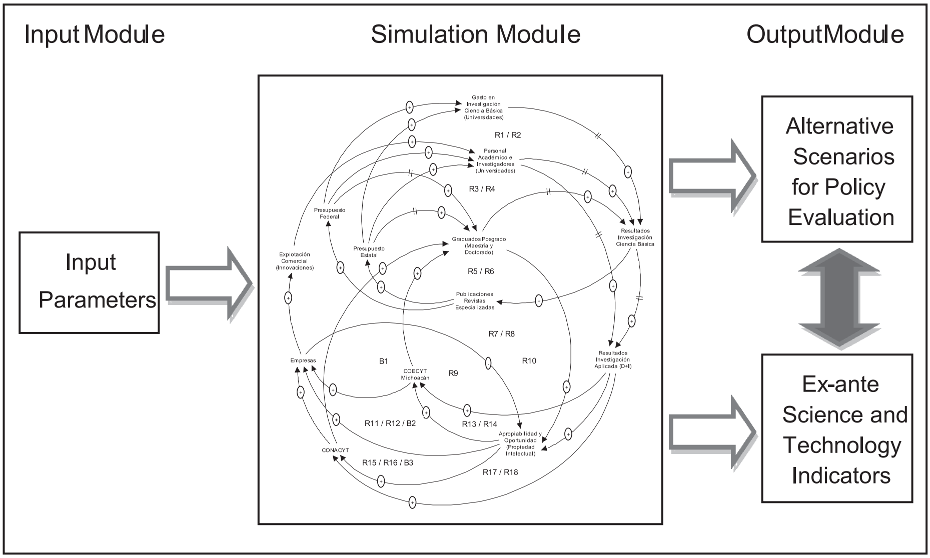
As it is known, there are two different types of loops: positive or reinforcing loops, and negative or balancing loops. Reinforcing loops can be understood as a change that is reinforced by generating major changes, while a balancing loop should be understood as a force which seeks a target (Kirkwood 1998). On the other hand, models that are built under the system dynamics approach can be understood as complex systems with a high degree of uncertainty. In practice, these two features characterizing the models of innovation systems suggest that they are constantly evolving, nonlinear, historically dependent, self-regulating, adaptive and counterintuitive, and characterized by being resistant to policy.

4. Science and Technology in Michoacán

This section describes the main features that characterize a model of science and technology in the province of Michoacán from the perspective of regional innovation systems. This analysis allows understanding more precisely the interactions that exist between the different actors that create and use science and technology in this province that in turn allows understanding the results of the evaluation of alternative public policies for promoting science and technology in order to establish an innovative regional economy. In addition, this section contains the causal loop diagram that conceptually explains the system of innovation in this province. An innovation system includes all organizations and institutions such as higher education institutions, universities, government agencies in charge of science and technology, as well as firms involved in generating and exploiting new knowledge to enhance competitive capabilities in the economy or region. In this sense, the analysis of science and technology policy from the perspective of innovation systems provides an adequate conceptual framework to integrate in the same analysis key institutions that generate science and technology with economic development purposes (Niosi, 2008). Thus, there are several approaches from the theoretical perspective of innovation systems revealing the dynamics of the relationships established between the actors that make up the systems.

Figure 1

Science and Technology Policy and Regional Innovation Strategy



In the case of the province of Michoacán, the objective is to determine the boundaries of the innovation system regarding the actors and their actions that flow in the process of generation and use of science and technology. In the case of this province, each actor must be analyzed from a perspective consistent with the role that they play in the process of generation and use of science and technology for the purpose of achieving higher levels of economic development and quality of life for people. However, from the perspective of the system dynamics methods, we aim to explain the role played by the articulation of competencies and skills as attributes of the companies within this system that in turn shapes the system (Stamboulis, 2007). In this sense, system dynamics support the analysis of the behavior of these actors taking into account their strategic direction and underlying mechanisms that drive their actions individually and govern their interactions with other actors (Stamboulis, 2007). Figure1 shows the case of the innovation system involving different actors who use science and technology in Michoacán.

The diagram that explains the production and use of science and technology in Michoacán contains eighteen positive or reinforcing loops, and three negative or balancing loops. The loop R1 explains how the results from basic science and research expenditure drawn at universities are generated after a time delay. This model assumes that the time delay is an average period of two years. Once basic science and research results have been obtained, they can be alternatively published in academic journals, or transferred to be developed as applied research. When basic research results are published in academic journals, there is a positive impact on the province budget to finance other research projects and generating a greater spending on basic research. The loop R2 explains these relationships, but emphasizing the positive impact of basic research results taking into account the federal budget to funding new grants for research projects.

The loop R3 explains how the staff of researchers involved in obtaining basic research results at universities may also develop applied research projects with a time delay. This loop explains how the results drawn from these researches could be promising in terms of opportunity and appropriability. However, these projects may be supported by government agencies in charge of managing science and technology programs, such as CONACYT or COECYT. Actually, these agencies evaluate the results of these projects for possible commercial exploitation, a fact which means additional support for academic staff and researchers at universities. In the same way, the loop R4 also explains the involvement of researchers and academics at universities in obtaining applied research results. The loop R5, as in the case of the loops R3 and R4, reflects the relationship between research findings in basic science and applied research results, but involving graduate students from doctoral programs. The loop R5 also contains two time delays: (1) the average time needed for obtaining basic research results (two years), and (2) the average time needed for obtaining applied research results (one year).

The loop R6 explains how graduate students are involved in publishing basic research results. An important feature characterizing this loop is that when the academic productivity of graduate students increases, this would incentive grants COECYT and CONACYT. The loops R7 and R8 show the inclusion of graduate students in generating applied research results that evaluated appropiability. This loop shows the inclusion of graduated studients on projects for developing and adopting new technologies. The loop R7 includes the evaluation by COECYT of processing and supporting research results as innovations. The loop R8 takes this same than in the loop R7, but taking into account the programs supported by CONACYT.

The loop R9 shows the relationship between applied research expenditure and the budget to financing graduate students by means of programs established by COECYT. The loop R10 takes into account the fact that many research results of applied research projects are generated as innovations from research programs arising from initiatives coming out the industry. The loops R11 and R12 extend the above concepts in the sense that once the results of basic research projects are generated, firms may develop new innovations for commercial exploitation by creating incentives for academic staff and researchers at universities. In practice, the meaning of this process can go directly from academics and researchers towards applied research results, loop R11, or through applied research, loop R12. In both cases there is a time delay when generating basic research results and applied research projects. The same relationship between academics and researchers, basic research results, applied research projects and firms can also be mediated through some government agencies in order to accelerate the process of generating a great number of innovations to the market. This is the case of the loops R13 and R14 with COECYT.

The loops R15 and R16 reflect the processes of university-industry technology transfer for innovation and commercial exploitation purpose. These loops explains the flow of knowledge generated at universities, academic staff and researchers support, results of basic research and applied research, assessing the degree of opportunity and appropiability by COECYT. The loops R17 and R18 reflect these relationships through CONACYT evaluation. Finally, the balancing loop B1 shows that when an innovation is not ready for the market, firms seek to gain a greater degree of appropriability through the generation and use of some kind of intellectual property, such as patents. In practice, the use of intellectual property becomes a mechanism by which a company guarantees to obtain economic rents to recover costs when developing innovations. Often, this process involves the support of some government agencies in order to facilitate the process of technology transfer from universities to industry, such as the case of COECYT. In other cases, the process of technology transfer goes directly from universities to industry. In these cases, re-evaluation of the degree of appropiability of new technologies is an important issue. This is precisely what explains the balancing loop B2 that essentially explains the same processes that in the case of the loop B1. In the case of the balancing loop B3, it is the same idea that in the case of the loop B1, but involving CONACYT as government agency in charge of assessing the degree of appropiability.

The model consists of 111 variables: 21 variables or stock level, 56 flows and 34 parameters. These variables allow generating a set of indicators related to scientific and technological activity undertaken by universities, businesses, and federal and province government agencies. Model validation and calibration was carried out taking into account information generated by federal and province government agencies in charge of science and technology activities. In this sense, the indicators presented in this paper are an example on how useful the model could be for policy designing. The main indicators are: publications, number of researchers, researchers in the national researchers system, basic research results, applied research results, innovations, innovative projects funding, total citations, publications, among others.

The results presented correspond to the years 2008, 2010 and 2015. This exercise seeks to demonstrate how this model can be used to design and evaluate an appropriate science, technology and innovation policy. In this regard, it is worth saying that the simulation model of science, technology and innovation developed in this research allows simulating and evaluating alternative science, technology, and innovation policies.

5. Simulation Results

As already stated, the most important indicators generated by the model are the following: publications, number of researchers, number of researchers in the national research system, basic research results, total quotes, average quotes, applied research, innovation projects. These results were simulated to the years 2008, 2010, and 2015 (Table 1):

Table 1

Model Simulation Results

Year	Publications	Researchers	NRS	NRS/Researchers	Basic Research	Applied Research	Innov.	Total Quotes	Avg. Quotes
2008	95	508	413	0.812	236	31	19	291	3.08
2010	151	517	437	0.845	260	43	29	416	2.75
2015	243	539	504	0.934	391	73	44	689	2.84

These results show the behavior of selected variables in the process of the generation and use of science and technology in the province of Michoacán. This simulation captures the conditions and structure where the innovation process is carried out in this province. However, this model can generate a greater number of indicators, as well as their behavior.

6. Conclusions

This paper discusses the possibility of developing appropriate indicators for supporting the design of the science, technology and innovation policy. The generation of such indicators is performed using the methods derived from system dynamics. The behavior of these indicators reflects the structure of the innovation system characterizing the generation and use of science and technology in this province of Mexico. In this sense, this structure is determined by the actors involved in these processes, as well as the relationships established between them. A scheme of this nature allows a priori evaluate alternative public policies that seek to foster the generation of scientific and technological advances and their application to promote and develop innovations to market.

Although the number of indicators simulated in this model is quite large, this paper only presents a few of them that can be compared to official statistics. In fact, the historical series of these indicators may serve to validate and calibrate the model. Further research should include the possibility to include detail behavior of some actors, resulting in higher quality indicators. On the other hand, it is possible to construct a model of science, technology and innovation model at national level, which would be useful to support and evaluate public policies under alternative scenarios.

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