



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

Elpida Samara^{a,*}, Patroklos Georgiadis^{b,1}, Ioannis Bakouros^{c,2}

^a University of Western Macedonia, Department of Mechanical Engineering, Mater Lab, Kozani 50100, Greece

^b Aristotle University of Thessaloniki, Department of Mechanical Engineering, Thessaloniki, Greece

^c University of Western Macedonia, Department of Mechanical Engineering Mater Lab, Kozani 50100, Greece

ARTICLE INFO

Available online 17 July 2012

Keywords:

National innovation system
Innovation process
Systems modelling
System dynamics

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.

© 2012 Elsevier Ltd. All rights reserved.

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 (Metcalf, 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

* Corresponding author. Tel.: +00302463024846.

E-mail addresses: esamara@uowm.gr (E. Samara), geopat@auth.gr (P. Georgiadis), ylb@uowm.gr (I. Bakouros).

¹ Tel.: +302310996046.

² Tel.: +302461056660.

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*.

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

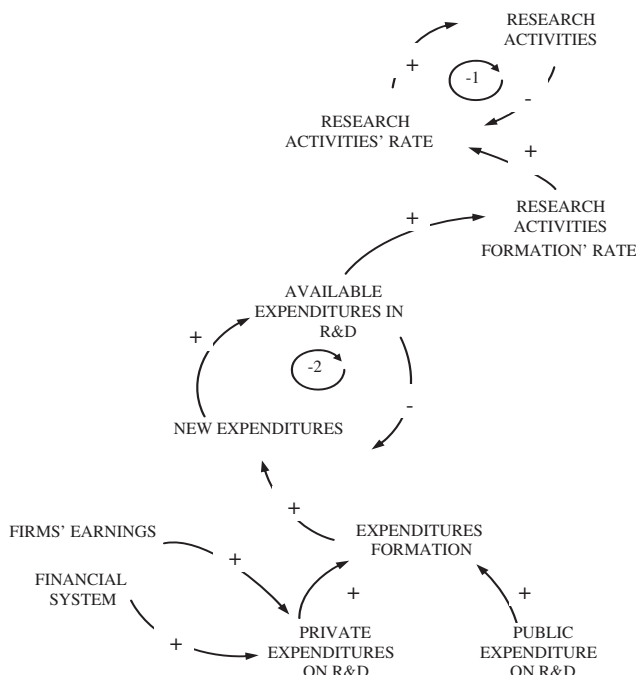


Fig. 1. Causal loop diagram of research activities.

of Greece can be generalized at least as likely directions for the rest of European Union countries which belong to the group of “moderate” innovators (like Cyprus, Estonia, Slovenia, Portugal).

The SD model is based on the basic beginnings introduced by Lee and Tunzelmann (2005). This work is one of the first SD-based NISs which study the interactions between its structural elements. However, the absence of governmental macroeconomic policy and governmental legal and financial systems are important limitations of the proposed model. In our modelling approach, the boundaries of the NIS are expanded constituting macroeconomic conditions and financial system as additional structural elements of the system. With regard to innovation process, our study is based on the product-process life cycle theory of Utterback and Abernathy (1975). The Utterback and Abernathy approach succeeds in encompassing the mutual relationships between the stages of a product's life cycle, the related production process' stages of development and competitive strategy. Using this approach, Milling and Stumpfe (2000) developed a simplified SD model that portrays the relation between product and process innovation but they define the R&D capacity exogenously. The endogenous definition of R&D capacity is an additional innovative element of our modelling approach.

The rest of the paper is organized as follows. Section 2 presents the systemic perception of the innovation process. Section 3 provides the generic structure of NIS, while the modelling of the innovation process is given in details in Section 4. In particular Section 4 contains the causal loop diagram, the mathematical formulation, the structural validity, the initial conditions and the units of measurement. Based on simulation results, Section 5 provides the innovative performance of Greece for a period of 10 years under what-if scenario analysis with regard to innovation policies. Finally, Section 6 provides a brief summary and potential future research aspects.

2. The systemic perception of innovation processes

There is a prevailing consensus among innovation theory scholars that a systems' approach to understand the dynamics of innovation is more realistic and provides a more useful policy guide than the linear innovation model (Carlsson et al., 2002). The adoption of the linear concept of innovation could lead to the conclusion that high investments in R&D would have positive consequences in productivity and growth. However, during the 70s and 80s, the emergence of new and important technologies was followed by a reduction of productivity in the majority of the OECD countries (OECD, 1991: 77). The apparent contradiction between these facts was known as the productivity paradox.

The systemic approach to innovation was initiated with the “chain-linked” model of Kline and Rosenberg (1986) and broadened and deepened by the NIS approach. Kline and Rosenberg (1986) argue that the linear model distorts the nature of the innovation process in several ways, especially because it considers R&D as the only source of innovation and since it ignores important feedback loops and interactions among the distinct stages of the process. Later, Abrunhosa (2003) justifies the innovation as a complex process where there is interaction between firms and organisations of education/scientific/technological system, and where innovative activities influence and are influenced by the market.

The systemic perception of NIS results in innovations as the outcome of the involved actors' actions and relations/interactions with each other (Abrunhosa, 2003). Through these interactions technologies, products (in which these technologies are embodied), markets, industries and supporting public and private institutions co-evolve (Levinthal and Myatt, 1994; Nelson, 1995). Co-evolution is

caused by the existence of positive and negative feedback mechanisms that link the development of technologies, products and markets to the development of industries and supporting institutions (Andersen and Lundvall, 1988; Arthur, 1994). However, these institutions may also delay the development of new technology-product-market combinations because of time delays in the decision making process and lock-in effects.

The existence of numerous positive and negative feedback loops in combination with significant time delays in decision making process and needed actions/activities, describes the non-linear dynamic behaviour of the innovation systems, making extrapolation of trends hazardous and prediction of the outcome impossible. As such, innovation systems can be considered to be complex systems, which Nicolis and Prigogine (1994) describe as “... systems that share the common feature to exhibit a great variety of behaviours”. On other hand, innovation systems are social systems because they are made by social actors namely, institutions and organisations (Johnson, 1997). As such, they constitute sets of habits, practices and rules for participating social actors. The nature of social systems is dynamic and open to external interaction (Lundvall, 1992); they can grow and can be modified by the context in which they operate in an irreversible way. Partnerships between organisations are influenced by endogenous factors such as commitment, social norms, power and exogenous factors such as information asymmetry and opportunism (Eng and Wong, 2006). However, in order to keep the cohesion of social systems, they must have a certain degree of internal coherence which must be higher than the respective degree of external environment. Given that social systems are influenced in an irreversible way by the external reality, innovation systems are path-dependent, namely, they are the results of the local socio-economic history (Johnson, 1997).

The complex and social nature of NISs justifies the SD methodological approach as an appropriate method for modelling the innovation process and studying the dynamic behaviour under what-if analysis scenarios. SD originated in the early 1960s and was pioneered by Forrester (1961), Forrester and Senge (1980). The SD philosophy rests on a belief that the behaviour (or time history) of an organization is principally caused by the organization's structure. A second aspect of this philosophy is the concept that organizations are viewed most effectively in terms of their common underlying flows instead of in terms of separate functions. According to Coyle (1996), “*System Dynamics deals with the time-dependent behaviour of managed systems with the aim of describing the system and understanding, through qualitative and quantitative models, how information feedback governs its behaviour, and designing robust information feedback structures and control policies through simulation and optimisation*”. SD is grounded in the theories of linear/nonlinear dynamics and feedback control. The literature suggests SD as a well-documented methodological approach for studying the dynamic behaviour of complex systems. In SD terminology, a ‘complex system’ is defined as “a high-order, multiple-loop, nonlinear feedback structure”. The dynamic behaviour of the system arises from the interactions among the agents over time. The dynamic complexity arises because systems are dynamic, tightly coupled, governed by feedback, nonlinear, history-dependent, self-organizing, adaptive, counter-intuitive, policy-resistant, and characterized by trade-offs (Stermann, 2000). Through analysing the processes of information feedback in the internal environment and by computer simulation, SD methodological approach shows how structure, policies, decisions and time delays within organizations and business systems are interrelated and influence growth and stability (Lee and Tunzelmann, 2005). Policies affect the dynamic behaviour of systems through the actions over time. Actions are the output of the way in which the management responds to close the gaps

combination of knowledge, dexterities, record and faculty of a nation's individuals so that they face the challenges, influenced from the values, the culture and their philosophy" (OECD, 2001). According to empiric studies of Galende and Suarez (1999) and Martinez-Ros and Salas (1999), it was observed that human capital positively influences the innovation process. According to Porter (1990), knowledge capital is defined as the reserve of a country in scientific, technological and general knowledge which is found in universities, governmental research institutions, private research centres, scientific bibliography and data bases. It is in general acceptable that the countries that allocate rich knowledge capital have better records in levels of innovative growth (Malhotra, 2003). In the present subsystem we measure the level of faculty and creation of scientific, technological and general knowledge which influence the function itself and the performance of an NIS. Moreover, we measure the quality of the educational system or the educational level of the workforce, factors aimed at pointing towards the future inventiveness of an NIS. R&D capacity is positively depended on the availability of suitable knowledge and human capital.

With regard to *Research Activities*, we focus in the roles that companies, universities, research institutes and the government of a country play for the configuration of research activities. R&D expenditure constitutes basic indicators of innovative input for the imprinting research activities of an NIS's actors (CIS, Frascati Manual). In addition, strongly positive correlations between R&D expenditure and output measures of innovative action have been detected empirically (European Innovation Scoreboard (EIS), 2009). Research activities increase the R&D capacity.

As far as *Market Conditions* are concerned, literature suggests that the larger the national market is (in terms of overall extension, affluence and sophistication) the greater will be the market opportunities for firms to produce and innovate (Godinho et al., 2004). Another important element, in such a view of market and demand conditions, is the way that consumers are spread in the national space. A territory with low population density will be much more difficult to serve than one where the population is more densely distributed (Godinho et al., 2004). Moreover, the companies innovate more in a market open to international flows

The diagram illustrates the innovation process as a complex system of interconnected components. At the top, 'Institutional Conditions' and 'Technological Performance' are shown. Below them, 'Research Activities' and 'Product Innovation' are key nodes. A dashed box encloses the core innovation process, which includes 'R&D Capacity', 'Product I. Rate', 'Desired Product I.', 'Desired Process I.', 'Process Innovation', 'Process I. Rate', 'Expenditure on R&D', 'Product Attractiveness', 'Prices', 'Production Capacity', 'Market Share', 'Sales', and 'Revenues'. 'Knowledge and Human Resources' and 'Market Conditions' are shown at the bottom, influencing the process. Arrows indicate the flow of influence and feedback loops between these components.

Fig. 2. The generic structure of NIS.

of goods, investments, persons and ideas (OECD, 1999). Finally, to a large extent, general macroeconomic conditions determine the general business climate, which, in turn, influences the innovation climate in national innovation systems (Van der Steen, 1999). There are several links between general macroeconomic conditions and innovation incentives. Three major links of such types are public deficits, inflation and interest rates. The market conditions influence indirectly the financial system and directly the R&D capacity.

The interdependence of national institutional settings and innovative activities at the national level lies at the centre of the NIS approach (Balzat, 2006). The objective of the *Institutional Conditions* subsystem is to evaluate national institutional framework conditions by means of taxation policies and regulatory framework (Samara et al., 2010). Taxation policy constitutes one of the basic incentives for R&D activities (Innovation Framework Report, 2004). Moreover, a fundamental role of the governments is the configuration of regulations and legislation via which a nation's innovative activity is influenced (Porter, 1990). The governments, in this way, create substantially the activation motives for innovative activities, influence all institutions of the NIS (companies, universities, research institutions etc) and the relations and interactions between them. In general, they shape the frame for the creation and development of research activities (Balzat and Pyka, 2005).

The *Financial System* of a country combines as many sources of finance as possible. We consider that elements of *Financial System* which significantly effect innovation growth are the national capitalized market development and soundness of banks, the level of main public expenses for R&D indicated by the interest-rates and the availability of venture capital which contributes in the configuration of R&D expenditures of companies (Tylecote, 1994). Other important elements are the financing of national programs or the attendance in international programs. The evaluation of the above mentioned elements can characterize the level of economic system's maturity which can support innovation at a national level.

With regard to *Technological Performance* subsystem, European Innovation Scoreboard (European Innovation Scoreboard (EIS), 2008) suggests that innovation outputs include two dimensions: (i) applications, which measure the performance, expressed in terms of labour and business activities, and their value added in innovative sectors; (ii) intellectual property, which measures the achieved results in terms of successful know-how.

Finally the subsystem *Innovation Process* constitutes the subsystem under study of this research and it is presented in details in the following section.

4. The innovation process modelling

Innovations are differentiated in various types; social, organizational, administrative or technical, incremental or fundamental, product or process (Jost et al., 2005). In this paper we examine the last two types, namely product and process innovations of companies. Scientific literature in many cases focuses either on product innovation or on process innovation, without explicitly considering the existing interactions between them. As mentioned, in our modelling approach the product/process innovation is based on the Utterback and Abernathy (1975) and Milling and Stumpfe (2000) models considering endogenous R&D capacity.

4.1. Causal loop diagram

The structure of a SD model contains stock (state) and flow (rate) variables. Stock variables are the accumulations within the

system. The flow variables represent the flows in the system, which result from the decision-making process. The behavior of a system is obtained by the evolution of state variables. Although delays exist in all flow variables, only the significant ones (compared with the simulation time step) are included in the model because they considerably affect the system's behavior (Sterman, 2000).

The structure of a system in SD methodology is captured by causal loop diagrams. A causal loop diagram represents the major feedback mechanisms. These mechanisms are either negative feedback (balancing) or positive feedback (reinforcing) loops. A negative feedback loop exhibits goal-seeking behavior: after a disturbance, the system seeks to return to an equilibrium situation. In a positive feedback loop an initial disturbance leads to further change, suggesting the presence of an unstable equilibrium. Causal loop diagrams play two important roles in SD methodology. First, during model development, they serve as preliminary sketches of causal hypotheses and secondly, they can simplify the representation of a model. The arrows represent the relations among variables. The direction of the influence lines displays the direction of the effect. The sign “+” or “−” at the upper end of the influence lines exhibits the sign of the effect. A “+” sign dictates that the variables change in the same direction; a “−” sign dictates the opposite.

Fig. 3 illustrates the causal-loop diagram of the innovation process. To improve appearance and distinction among the variables, stock variables are written in capital letters and the flow variables are written in small letters. The diagram consists from three positive feedback loops. The first loop L1 (*Product Innovation, Desired Process Innovation, Process Innovation, Desired Product Innovation, Product Innovation*), shows the relation between product and process innovation. It describes that more process innovation leads to the increase of pressure for desired product innovation and the increase in product innovation increases the need for desired process innovation.

The second loop L2 (*R&D Capacity, Product Innovation Rate, Product Innovation, Product Attractiveness, Market Share, Sales, Revenues, Expenditure on R&D, R&D Capacity*), shows that an increase in R&D capacity leads to high rates of product innovation that leads to higher innovator performance (product and process innovation). Higher product innovation results in an increase in product attractiveness which increases the market share and sales leading to increased profits. Increased profits lead to high investments in R&D that improve the capacity for R&D.

In the same way, the third loop L3 (*R&D Capacity, Process Innovation Rate, Process Innovation, Production Capacity, Price, Product Attractiveness, Market Share, Sales, Revenues, Expenditure on R&D, R&D Capacity*), shows the positive influence on R&D Capacity via process innovation.

4.2. Mathematical formulation

The next step of SD methodology includes the development of the mathematical model, usually presented as a stock-flow diagram that captures the model structure and the interrelationships among the variables. The stock-flow diagram is easily translated to a system of differential equations, which is then solved via simulation. Nowadays, high-level graphical simulation programs (such as *i-think*[®], *Powersim*[®], *Vensim*[®], and *Stella*[®]) support such an analysis (Galanakis, 2005).

The stock-flow diagram of innovation process subsystem, which has been developed using the *Powersim*[®] 2.5c software, is exhibited in Fig. 4. The diagram is constructed using building blocks (variables) categorized as stocks, flows, delays, converters and constants. Stock variables (symbolized by rectangles) are the state variables, flow variables (symbolized by valves) are the rates

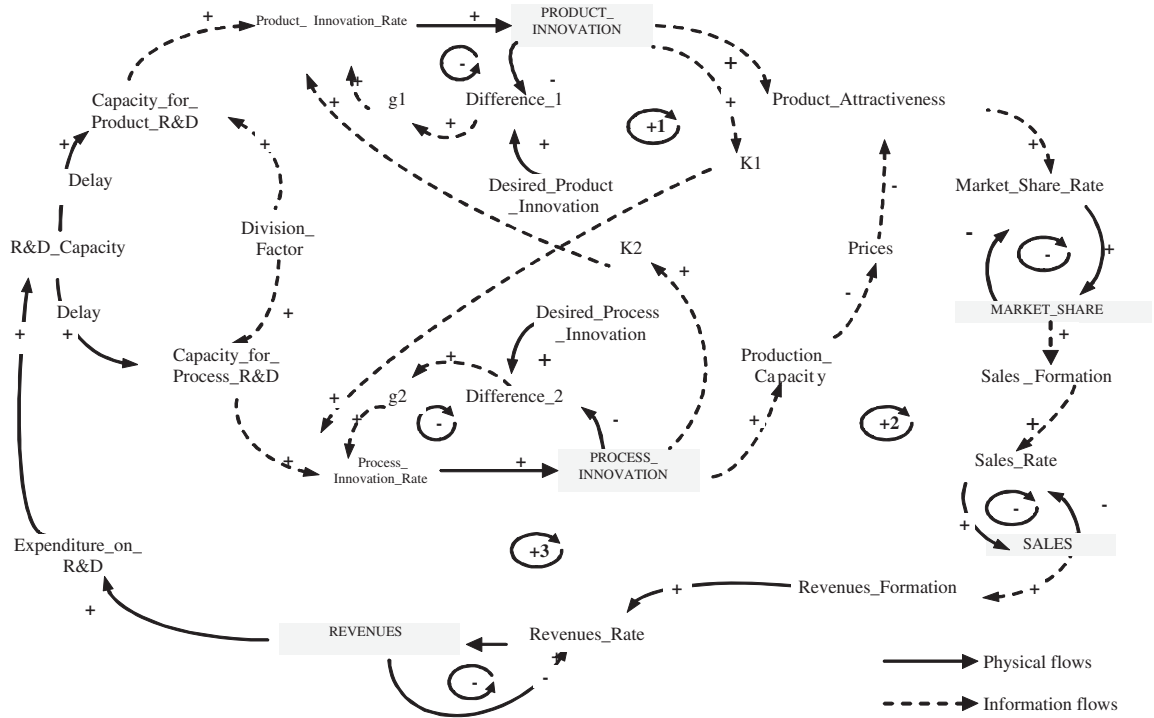


Fig. 3. Causal loop diagram of the innovation process subsystem.

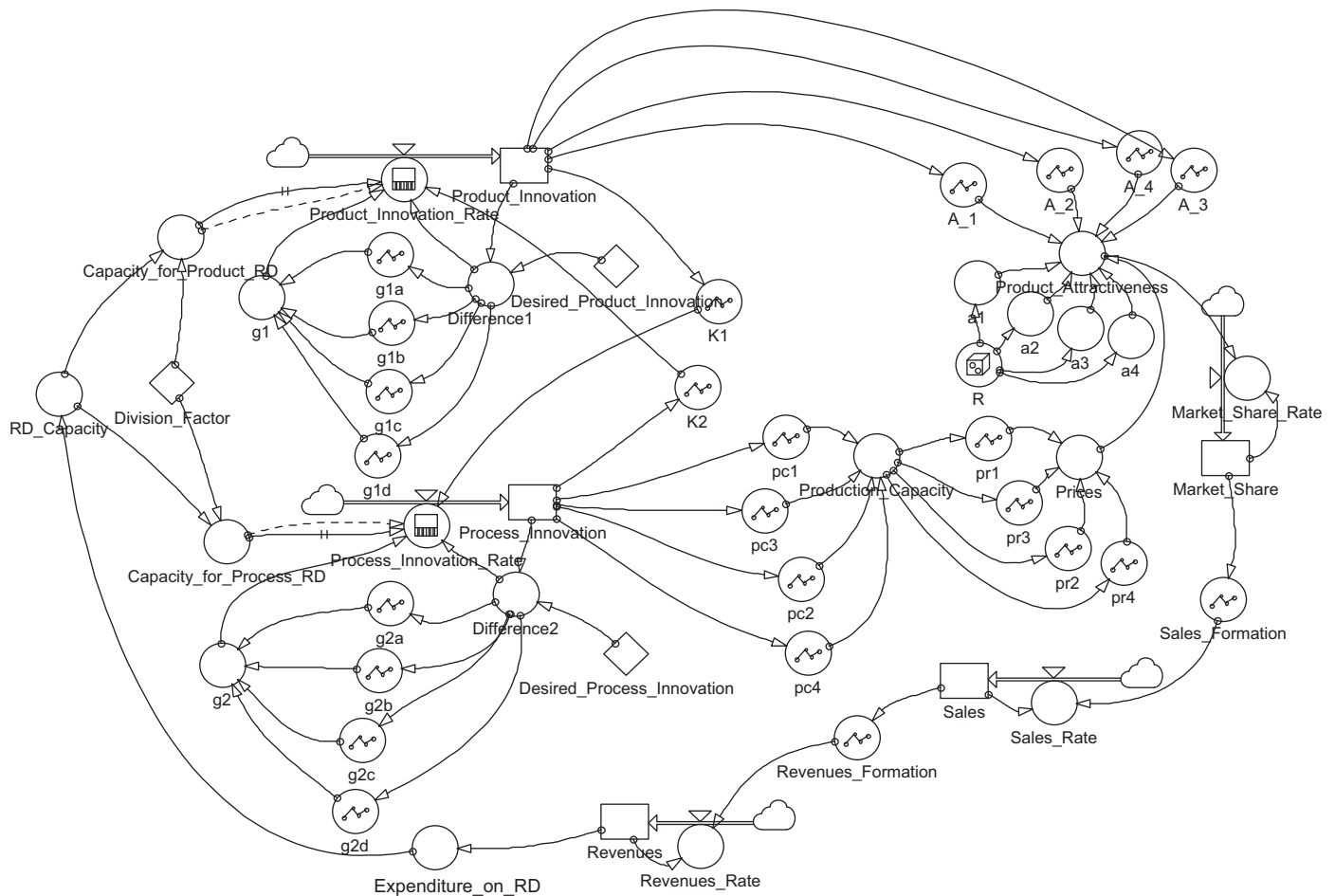


Fig. 4. Stock and flow diagram of innovation process.

of change in stock variables and they represent those activities, which fill in or drain the stock variables. Delays (represented by circles with a rectangular) introduce time delay in material or information channels. Converters (represented by circles) are intermediate variables used for auxiliary calculations. Constants (represented by rhombuses) are the model parameters. Finally, the connectors, represented by simple arrows, are the information links representing the cause and effects within the model structure, while the double line arrows represent physical flows. Double lines across the arrows indicate a delayed information.

The stock-flow diagram is a graphical representation of the mathematical model. The embedded mathematical equations are divided into two main categories: the stock equations, defining the accumulations within the system through the time integrals of the net flow rates, and the rate equations, defining the flows among the stocks as functions of time.

The equations of our model have been regulated by using data from the Greek innovation system. *Product Innovation* and *Process Innovation*, measure the national innovative performance as the percentage of enterprises performing innovative activities. Further details are given in Section 4.3 Below we present selected formulations related to important model assumptions. More specifically, the stock equations of the innovation process subsystem can be derived from the stock and flow diagram of Fig. 4 as follows:

$$d(\text{Product Innovation}(t)) = [\text{Product Innovation Rate}(t)] * dt \quad (1)$$

$$d(\text{Process Innovation}(t)) = [\text{Process Innovation Rate}(t)] * dt \quad (2)$$

$$d(\text{Market Share}(t)) = [\text{Market Share Rate}(t)] * dt \quad (3)$$

$$d(\text{Sales}(t)) = [\text{Sales Rate}(t)] * dt \quad (4)$$

$$d(\text{Revenues}(t)) = [\text{Revenues Rate}(t)] * dt \quad (5)$$

The *Product Innovation Rate* appeared in Eq. (1) is defined by Eq. (6) given in Powersim format, as a material delay. In particular *Product Innovation Rate* is a third-order exponential smoothing of *Capacity for Product RD* with a mean value of delay equal to two years, implying a smoothing coefficient of 1/2. The initial value of *Product Innovation Rate* is set equal to zero. *Difference1* is the discrepancy between the desired and the actual values of *Product Innovation*, *g1* is the annual rate of change for *Product Innovation Rate* and parameter *K2* regulates the acceleration of the system concerning the *Process Innovation* and the *Product Innovation*. Increase in the process innovation leads to higher pressure for desired product innovation (Kim et al., 1992, p. 56).

$$\text{Product Innovation Rate}(t) = \text{DelayMTR}(\text{Capacity for Product RD}, 2, 3, 0) * \text{Difference1} * g1 * K2 \quad (6)$$

The equation for *Process Innovation Rate* may be deduced in the same way as a material delay of *Capacity for Process RD*, where *Difference2* is the discrepancy between the desired and the actual values of *Process Innovation*, *g2* is the annual rate of change for *Process Innovation Rate* and *K1* regulates the acceleration of the system concerning the product innovation and the process innovation.

$$\text{Process Innovation Rate}(t) = \text{DelayMTR}(\text{Capacity for Process RD}, 2, 3, 0) * \text{Difference2} * g2 * K1 \quad (7)$$

The flow equation for the *Market Share Rate* appeared in Eq. (3) describes the annual rate of increase in *Market Share*. It is defined by Eq. (8), as a proportional increase of the current value of *Market Share* and is affected by *Product Attractiveness*. The values of *Product Attractiveness* are normalized on a 1 (worse)-to-7 (best) scale. Further details on normalization are given in Section 4.3.

The values of annual rate of increase in *Market Share* are estimated as the mean values of *Market Share* in Greece over a period from 1999 to 2008 (GSRT, 2009; Hellenic General Secretariat of Research and Technology, "The Greek Innovation System", 2009.).

$$\text{Market Share Rate} = \text{IF}[4 < \text{Product Attractiveness} < 7, 0.07 * \text{Market Share}, 0.035 * \text{Market Share}] \quad (8)$$

In the same way, by Eqs. (9) and (10) we define the flow equations for *Sales Rate* and *Revenues Rate* appeared in Eqs. (4) and (5), respectively.

$$\text{Sales Rate} = \text{IF}[4 < \text{Sales Formation} \leq 7, 0.082 * \text{Sales}, 0.041 * \text{Sales}] \quad (9)$$

$$\text{Revenues Rate} = \text{IF}[4 < \text{Revenues Formation} \leq 7, 0.08 * \text{Revenues}, 0.04 * \text{Revenues}] \quad (10)$$

The *Product Attractiveness* in a market depends on the achieved level of *Product Innovation*. This dependency is defined in the modelling approach under scenario analysis with regard to market behaviour. More specifically, we incorporate four alternative forms of market behaviour as shown in Fig. 5. In A1 the behaviour is assumed as proportional. In A2, consumers present innovative demand and therefore product attractiveness reacts fast for low levels of product innovation, while in A3 the response is slow and becomes more acute for high levels of product attractiveness. Finally A4 combines A2 and A3. The relation has the form of an S-curve (sensitive market for very poor or very good product innovation).

In the same way, we define the influence of *Process Innovation* on *Production Capacity* (Fig. 6), of *Production Capacity* on the configuration of innovative product *Prices* (Fig. 7), of *Difference1* on the percentage *g1* (annual rate of change for *Product Innovation Rate*) (Fig. 8) and of *Difference2* on the percentage *g2* (annual rate of change for *Process Innovation Rate*) (Fig. 9). *Production Capacity* and *Prices* are measured on a 1-to-7 scale.

4.3. Initial conditions and units of measurement

As mentioned above, the modelling of innovation process subsystem contains in total five state variables. These state variables are frequently mentioned as indicators in innovation issues related review reports and statistical analyses. Two state variables (*Product Innovation* and *Process Innovation*), measure the

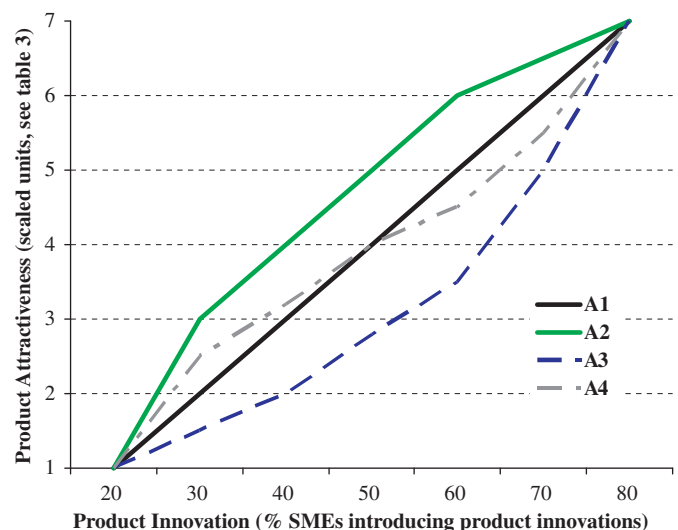


Fig. 5. Influence of product innovation on product attractiveness.

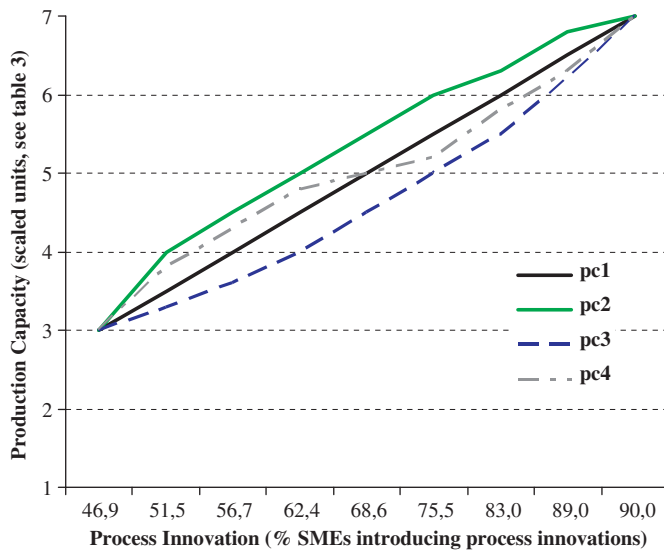


Fig. 6. Influence of process innovation on production capacity.

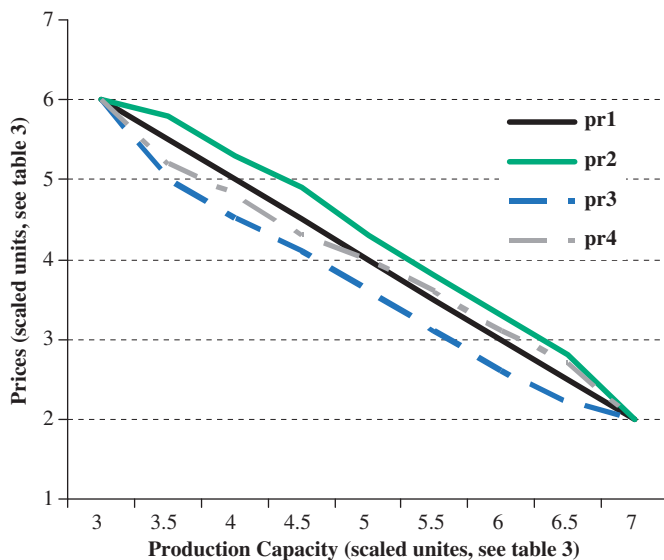


Fig. 7. Influence of production capacity on prices.

national innovative performance. Because of their central role in evaluating the effectiveness of innovation policies, the dynamic behaviour of these variables is of interest to the study presented in this paper.

The initial values of state variables are given in Table 1 and refer to the year 2008. The table also provides a short definition of state variables, their units of measurement and the sources of data.

In Table 1, *Product Innovation* and *Process Innovation* represent the share of enterprises with activities in product and process innovation, respectively. Because of Greek SMEs perform the majority of innovative activities, *Product Innovation* and *Process Innovation* are measured as percentage of total number of Greek SMEs; scale from 0 to 100% as shown in Table 2 (GSRT). According to the Background Report for the Review of Greece's Innovation Policy by the OECD (2009), the total number of Greek SMEs is approximately 30,000 (GSRT). Recall from previous section that *Product Attractiveness*, *Production Capacity* and *Prices* are normalized on a 1-to-7 scale. The normalization procedure is based on the Report of World Competitiveness (World Economic Forum,

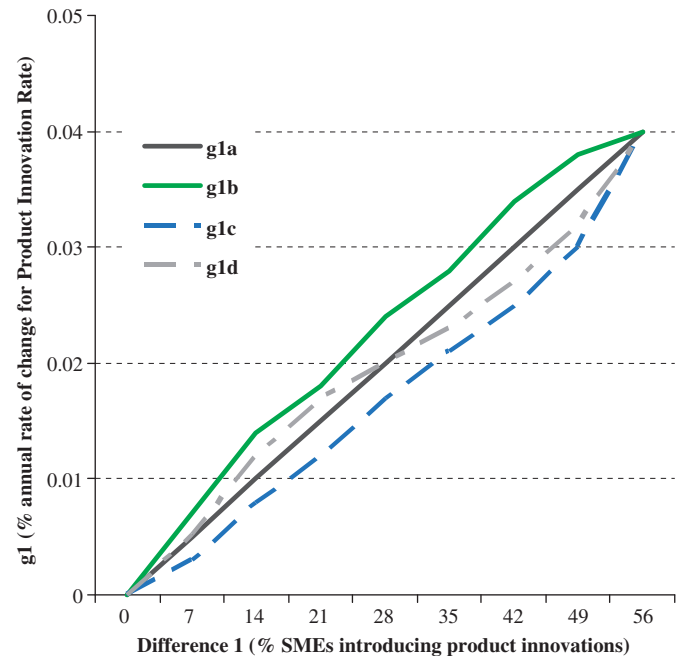


Fig. 8. Influence of Difference1 on annual rate of change g1.

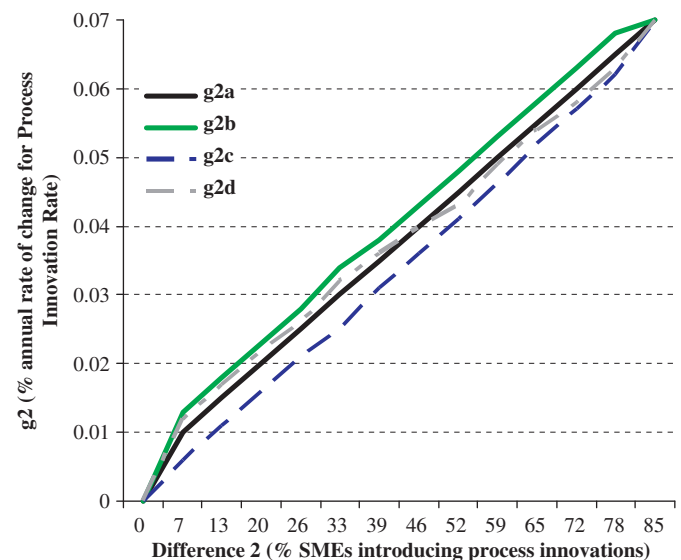


Fig. 9. Influence of Difference2 on annual rate of change g2.

2008). In particular for each variable-indicator, we found the countries with the best and the worst record. The country with the best record was fixed in level 7, while the one with the worst in level 1. All the remainders were smoothed out in intermediary categories. The qualitative scale is shown in Table 3. The same 1-to-7 scale is used for the measurement of the independent variables of our SD model. These independent variables practically represent the system's parameters. All system parameters are given in a following section while studying the effect of innovation policies on the performance of NIS (Section 5.2).

4.4. Model validation

SD practitioners have developed a wide variety of tests to improve models (Stermann, 2000). We firstly tested the structural validity of the model; specifically, its dimensional consistency. In particular each equation was checked to confirm that the

Table 1

Initial values, units of measure and sources of data.

State variables- indicators	Definition	Units of measurement	Initial conditions (2008)	Sources of data
Product innovation	SMEs introducing product innovations	Percentage of total number of SMEs	32.4	GSRT ^a (CIS4 ^b)
Process innovation	SMEs introducing process innovations	Percentage of total number of SMEs	41.8	GSRT (CIS4)
Market share	SMEs market share with innovative activities	%	37.9	GSRT
Sales	Sum of total turnover of new or significantly improved products for all enterprises	Percentage of turnover	25.64	EUROSTAT
Revenues	Total annual revenues from innovative products' sales	Million euros	3	GSRT

^a GSRT: Hellenic general secretariat of research and technology.^b CIS4: Community innovation survey 4.**Table 2**

Scale for product innovation and process innovation.

Scale (%)	Characterization
90–100	Perfect
75–90	Very good
65–75	Good
50–65	Adequate
30–50	"Poor"
< 30	"Very poor"

Table 3

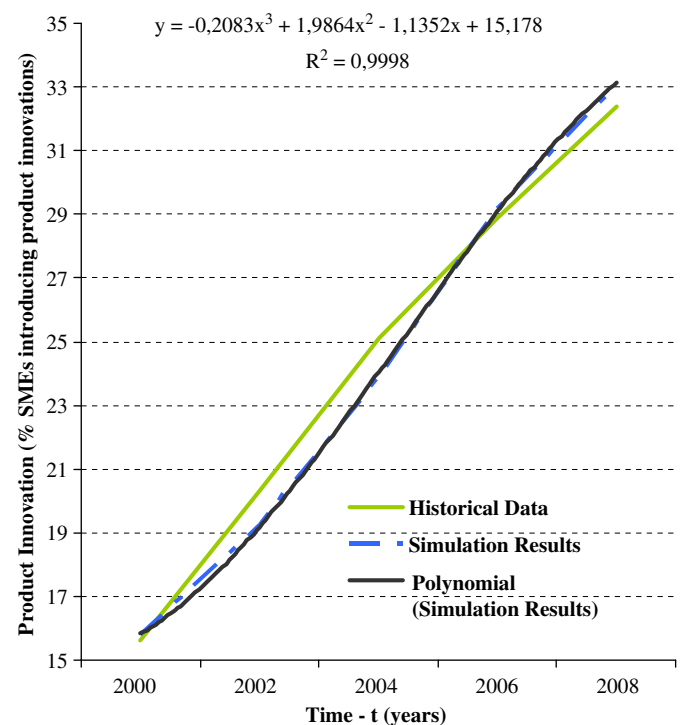
Qualitative scale for normalized variables/parameters.

Scale	Characterization
6–7	Perfect
4–6	Very good
3–4	Good
2–3	Adequate
< 2	"Poor"

Table 4

Historical data and simulation results for product innovation and process innovation.

Year	Historical data		Simulation results	
	Product innovation	Process innovation	Product innovation	Process innovation
2000	15.6	14.7	15.8	16
2002	20.3	23.2	19.27	23
2004	25.1	31.8	23.9	31.88
2006	28.9	37.3	29.17	37.23
2008	32.4	42.6	33.1	41
			MAPE: 0.00503	MAPE: 0.0037
			BIAS: −0.022	BIAS: −0.06125

**Fig. 10.** Historical data, tendency and simulation results for the case of *Product Innovation*.

dimensions of the left part are the same with the right part. Then we conducted extreme-condition tests checking whether the model behaves realistically no matter how extreme the policies imposed may be. For example we checked that if *R&D Capacity* equals to zero then *Product Innovation* and *Process Innovation* remained stable and equal to their initial value, since *Product Innovation Rate* and *Process Innovation Rate* are mainly affected by *R&D Capacity*. Integration error tests were subsequently conducted (Sterman, 2000). In our model we used the Euler numeric method since the integration method Runge–Kutta should be avoided in models with random disturbances. The simulation horizon is set equal to ten years; a strategic horizon to be able to study the improvement of an NIS performance and also to facilitate the tuning of model parameters. Moreover, since the model's shortest time constant is set to one year and standard practice in SD suggests that the integrating time step (DT) should be maximum 1/4 of the shortest time constant in the model, we set the DT initially at 1/4 year and ran the model. Then we cut the DT in half and ran the model again. The results did not significantly change, so we chose DT=1/4 year.

The ability of a mathematical model to reproduce the behaviour that is observed in the real-world, constitutes another test of validation. The behaviour of the Greek innovation system during 2000–2008, is given in Table 4 and Figs. 10 and 11. Table 4 shows the historical data and simulation results for the cases of *Product Innovation* and *Process Innovation*, while Figs. 10

and 11 show the tendency for the cases of *Product Innovation* and *Process Innovation*, respectively. The mean absolute percent error (MAPE) between the real values of *Product Innovation* and *Process Innovation* (A) and the equivalents obtained by simulation results

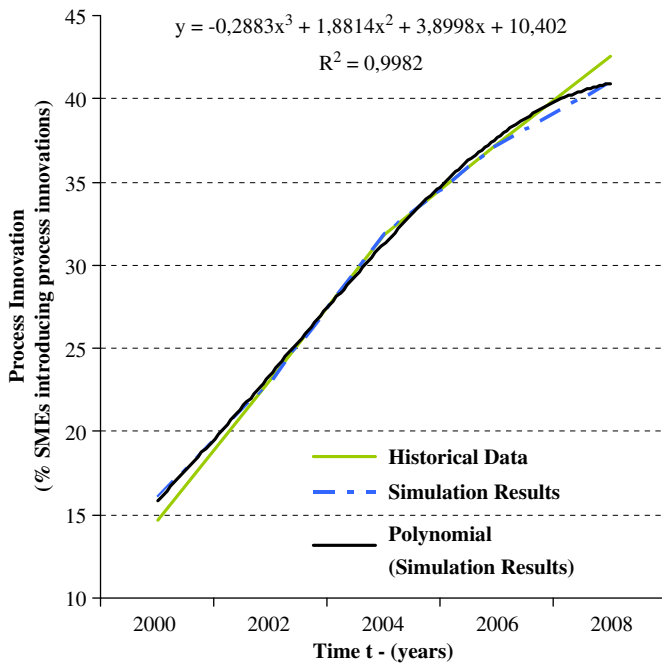


Fig. 11. Historical data, tendency and simulation results for the case of Process Innovation.

Table 5

Thiel statistics for Product innovation and Process innovation (2000–2008).

Parameter	Theil's inequality statistics			
	MAPE	Bias	R ²	N
Product innovation	0.00503	0.0222	0.9998	8
Process innovation	0.0037	0.06125	0.999	8

(F) is given by:

$$MAPE = \frac{1}{n} \sum_{t=1}^n \left| \frac{At - Ft}{At} \right|$$

Table 5 summarizes the statistical results. The values of MAPE (< 0.6%) and the small divergences (bias), indicate the absence of systematic errors. Consequently, the model can effectively repeat effectively the system's behaviour (Thiel, 1966).

From the above we conclude that our model can express the innovative performance of an NIS.

5. The effect of innovation policies on the performance of NIS—The Greek innovation system

5.1. Overview of existing situation

According to the European Innovation Scoreboard (European Innovation Scoreboard (EIS), 2008), the Summary Innovation Index (SII) gives an “at a glance” overview of aggregate national innovation performance and is calculated as a composite of the 29 EIS indicators. Based on a statistical cluster analysis of SII scores over a five-year period, the countries can be categorized into the following groups:

- Innovation leaders (Sweden, Finland, Germany, Denmark and the UK), with innovation performance above that of the EU27 average and all other countries.

- Innovation followers (Austria, Ireland, Luxembourg, Belgium, France and the Netherlands), with innovation performance below that of innovation leaders but above that of the EU27 average.
- Moderate innovators (Cyprus, Estonia, Slovenia, Czech Republic, Spain, Portugal, Greece and Italy) with innovation performance below that of the EU27 average.
- Catching-up countries (Malta, Hungary, Slovakia, Poland, Lithuania, Romania, Latvia and Bulgaria). Although their innovation performance is below the EU average, this performance is increasing towards the EU average over time.

The comparative study of European Innovation Scoreboard (EIS) 2007 and European Innovation Scoreboard (EIS), 2008 indices reveals that all countries remain in the same group except Greece and Portugal which have moved from the catching-up countries to the group of moderate innovators. This transition can be explained from their strong growth in innovation performance and from the revised set of indicators used in calculating average innovation performance (European Innovation Scoreboard (EIS), 2008).

The Greek innovation system, in particular, is shaped and it is progressively strengthened, mainly with the intervention of the government. The government indeed followed the EU lines, facing with a systematic way the creation of an environment favourable for innovation. According to European Innovation Scoreboard (EIS) (2008) records, Greece had one of the higher growth rates between the 15 fundamental EU members. Precisely, from the decade of '90 the annual growth rate of GDP was continuously higher than the average rate of the EU-15 countries (3% on 1991–2004 compared with the 2% of EU-15). In 2006, according to the Hellenic National Statistical Service, the GDP was increased at 4.3% despite the high oil prices. However, its classification to the competitiveness indicators between 80 countries according to the WEF (World Economic Forum) in Global Competitiveness Report 2008–2009 shows clearly that its innovative activity is low. Furthermore, it shows that Greece is an imitative economy, which constitutes importer of innovations, while the technologies are only adopted by its institutions, when they are checked and applied in advanced countries or simply are incorporated in equipment and products (Komninou and Tsamis, 2008).

As mentioned, the majority of Greek firms are SME's, being thus unable to play a leading role for the NIS. The relations and the interactions between the NIS's actors can be considered as satisfactory. However, the dependency of the firms to a great degree from the government owned financing constitutes a barrier for increased innovative efforts.

5.2. Sensitivity analysis

The present NIS performance model is able to contribute as an “experimental tool” to conduct extensive what-if analysis scenarios, aiming to investigate the effectiveness of alternative innovation policies on the performance of innovation actions at a national level. In this section we provide the analysis of the effect of innovation policies under three alternative scenarios. In the first scenario (basic scenario), the definition of Product Attractiveness, Production Capacity, Prices, g1 and g2 follows the proportional scenario shown in Figs. 4–8 (A1, pc1, pr1, g1a and g2a, respectively). The second scenario examines the performance of Greek NIS under the Lisbon treaty scenario. We study in particular, the effect of the hypothesis “the accomplishment of targets that have been set by the Lisbon Treaty for Greece” on the innovative performance (Product Innovation, Process Innovation). Finally in the third scenario, we study the behaviour of Greek NIS under different system parameters settings.

5.2.1. Basic scenario

The initial conditions are given in Section 4.3 (Table 1). The values of *Product Innovation* (32.4%) and *Process Innovation* (41.8%) in 2008 exhibit a “poor” performance, according to the scale given in Table 2.

Based on simulation results for a time horizon 2008–2018, we observed that the performance for the *Product Innovation* still remains into the “poor” scale while for the *Process Innovation* reaches the “adequate” scale (Fig. 12). In terms of real world effect, taking into consideration that there are approximately 30,000 SMEs operating in Greece there will be an increase of about 9,000 new enterprises with activities in product innovation and about 12,500 with activities in process innovation. The higher percentage of increase for the case of *Process Innovation* is in line with the Hellenic GSRT expectations, since the share of firms with activities in process innovation is already higher than the share in product innovation.

5.2.2. The Lisbon Treaty scenario

In the frames of the Lisbon Treaty, the EU countries owed to converge with certain objectives that have been placed, in order to converge in the same levels with regard to innovation. The main challenges faced by the Greek National Innovation System are:

1. *Limited impact of innovation policies on economy and employment:* In Greece there is a general tendency to exhibit better performance in indicators measuring the input of innovative process (like Business R&D expenditures, Public R&D expenditures, etc.) and worse performance in innovation output indicators. Output indicators are connected with the technological performance subsystem and are the following: *Patents, Trademarks, Sales New to the Market, Sales New to the Firm, Service Sector Employment and Manufacturing Employment*. In order to converge, the initial values of innovation output indicators of the model (year 2008) are raised compared to those of the basic scenario (see Table 6).
2. *Lack of emphasis on knowledge creation and innovation as a component of business strategies:* As mentioned in Section 5.1, this is due to the fact that Greek companies are largely

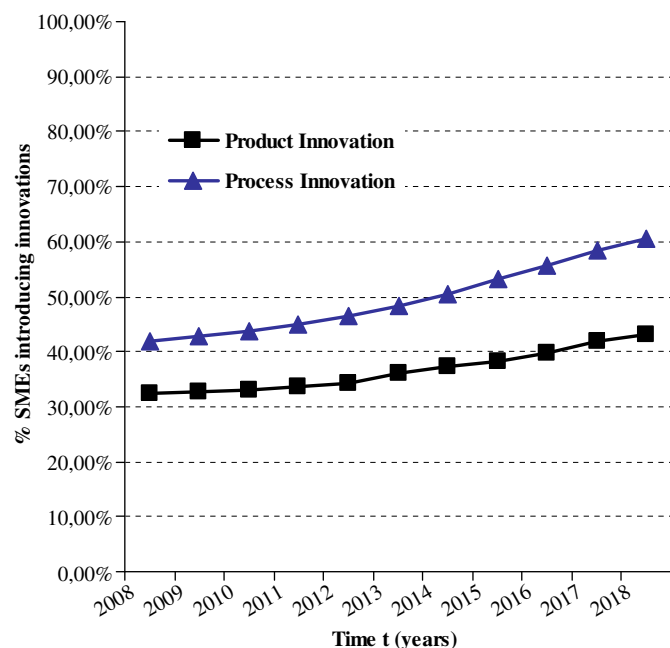


Fig. 12. Performance of product and process innovation for the basic scenario.

dependent on governmental funding, leading to reduced efforts in innovative actions. To capture this effect in our model, we test the participation rate of private expenditure on R&D. In particular, according to the evidence so far, R&D expenditure in Greece came at a rate of 75% from the public sector and only 25% from companies. Therefore, according to Lisbon Strategy this should reverse to 60% and 40% between public and private expenditure. The variable that captures this percentage rate belongs to the innovation process subsystem; *Expenditure on R&D* in Figs. 3 and 4, is influenced by the *Participation rate of private expenditure on R&D* given in Table 6.

3. *Shortages and quality issues in education and training:* During the last decades Greece has a high Tertiary Education Participation Indicator. This creates expectations of raising the level of innovation in Greece, since tertiary education graduates are an important driving force for innovation. This does not refer necessarily to science and technological intensive innovation but, to innovation resulting from relations and networking in the market, adaptation to customers' needs and business model innovation. This positive factor is mitigated however by the low Educational System and Research Organizations' Quality indicators. Consequently, in order to be in line with the Lisbon Strategy targets, the initial values of education quality indicators should be raised compared to those of the basic scenario. These indicators are connected with the knowledge and human resources subsystem and are the following: *Total Public Education Expenditure and Quality of Scientific Research Institutions* (Table 6).

Overall, under the Lisbon Strategy targets the Greek NIS model setting is summarised in Table 6.

Fig. 13 exhibits the simulation results for the time horizon 2008–2018. We observe that the effect of implementing the Lisbon Treaty scenario is not significant on the overall innovation performance at a country level. More precisely, the simulation results of the basic scenario and Lisbon Treaty scenario are compared in Table 7. In case of *Product Innovation*, the position at the end of 2018 has improved by 4.7% in comparison to that of the basic scenario, remaining though at the “poor” scale. In case of *Process Innovation*, the position has improved by 5.3%, remaining, however, at the high level of the “adequate” scale.

The slow improvement of the innovative performance was expected given the fact that for most of the indicators, the simulation of the Greek NIS starts in 2008 from a very low position comparing to that of the E.U average. In addition, the changes in the values of Table 6 are related to the structures and values of the society and therefore the improvement at a national level is difficult. However for the same settings given in Table 6 but by extending the simulation horizon from 10 to 20 years, we observe a significant improvement in the performance; performance rises at a level that qualifies as “good” for *Product Innovation* and “very good to excellent” for *Process Innovation* (Fig. 14). Due to the very long time horizon of 20 years, these results could not be considered as accurate forecasts. However they demonstrate that the improvement in innovation performance is a long term target that requires a persistent and systematic effort.

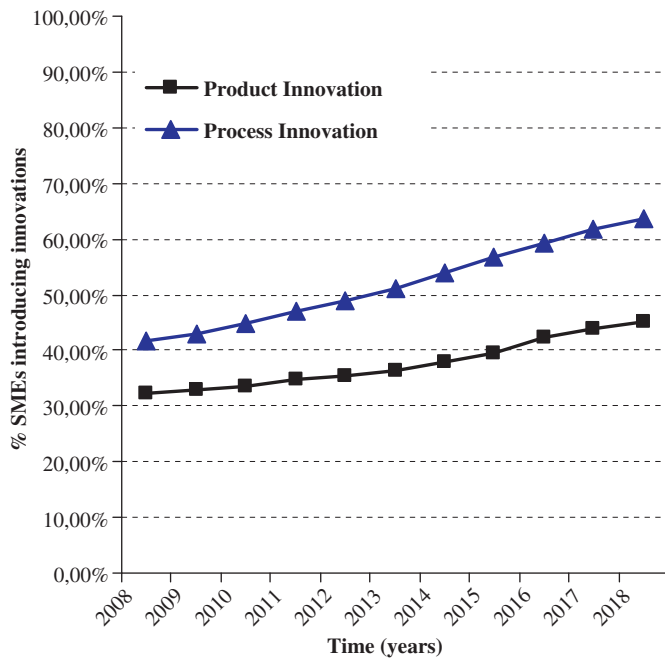
5.2.2. Third set of investigation

Our model consists of 39 independent variables shown in Table 8. Practically, these variables are the system parameters which are normalized on a 1-to-7 scale given in Table 3. To clarify “NIS performance”, a comprehensive study of the effects of these variables on system behavior is required. A prerequisite for a

Table 6

Different settings for independent variables in order to improve the Innovative Performance of Greek NIS (Lisbon Treaty scenario).

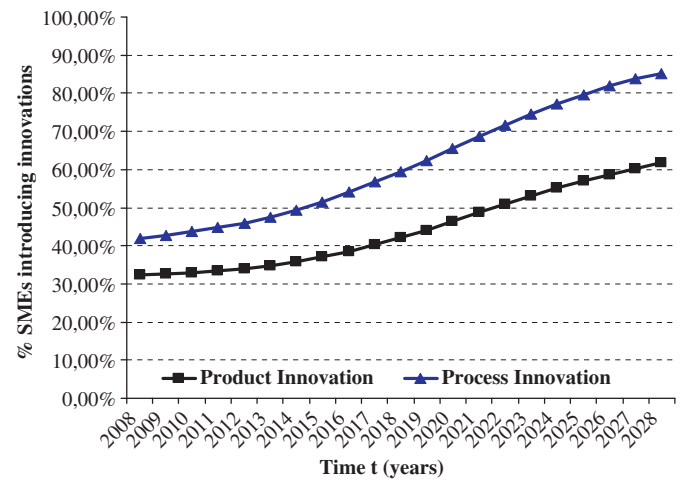
Model's subsystem	Independent variables	Initial values in the basic scenario (2008) (units of measure as in Table 3)	Initial values for the Lisbon treaty scenario (2008) (units of measure as in Table 3)
Technological performance	Patents	1	3
	Trademarks	1	3
	Sales new to the market	5	7
	Sales new to the firm	5	7
	Service sector employment	3	6
	Manufacturing employment	2	4
Innovation process	Participation rate of private expenditure on R&D	2	4
	Total public education expenditure	2.8	4
Knowledge & human resources	Quality of scientific research institutions	3.6	6

**Fig. 13.** Performance of product and process innovation for the Lisbon Treaty scenario.**Table 7**

Simulation results of the basic scenario and the Lisbon Treaty scenario.

Scenario	Simulation results (2008–2018)	
	Product innovation (%)	Process innovation (%)
Basic scenario	43	60.5
Lisbon treaty scenario	45	63.7
Rate of change	4.7	5.3

full-factorial experimental design of the model's behavior is the systematic study of all cases, occurring when all independent variables of the system are at different value levels, i.e., the planning of a statistical test with all the independent variables in at least two levels. Such a detailed test, because of the large number of independent variables, is prohibitive as it would require conducting at least 2^{39} simulation runs. Therefore, we should plan tests with a “reasonable” number of independent variables. However, in case that the investigation of the interaction of innovative performance with governmental policies calls to take into account all 39 variables, the only solution is to

**Fig. 14.** Performance of product and process innovation for a 20 year simulation horizon.

separate the independent variables into groups displaying similar properties and then to study the impact of each group on the system's performance. In our model, these groups of independent variables are defined as the six subsystems that make up the NIS (the innovation process subsystem does not contain independent variables).

The six groups of independent variables are given in Table 8 (A to F). The basic scenario provides the original values of all independent variables for the year 2008. We carried out six simulation experiments. In each experiment, we changed the values of one group of independent variables while keeping all the others equal to those of basic scenario (original values). In particular, by using the 1-to-7 scale, the original value of each independent variable is increased and set at the maximum of the next higher scale. The experimental design is shown in Table 8 (Case A to Case F). In every simulation run we studied the impact of changes on the performance of NIS through the dynamic behaviour of *Product Innovation* and *Process Innovation* in a time horizon 2008–2018.

The results are summarized in Table 9. We observe that the institutional conditions have the greatest impact on innovation performance, though a small one. In particular, innovation performance increases by 2.1% (*Product Innovation*) and 2.5% (*Process Innovation*). The regulatory framework is a key driver of competitiveness, the effectiveness of market processes and other similar conditions related to innovation. In Greece, despite efforts to enhance competition in various sectors, there is a gap, as various administrative barriers exist in many economic activity areas.

Table 8

Model's independent variables (reference year 2008) and alternative case settings.

	Independent variables	Basic scenario	Case A	Case B	Case C	Case D	Case E	Case F	Holistic Case
A. Knowledge & human resources	1. Population with tertiary education per 100 population aged 25–64	3	4						4
	2. S&E and SSH doctorate graduates per 1000 population aged 25–34	2.8	4						3.8
	3. Participation in life-long learning per 100 population aged 25–64	1.7	3						2.7
	4. Education expenditure	4	6						5
	5. Quality of scientific research institutions	3.6	6						4.6
B. Research Activities	6. Business R&D expenditures (% GDP)	2		4					3
	7. Public R&D expenditures (% GDP)	3.1		6					4.1
	8. Gross domestic expenditure on R&D (GERD) (% GDP)	2		4					3
C. Market conditions	9. Government debt (% GDP)	2			4				3
	10. Government budget balance (% GDP)	2			4				3
	11. Inflation	6			7				7
	12. GDP (current prices) per capita	5			7				6
	13. National income per capita	3			6				4
	14. Population density	3			6				4
	15. Brain drain	3			6				4
	16. International co-publications	4			6				5
	17. Foreign direct investment/GDP	4.3			7				5.3
	18. Imports/ GDP	2			4				3
	19. Exports/GDP	2			4				3
	20. Medium and high-tech manufacturing exports (% of total exports)	3			6				4
D. Institutional conditions	21. Extent and effect of taxation	3.3				6			4.3
	22. B indicator ^a	1				3			2
	23. Total tax rate	3				6			4
	24. Burden of government regulation	2.4				4			3.4
	25. Number of procedures required to start a business	3				6			4
E. Financial system	26. Soundness of banks	5.9					7		6.9
	27. Venture capital at early stage (% of GDP)	1					3		2
	28. Venture capital expansion (% of GDP)	1					3		2
	29. Venture capital availability	3					6		4
	30. Financial market sophistication	4.6					7		5.6
	31. Interest rate spread	1					3		2
	32. Direct investment by government	3					6		4
	33. National Projects	6					7		7
F. Technological performance	34. New-to-firm sales (% of turnover)	5						7	6
	35. New-to-market sales (% of turnover)	5						7	6
	36. Employment in knowledge intensive services (% of workforce)	3						6	4
	37. Employment in medium & high-tech manufacturing (% of workforce)	2						4	3
	38. European Patent Office patents per million population	1						3	2
	39. Community trademarks per million actpopulation	1						3	2

^a The B index specifies the pre-tax income of a firm that is required to break even one US-dollar of R&D expenditure, given the level of corporate tax income, existing tax allowances for R&D spending and the depreciation rate of those capital assets that are directly involved in the carrying through of R&D activities (see OECD, 2003).

Table 9

Simulation results of the third set of investigation.

Scenario	Simulation results	
Simulation horizon (2008–2018)	Product innovation (%)	Process innovation (%)
Basic scenario	43	60.5
Case A	43.2	60.9
Case B	43.3	60.9
Case C	43.8	61.6
Case D	43.9	62.0
Case E	43.3	61.0
Case F	43.8	61.7%
Holistic Case	46.98	67.92
Rate of change for Case D	2.1	2.5
Rate of change for the holistic case	9.25	12.3

Governmental regulations, in a market based economy, often are considered as a negative impact on innovation. For this reason Greece should improve the indicators of *Burden of Government Regulation* and *Number of Procedures Required to Start a Business*, in order to get closer in achieving higher innovative performance. Overall, however, it is noted that bureaucracy, regulations and taxation, since they are connected to structures and values of society, are difficult and slow to improve (a fact which is also considered by a delay that we introduced in our model in the subsystem of institutional environment).

In addition, we studied a holistic case where we changed all independent variables simultaneously but in a moderate degree (+1 from their original value in 2008). The case is also shown in Table 8. The basic observation from the simulation of the holistic case is that moderate changes result in almost four and five times higher rate of change in product and process innovation, compared to the results obtained by the case of basic scenario. Therefore, we observe that a strategy directed to upgrade just few indicators, and even in high

degrees, will rather result in a lack of innovative behaviour for Greece. Given that the overall innovative behavior is formulated from many independent variables, the achievement of a substantial growth in innovation performance calls the government to focus on the concurrent strengthening of a set of them, even in a moderate rate. This calls for more holistic types of strategy for the public government. For example, admit that developing a reliable knowledge production and exploitation structure is an impossible task so they need to reinforce the knowledge transfer and dissemination mechanisms, together with encouraging organizational changes. Certainly it must be considered that many of these policies that affect the system interrelate with all economic, institutional and social environment. For this reason, their parallel improvement is difficult and time-consuming, requiring simultaneously radical changes in the mind-sets of the relevant actors.

6. Conclusions and future research aspects

In this paper, we have developed a SD-based model that provides the dynamic analysis of the impact of innovation policies on the performance of an NIS. Formulating innovation performance as the output of many independent variables, the model supports policy makers to reveal structures for generating change and also develop and test strategies for the government. Simulation results under alternative policies and scenario settings show that a combination of sustained efforts is needed to strengthen innovative behaviours. Based on these results policy makers are suggested to formulate a strategy characterized by symmetry in its objectives, aiming at improving a set of performance indicators even in a moderate rate compared to targets set by isolated aggressive upgrading policies. Simulation results also reveal that improvement of innovation performance is a long-term target that requires continuous and systematic efforts, since many policies that affect the system interrelate with the national, economic, institutional and social environment. Hence, governments and regulators should not expect the improvement to appear over short-term cycles.

The presented model establishes SD as an appropriate method for the development of dynamic models to deal with the structural and functional complexity of the innovation processes at a national level. This study integrates the simulation discipline and the theory of nonlinear dynamics and feedback control into a dynamic consideration of the NIS. The approach provides an “experimental” tool to reproduce historic results, test the efficiency of alternative innovation-policy scenarios both individually and in combination, and reveal effective policy suggestions. The paper also presents an application of this experimentation for the case of Greece. The key finding is that the institutional conditions have shown the greatest impact on innovation performance; however, aggressive upgrading policies still result in partial innovative behaviors.

The conclusions of this paper may be inappropriate for other European countries, since they are based on the Greek case. However, for countries like Czech Republic, Cyprus, Estonia, Italy, Portugal, Slovenia and Spain, which according to EIS categorization belong to a group of countries exhibiting the same SII score as Greece, the results of such analyses might be similar. Hence, an interesting direction for future research is to conduct comparative studies between E.U. countries that belong to groups with significantly different SII scores. Furthermore, the results do not exhaust the possibilities of investigating all the effects of innovation policies on the performance of an NIS. The versatility of the model, allows for suitable modifications to investigate other effects. For instance, it would be useful to study the effect due to the existence and operation of clusters that function in sectoral and regional levels.

References

- Abrunhosa, A., 2003. The National Innovation Systems Approach and the Innovation Matrix. DRUID Summer Conference.
- Andersen, E.S., Lundvall, B.A., 1988. Small National Systems Of Innovation, facing technological revolutions: an analytical framework. In: Freeman, C., Lundvall, B.A. (Eds.), *Small Countries Facing the Technological Revolution*. Pinter, London, pp. 9–31.
- Archibugi, D., Michie, J., 1995. The Globalization of technology: a new taxonomy. *Cambridge Journal of Economics* 19 (1), 121–140.
- Arthur, W.B., 1994. Increasing returns and path dependency in the economy. The University of Michigan Press, Ann Arbor.
- European Commission, 1996. Groenboek over innovatie. Supplement 5/95 van het Bulletin van de Europese Unie. European Commission Luxembourg.
- Balzat, M., 2006. Economic Analysis of Innovation Extending the Concept of National Innovation Systems. Printer: MPG Books Ltd, Bodmin, Cornwall.
- Balzat, M., Pyka, A., 2005. Mapping National Innovation Systems in the OECD Area. *Beitrag Nr. 279*.
- Calia, R.C., Guerrini, F.M., Moura, G.L., 2007. Innovation networks: from technological development to business models reconfiguration. *Technovation* 27 (8), 426–432.
- Carlsson, B., Jacobsson, S., Holmen, M., Rickne, A., 2002. Innovation systems: analytical and methodological issues. *Research Policy* 31 (2), 233–245.
- Chang, P.L., Shih, H.-Y., 2004. The innovation system of Taiwan and China: a comparative analysis. *Technovation* 24 (7), 529–539.
- Chesbrough, H.W., 2003. The era of open innovation. *MIT Sloan Management Review* 44 (3), 35–41.
- Coyle, R.G., 1996. *System Dynamics Modelling: A Practical Approach*. Chapman & Hall, New York.
- Edquist, C. (Ed.), Pinter Publishers, London, Washington.
- Eng, T.Y., Wong, V., 2006. Governance mechanisms and relationship productivity in vertical coordination for new product development. *Technovation* 26 (7), 761–769.
- European Innovation Scoreboard, 2008. INNO-METRICS. Pro-Inno, Europe.
- European Innovation Scoreboard, 2009. INNO-METRICS. Pro-Inno, Europe.
- Filippetti, A., Archibugi, D., 2011. Innovation in times of crisis: National Systems of Innovation, structure and demand. *Research Policy* 40 (2), 179–192.
- Forrester, J.W., 1961. *Industrial Dynamics*. MIT Press, Cambridge, Massachusetts.
- Forrester, J.W., Senge, P.M., 1980. Tests for building confidence in system dynamics models. In: Legasto, A.A., Forrester, J.W., Lyneis, J.M. (Eds.), *System Dynamics, Studies in the Management Sciences*. North Holland Publishing Company, pp. 209–228.
- Galanakis, K., 2005. Innovation process. Make sense using systems thinking. *Technovation* 26 (11), 1222–1232.
- Galende, J., Suarez, I., 1999. A resource-based analysis of the factors determining a firm's R&D activities. *Research Policy* 28, 891–905.
- Gibbons, M., Limoges, C., Nowotny, H., 1994. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. Sage, London.
- Global Competitiveness Report, 2008–2009. World Economic Forum.
- Godinho, M.M., S., Mendonça and Pereira, T.S., 2004. Towards a Taxonomy of Innovation Systems, paper presented at the Second Globalistics Conference: Innovation Systems and Development: Emerging Opportunities and Challenges. Beijing, 16–20 October 2004.
- GSRT (Hellenic General Secretariat of Research and Technology), 2009. The Greek Innovation System: Review of Greece's Innovation Policy by the OECD Background Report.
- Harding, R., 2003. New challenges for innovation systems: a cross country comparison. *International Journal of Technology Management* 26 (2/3/4), 226–246.
- Huizingh, E.K.R.E., 2011. Open innovation: state of the art and future perspectives. *Technovation* 31 (1), 2–9.
- Innovation Framework Report, 2004. Measuring Innovation for National Prosperity. Version 3.0.
- Janszen, F.H.A., Degenaars, G.H., 1997. A dynamic analysis of the relations between the structure and the process of national systems of innovation using computer simulation; the case of the Dutch biotechnological sector. *Research Policy* 27, 37–54.
- Johnson, B., 1997. Systems of innovation: overview and basic concepts—introduction. In: Edquist, C. (Ed.), *Systems of Innovation: Technologies, Institutions and Organisations*. Pinter Publishers, London, pp. 36–40.
- Jost, A., Lorenz, T. and Mischke, G., 2005. Modelling the Innovation-Pipeline. System Dynamics Society Conference, Massachusetts Institute of Technology, Sloan School of Management, Cambridge, Massachusetts USA.
- Kim, J.S., Ritzman, L.P., Benton, W.C., Snyder, D.L., 1992. Linking product planning and process design decisions. *Decision Sciences* 23, 44–60.
- Kline, S., Rosenberg, N., 1986. An overview of innovation. In: Landau, R., Rosenberg, N. (Eds.), *National Systems of Innovation*. Oxford University Press.
- Komninos, N., Tsamis, A., 2008. The system of innovation in Greece: structural asymmetries and policy failure. *International Journal of Innovation and Regional Development* 1 (1).
- Kramer, J.P., Marinelli, E., Iammarino, S., Diez, J.R., 2011. Intangible assets as drivers of innovation: empirical evidence on multinational enterprises in German and UK regional systems of innovation. *Technovation* 31 (9), 447–458.
- Lee, T.L., Tenzelmann, N., 2005. A dynamic analytic approach to national innovation systems: the IC industry in Taiwan. *Research Policy* 34, 425–440.

- Levinthal, D., Myatt, J., 1994. Co-evolution of capabilities and industry: the evolution of mutual fund processing. *Journal of Strategic Management* 15, 45–62.
- Liu, X., White, S., 2001. Comparing innovation systems: a framework and application to China's transitional context. *Research Policy* 30 (7), 1091–1114.
- Lundvall, B.A. (Ed.), 1992. *National Systems of Innovation - Towards a Theory of Innovation and Interactive Learning*. London: Pinter.
- Malhotra, Y., 2003. *Measuring the Knowledge Assets of a Nation, Knowledge Systems for development*, Ad Hoc Group of Experts Meeting, Knowledge systems for Development. United Nations Headquarters, New York City.
- Mandinach, E.B., Cline, H.F., 1994. *Classroom Dynamics: Implementing a Technology-based Learning Environment*. Lawrence Erlbaum Associates, Hillsdale, NJ.
- Marklund, G., Nilsson, R., Sandgren, P., Granat Thorslund, J., Ullström, J., 2004. *The Swedish National Innovation System 1970–2003: A quantitative International Benchmarking Analysis*. VINNOVA Analysis VA, Stockholm 2004:01.
- Martínez-Román, J.A., Gamero, J., Tamayo, J.A., 2011. Analysis of innovation in SMEs using an innovative capability-based non-linear model: a study in the province of Seville (Spain). *Technovation* 31 (9), 459–475.
- Martínez-Ros, E., Salas, F., 1999. Do workers share innovation returns?: a study of the Spanish manufacturing sector. *Management Research* 2 (2), 147–160.
- Metcalfe, S., 1995. The economic foundations of technology policy: equilibrium and evolutionary perspectives. In: Stoneman, P. (Ed.), *Handbook of the Economics of Innovation and Technological Change*. Blackwell, London, pp. 409–512.
- Milling, P., Stumpfe, J., 2000. *Product and Process Innovation, A System Dynamics-Based Analysis of the Interdependencies*. The 18th International Conference of The System Dynamics Society, Bergen, Norway.
- Nelson, R.R. (Ed.), 1993. *National Innovation Systems: a comparative analysis*, Oxford University Press, Oxford, pp. 505–523.
- Nelson, R.R., 1995. Co-evolution of industry structure, technology and supporting institutions, and the making of comparative advantage. *International Journal of Business Economics* 2, 171–184.
- Nicolis, G., Prigogine, I., 1994. *The fourth European Framework Program and Research on Complex Systems*, Paper on: The University. Facing up its European responsibilities. Pisa. 23–26 November.
- OECD, 1991. *Technology in a Changing World*. OECD, Paris.
- OECD, 1996. *Measuring what People Know: Human Capital Accounting for the Knowledge Economy*. OECD, Paris.
- OECD, 1999. *Managing National Innovation Systems*. OECD, Paris.
- OECD, 2001. *Innovative Networks: Co-operation in National Innovation Systems*. OECD, Paris.
- OECD, 2003. *Main Science and Technology Indicators*, vol. 2003/1–2 (CD-ROM edition). OECD, Paris.
- OECD, 2009. *Annual report*. OECD, Paris.
- Porter, M.E., 1990. *The Competitive Advantage of Nations*. Macmillan.
- Rothwell, R., 1997. Towards the fifth-generation Innovation Process. *International Marketing Review* 11 (1), 7–31.
- Rycroft, R.W., Kash, D.E., 2004. Self-organizing innovation networks: implications for globalization. *Technovation* 24, 187–197.
- Samara, E., Bakourous, ., Galanakis, K., Platias, S., 2010. The Spin-off Chain. *Journal of Technology Management and Innovation* 5 (3), 51–68.
- Smith, K., 2001. Cross-country comparisons: comparing economic performance in the presence of diversity. *Science and Public Policy* 28 (4), 267–276.
- Sterman, J.D., 2000. *Business Dynamics: Systems Thinking and Modelling for a Complex World*. McGraw-Hill, New York.
- Thiel, H., 1966. *Applied Economic Forecasting*, North-Holland, New York.
- Tylecote, A., 1994. *Financial Systems and Innovation*. In: Dodgson, Mark, Rothwell Roy (Eds.), *The Handbook of Industrial Innovation*. Edward Elgar, Cheltenham UK, Brookfield US.
- Utterback, J.M., Abernathy, W.J., 1975. A dynamic model of process and product innovation, omega. *The International Journal of Management Science* 3 (6), 639–656.
- Van der Steen, M., 1999. *Evolutionary Systems of Innovations*. Van Gorcum Press, Assen. The Netherlands.