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The impact of innovation policies on the performance of national innovation systems: A system dynamics analysis

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ABSTRACT

There has been a growing significance for the National Innovation System (NIS) and its use as a tool for the competitive advantage of a country to date. In this paper, an NIS model has been developed with the use of system dynamics (SD) methodological approach. The objective of this model is to integrate the systemic approach, the computer modelling and the simulation discipline into a holistic dynamic consideration of the NIS. From this central structure, the paper analyzes the impact of innovation policies on the NIS performance. In particular the SD model is used as an "experimental tool" to conduct extensive what-if analysis scenarios with regard to alternative innovation policies. The effectiveness of policies is investigated through the dynamic behaviour of product innovation and process innovation which are obtained by simulation results. By using data from a European Union country with innovation performance below that of the EU27 average, the analysis of results reveals insights over a strategic time horizon.

1. Introduction

Innovation is a complex phenomenon involving the production, diffusion and translation of technological knowledge into new products or new processes. The concept of innovation has undergone several transformations due to the evolution of models aiming at better understanding of the innovation process (Rothwell, 1997). After the Second World War the linear model was the generally accepted model. In this model, new technology begins with basic research and advances through applied research, invention, commercial market test, and is eventually led to diffusion. Innovations are seen as the end result of a linear process that consists of different steps performed in a sequential, hierarchical, and unidirectional order. Later on, Kline and Rosenberg (1986) mentioned the conversion from the linearity of the innovation process to its dynamic-systemic behavior. The innovation process involves interactive relations among different actors, it follows a non linear path and is characterised by complicated feedback mechanisms (Kline and Rosenberg, 1986; Edquist, 1997).

The systemic approach to innovation is grounded on the presumption that innovation processes cannot be decomposed into several isolated phases that take place in a strictly proceeding sequence. The growing relevance of the interactive, collaborative and inter-disciplinary character of innovation, together with the rejection and obsolescence of linear innovation processes has been described as the transition from mode 1 to mode 2 processes in the creation of knowledge (Gibbons et al., 1994) and from 'close' to 'open' innovation in the field of exploration and exploitation of innovation (Huizingh, 2011; Chesbrough, 2003). Ultimately, this perspective of innovative processes serves as a valuable starting point for the definition and empirical application of the innovation systems approach in general (Balzat, 2006). It also constitutes the foundation for the National Innovation System (NIS) approach, in particular if the distinctive national content and dimension of innovative processes and of institutional settings are considered. In the last decade, NIS is the most frequently used approach to understand the complex relations that constitute the innovation process (Carlsson et al., 2002).

An NIS can be described as the set of institutions, which jointly and individually contribute to the development and diffusion of new technologies and which provide the framework, within which governments form and implement policies to influence the innovation process (Metcalfe, 1995). From this perspective, the innovative performance of an economy depends not only on how the individual institutions perform in isolation, but on how they interact with each other as elements of a collective system of

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knowledge creation and use (Rycroft and Kash, 2004; Calia et al., 2007), which is subject to dynamic processes (Smith, 2001). Understanding these dynamics is one of the central topics in the studies of NIS, mainly under macroeconomic concept. Yet, the concept calls for a decomposition into different elements because of manifold activities which are carried out by different type of actors within an NIS. The NIS approach stresses that understanding the linkages among the actors involved in the innovation process is the key to improve innovative performance of a country (Lundvall, 1992; Nelson, 1993). Under this perspective, the innovation process is the result of a complex set of relationships among actors which are producing, distributing and applying various types of knowledge—tangible and intangible. Innovative performance, however, relies more frequently on intangible assets as the economy moves to specialised non-repetitious activities (Kramer et al., 2011).

NIS concept has emphasised the importance of systemic co-operation in innovation processes. NISs have already been analysed for different countries resulting thus in a rich sample of variety of participating institutions and organisations and their networks of interrelations (Lundvall, 1992; Nelson, 1993). Additionally, empirical research underlines the differences and functional equivalents between countries in the organisational configuration of an NIS and its impact on a country's economic performance (Nelson, 1993; Lundvall, 1992; Harding, 2003) and vice versa (Filippetti and Archibugi, 2011). Despite the systemic nature of innovation, the non-linearity of processes has been identified as a realistic concept of innovation as well (Kline and Rosenberg, 1986). This non-linearity directs attention to the interaction of the actors in an NIS, since it involves communication and feedback. An example of these complicated feedback mechanisms is presented in Fig. 1. In particular, the causal loop diagram shown in figure, presents the working mechanism for *Research Activities*, a variable of special interest for many empirical studies dealing with national innovative strength (Archibugi and Michie, 1995). The diagram consists of two negative feedback mechanisms, Loop 1 and Loop 2. In Loop 1, the actual level of *Research Activities* is influenced by *Research Activities' Increasing Rate*; the higher the rate is, the higher the *Research Activities* become. However, high levels of actual *Research Activities*, limit the increasing rate in producing new activities due to saturation phenomena (negative influence). On the other hand, the literature review proposes the expenditures on R&D activities as a basic indicator of innovative input in imprinting the research activities of an NIS' actors (Martínez-Román et al., 2011; European Innovation Scoreboard, 2008 and 2009). Loop 2 shows this dependency; *Available Expenditures in R&D* increase when *New Expenditures* increase, but again saturation phenomena limit the rate of increase of new expenditures, creating the negative Loop 2. *Available Expenditures* in R&D then positively influence *Research Activities Formation Rate* which, in its turn, shapes *Research Activities' Rate*.

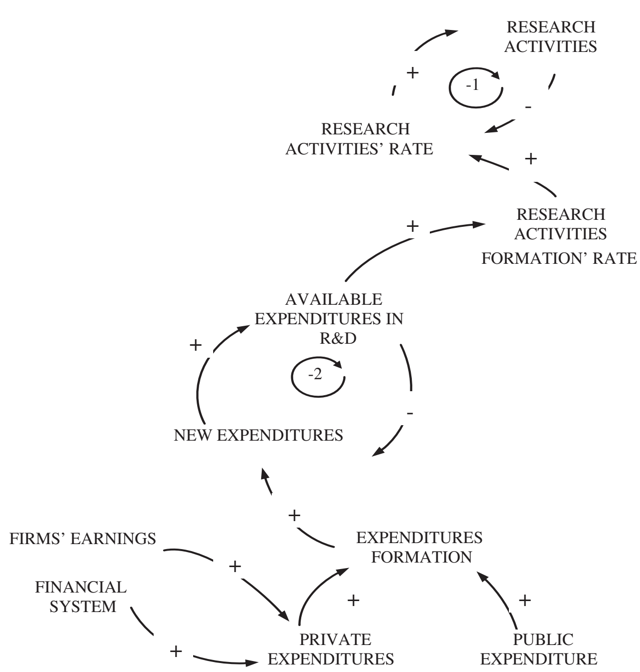

Fig. 1. Causal loop diagram of research activities.

In early 1990s, many studies have been carried out by using the NIS approach as an analytical frame, in order to reveal the structure of national innovation processes and the main involved actors. These studies can be listed in three categories. The first category contains policy-oriented studies that combine the NIS approach with the terminology of corporate benchmarking. A collection of these studies can be found in Nelson (1993). The early and descriptive studies have not been aimed at providing a formalized methodology or a clearly delineated structure of the NIS concept. These limitations have simulated research efforts to carry out system-level comparisons as well as to formalize the NIS concept. These efforts have led to the introduction of descriptive frameworks and to the development of analytical models. The studies of the second category focused to develop models to carry out international comparisons of innovative strength (Liu and White, 2001; Chang and Shih, 2004; Marklund et al., 2004). Cluster analysis techniques and factor analysis methods constitute the main methodological approaches used in these studies. The third category of studies is related with the mathematical modelling of NIS (Janszen and Degenaars, 1997; Lee and Tunzelmann, 2005). Mathematical models from one hand can provide significant insights about the dynamics of the innovation process and from the other hand can be tools to study the impact of innovative policies on the performance of an NIS. However, the limited number of such models is remarkable and more importantly, there are still interactions that have not been studied providing thus, only information for likely directions for future research. Towards to this direction, the need for holistic dynamic mathematical models which can be used as a tool to describe and to analyze the complex and dynamic nature of NISs is obvious.

The contribution of our research is two-fold. First, we provide a holistic modelling approach to the NIS concept, in order to reveal the functions of its actors and the mechanisms which lead to the innovative performance of a country. The modelling approach is based on the system dynamics (SD) theory and constitutes a tool for the analysis of relations between the actors of an NIS as well as the dynamic study of the innovative performance. Second, we investigate the impact of innovation policies on the NIS's performance by studying the case of Greece. In particular, the developed SD model is used as an "experimental tool" to conduct dynamic what-if analyses, which aim to investigate the effectiveness of innovation policies on the performance of innovative actions at a national level. Extensive simulation results exhibit the dynamic behaviour of product innovation and process innovation for a time horizon of ten years. The observations obtained by the results are organized under alternative scenarios with regard to innovation policies and reveal insights for the innovative performance of Greece. According to the European Innovation Scoreboard (European Innovation Scoreboard (EIS), 2008), the current level of innovation performance of Greece is ranked under the group of "moderate" innovators. Consequently, the observations obtained for the case