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Systems Thinking in Economics, Science and Innovation Policy

Roberto E Lopez–Martinez[1]

Manchester Business School, The University of Manchester and Instituto de Ingeniería, Universidad Nacional Autónoma de México (UNAM)

E-mail:

robertol@servidor.unam.mx

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[1] This article is derived from doctoral research carried out at Manchester Business School and sponsored by UNAM. Permanent address: Tlalpan 4456 A–802, 14050 Mexico, DF, Mexico. Tel: + 52 55 5623 3600 ext. 8102. Fax:+ 52 55 56223611. E–mail: robertol@servidor.unam.mx

Abstract

This article suggests an alternative approach to the use of systems notions in the field of innovation policy. Within this framework, it is shown that science and technology policies include elements, structure and methods derived from systems thinking since its inception. These are reflected in the structuring of a control mechanism or purposeful system to promote knowledge generation and its subsequent social and economic benefits. Therefore, the main argument is not centred on the perception of economic phenomena as a system but in the way in which innovation policies constitute a system. The actual design and implementation of this mechanism by the OECD is also discussed, and it is argued that despite the evolution and refinement of its methods its basic structure has not changed over time.

Keywords

Systems approach, innovation systems, innovation policy.

1. Introduction

The notion of systems has been broadly used in innovation policy studies[2], particularly since the publication of diverse and heterogeneous works using the concept of national system of innovation (Freeman 1987; Lundvall 1992a; Nelson 1993). These have stressed the need to use a holistic approach to address the study of the production and diffusion of economically useful knowledge and suggest a general framework consisting in the decomposition of the economic system into the elements and interactions that constitute innovation processes.

[2] We will use the concept of innovation policy with the current meaning that synthesises science, technology and innovation policies.

Despite having some theoretical problems, such as theoretical diffuseness (Edquist 1997, 2005), the framework has had a surprising diffusion and some of its aspects have been either adopted by innumerable scholars, policy analysts politicians and international organisations, or adapted as departing point for similar approaches such as sectoral and regional systems of innovation and technological systems (Breschi and Malerba 1997; Carlsson 1994; Cooke et al. 1997). However, given the theoretical ambiguity of the notion this diffusion has implied different interpretations. In what follows we will briefly discuss the origin of the concept of innovation systems and the main subsequent interpretations.

The origin of the use of the notion of systems associated with innovation studies can be found in the evolution of the concept of innovation. Particularly, when interactive models of this process were developed in opposition to the dominant linear view and which implied also the participation of a broad group of agents. Andersen (1994) suggests that this association can be found in the works of several scholars related with Christopher Freeman and SPRU. There is for example, an OECD study prepared by Keith Pavitt in the early 1970s where the notion of innovative system is used referring to the factors and interactions that make possible the innovation process. While discussing the methodological framework of the report on the conditions of success in innovation, Pavitt mentioned the possibility of addressing this process "as a system of creating, coupling, transfer and use of information" (OECD 1971a, p. 22). However, given the complexity of the model involved and the lack of empirical information, a simpler approach was chosen.

These interpretations of the innovation process are perhaps more related with notions such as social networks than with systems, since these latter have particular, more complex connotations than the interaction between components, which will be explained in section 2. Nevertheless, what is clear is that these early associations between systems and innovation implied the conceptualization of this phenomenon as a non–linear process involving the coordinated participation of a wide range of actors.

The subsequent use of the notion of systems of innovation, in the late 1980s and early 1990s, involved an extension of the network conceptualisation of the innovation process to include the role of institutions and to a certain extent some aspects of evolutionary economics. It has been extensively discussed that there is not a unified notion of systems of innovation[3], since the main proponents corresponded to different research traditions, where probably the common denominator was Schumpeter. However, apart from the similarities between approaches suggested by Edquist (1997, 2005), it seems that the 'basic original interpretation' was aimed at explaining national patterns of growth and economic development through the analysis of the interactions between the actors and institutions participating in innovation networks[4].

Linked with this primary objective, there was also an implicit or explicit policy orientation that is more clearly stated in the Aalborg version in terms of 'institutional learning' (Dalum et al. 1992). It could be said that this original interpretation was some sort of 'appreciative' evolutionary framework to explain national innovative performance. The main structure of the framework consisted of actors, institutions and relationships involved in innovation activities and from this probably followed

[3] The classic reference in this respect is Charles Edquist (1997); another early analysis of these differences was made by Maureen McKelvey (1991). Subsequent works of the main proponents usually make reference to the differences between their frameworks (Freeman 1995; Freeman 2002; Lundvall et al. 2002; Nelson and Nelson 2002).

[4] There are some similarities between our analysis and that of Sharif (2006), concerning the origin of the national innovation system concept (see for example our analysis in section 5). However, while this approach is focused on the social construction of the concept, ours is devoted to the influence of systems methods in the development of science and innovation policies.

the association that it was possible to refer to specific, national innovation systems, i.e. elements and interactions constituting systems at the national level.

Despite the policy orientation, none of the original approaches included an operational version of the systems of innovation approach. This has been mainly developed by the OECD, which adopted the notion since the late 1980s (David and Foray 1994; OECD 1992). From this followed what can be called the ‘generalised interpretation’ of the systems of innovation approach which implies that particular systems can be sufficiently described by enumerating the main components involved in innovation processes and analysing some of their relationships. From the analysis of how these interactions shape successful innovation systems it follows that, either missing components and institutions or best institutional practices can be also identified as guides for international institutional learning. This generalised interpretation has been refined in several OECD reports (OECD 1994, 1999, 2002) as well as in studies carried out by other international organisations such as those of the European Union (Edquist et al. 1998; Soete and STRATA-ETAN Expert Group 2002) and is usually the one used in the plethora of studies published in the literature that refer to innovation systems.

While the original and the generalised interpretations seem to be very similar, there are subtle theoretical differences that from the point of view of some of the original proponents are of considerable importance. These are mainly referred, firstly, to the limits of international institutional learning with regard to historically determined path dependency (Lundvall and Tomlinson 2001). And, secondly, to the shift from allocation to innovation and from decision–making to learning (Andersen et al. 2002; Lundvall 1992b; Lundvall et al. 2002). This shift of perspective seems to be more a theoretical construct to emphasise the opposition of this approach to orthodox economics than a realistic view of policy–making. And it is reflected in the fact that the policy recommendations included in *National Systems of Innovation* (Dalum et al. 1992) as well as the literature concerning 'system failures' (Carlsson and Jacobsson 1997; Malerba 1996; Smith 1998), cannot escape from the allocation–decision–making framework. Nevertheless, what these differences emphasise is the orientation of the systems of innovation approach as a theoretical structure to make detailed case studies aimed at identifying features of economic systems that differentiate one national system from another.

The existence of these interpretations suggests therefore, that an in–depth analysis of the systems of innovation framework from the point of view of systems theory could be useful to suggest a unified perspective. However, our purpose for this paper is more limited. We will suggest an alternative approach based on systems thinking, to the use of the notion of systems in the field of innovation policy. And within it we will attempt to show that innovation policies include elements, structure and methods derived from systems thinking since its inception. This implies that the implementation of the market failure rationale and its practical adaptation as well as its theoretical treatment through the works of Richard Nelson and Kenneth Arrow among others, on which these policies are based, have consisted in the structuring of a purposeful mechanism or system. Additionally, we will show that though this system has evolved in its composition and methods, its basic structure has not changed over time. Finally, the actual design and implementation of this system will be also discussed.

2. Basic background for a systems approach to innovation policy

Our purpose for this section is to suggest a different way to use systems concepts within the economic analysis of innovation policies; more precisely, we will use use the systems approach as a means to understand the policy–making processes that affect innovation. This implies that we will make a distinction between the set of measures intended to modify economic processes and the actual economic processes themselves. Our approach will consider the models representing the latter, but will emphasise the role and characteristics of the former.

The first thing we need to do when dealing with problems we want to address from the systems perspective is to define the point of view of the observer who perceives and analyses reality. This is important because systems are intellectual constructs to deal with complexity, but we do not have elements to assert that they actually exist. When an observer identifies systemic characteristics of a particular object, situation or phenomenon, those characteristics are determined by his or her point of view, interests and purposes. This means that the aspects that are essential to define systems, such as components, interactions, boundaries, and so on, are dependent on the particular perspective of the observer. It is also important to make explicit, that while dealing with systems we are not determining absolute facts; we are simply establishing a set of conventions more or less useful for our analysis. Thus, the perspective that we shall adopt in this work corresponds to the point of view of a policy analyst who is observing economic activities and is interested in modifying certain components and processes of the economy to achieve specific goals.

Secondly, it is necessary, at least, to specify the type of system we are dealing with, which in turn implies some taxonomic considerations; and, subsequently it is necessary to adopt a suitable definition of system consistent with and useful for the type of system under study.

Our first assumption is that the policy–making activities, in which we are interested, constitute a subset of reality that interacts with another subset consisting of economic phenomena. It is important to mention that these activities involve actions to observe and to modify the processes that take place within the economic subset. To do this, these activities resort to simplified representations or models of what is happening in the subset it observes, as means to reduce the complexity of the observed reality, as well as several types of mechanisms or tools of observation and transformation, which are inextricably linked to the former.

At first sight it seems that the type of situation we are describing could be treated from the systems perspective, firstly, because it resembles conditions that seem to coincide with a commonsensical notion of systems. Secondly, because this same notion makes us believe that the systems perspective is useful to deal with complex problems, and this one, though simply stated, appears to involve high levels of complexity. Thus, our second assumption is that we can analyse innovation policy problems from the systems approach. However, this is in fact a broad transdisciplinary area that involves the participation of several disciplines from philosophy and natural sciences to engineering and social sciences. Therefore, it will be also important to specify from which area of the systems approach we are going to analyse policy–making activities.

Since the systems approach is based on the hypothesis that it is insightful to consider the apparently chaotic real world not as a set of unarticulated phenomena but rather as a complex of interacting entities, it is natural that a number of general attempts to describe and classify the possible types of systems have been made. These range from the simple and general polar distinctions such as concrete and abstract, living and non–living, open and closed systems, to more ambitious and detailed ones. However, there is yet no generally accepted classification and many of the suggested proposals reflect a particular outlook, interest or purpose that might invalidate any general systems description of the world. For example, we can find in the literature system's classifications based only on behavioural characteristics (Ackoff 1971), and several attempts to define taxonomic principles or general classifications of all possible systems (Boulding 1956; Checkland 1981; Jordan 1968; Mingers 1997; von Bertalanffy 1968).

For our purposes, we think that from the above literature, Checkland's classification is sufficient and useful. This is based on the origin of the entities that can be observed in the real world and suggests that any entity which an observer perceives may be described as a system or as a combination of systems selected from the following five classes: natural, designed physical, designed abstract, human activity and transcendental systems. It is worth noting that according to this classification, social systems, defined very generally as groupings of people who are aware of and acknowledge their membership of the group, are considered as the frontier between natural systems and human activity systems.

Additionally, and most importantly, human activity systems include an account of the observer and the point of view from which his or her observations are made. From this follows that human activity systems *do not actually exist*, they are perceptions of sets of self–conscious activities made by specific observers from particular perspectives. Thus, the crucial difference which distinguishes this from some other systems approaches rests on the use of the term system and its implications, i.e. what is systemic is not the complex real world, but the process of inquiry that is used to explore reality. Consequently, the models derived from this perspective are not attempts to model the world, but epistemological devices used to understand reality and to contribute to the debate about possible change[5]. From the above discussion it follows that our third assumption is that policy–making activities as well as the parts of the economic system with which they interact are human activity systems.

The next aspect to analyse concerns how to characterise and define human activity systems. In this case it seems more appropriate to concentrate on a subclass of them, and assume that that these types of systems are examples of purposeful or teleological entities, i.e. "things some of whose properties are functional" (Churchman 1971, pp.42). We are suggesting then, that innovation policies and its interactions with part of the economic system can be interpreted as constituting a purposeful system.

2.1. Purposeful and sustainable systems

The necessary conditions that something *S* be conceived as a purposeful system include according to Churchman (1971, pp. 42-43) that:

1. *S* is teleological.

2. *S* has a measure of performance.

3. There exists a social entity whose interests are served by *S*.

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[5] We can find a similar approach in systems analysis, particularly in the works of C.W. Churchman (1968; 1971; 1979). Another implication previously perceived by Churchman is that in the process of inquiry the observer becomes part of the complexity he is studying; this issue has also been addressed from the perspective of self–referential systems (Luhmann 1995).

4. *S* has teleological components which co–produce the measure of performance of *S*.

5. *S* has an environment which also co–produces the measure of performance of *S*.

6. There exists a decision maker who can produce changes in the measures of performance of *S*'s components and in the measures of performance of *S*.

7. There exists a designer who conceptualises the nature of *S* in such a manner that the designer's concepts potentially produce actions in the decision maker, and hence changes in the measures of performance of *S*'s components and in the measures of performance of *S*.

8. The designers intention is to change *S* so as to optimise *S*'s value to the social entity.

9. *S* is "stable" with respect to the designer in the sense that his or her intention is ultimately realisable.

This characterisation refers to the system purposefully designed to transform reality. However, we still need a systemic representation of the part of reality within which it operates; to accomplish this, we suggest adopting the viable system model (Beer 1972, 1979, 1985). This is based on the application of concepts from neurophysiology and cybernetics to the understanding of the functional structure of systems. It is a general recursive model containing the sufficient functional elements and structure that any system needs to be viable, i.e. able to maintain a separate existence. The recursiveness of the model implies that one of the functional elements contains a copy of the whole system, generating a series of nested subsystems, all with the same structure. Therefore, the basic structure of the model is able to map and represent any complex system. For example, in our area of interest, we can start the analysis at the level of a firm —a viable system itself, which is part of an industry, which in turn belongs to the private sector, within a national economy, which belongs to the European Union. All the levels of recursion are nested and have the same structure that makes them viable.

Any system that is capable of maintaining its identity independently of other systems within a shared environment performs two fundamental functions: current and long–term stabilisation. These are carried out by two composite subsystems —the system and the metasystem, that operate in different dimensions of recursion and perform five sub–functions: (1) production of the whole system itself; (2) regulation or coordination of the diverse productive components; (3) self–awareness of the system's identity and control; (4) foresight, innovation and planning; and, (5) establishing policies to guarantee the cohesion of the whole (see table 1 and figure 1). Given their nature, production and foresight include an additional function of perception or link with the environment.

[INSERT TABLE 1 ABOUT HERE]

The next important characteristic is the network of interactions that connect the functional components. The nature of the relationships is partly defined by the function of the elements and partly by the characteristics imposed by the purpose of the whole system. These interactions imply the flow of information containing encoded variety[6]. In fact, the whole system is an entity whose main task is to deal with complexity by variety engineering. This means that the system faces an environment which presents a vast number of possible states and thus, it must be capable of generating an equal number of internal states to absorb the variety of the environment. Consequently, its internal network of interactions corresponds to the flow of different types of resources as well as regulations and coordination rules that allow the production components to respond to the variety of the environment. This entire network is structured and regulated by the law of requisite variety (Ashby 1956, 1958), which in a simplified form states that only variety absorbs variety[7].

[INSERT FIGURE 1 ABOUT HERE]

3. The economy as a sustainable or viable system

We are suggesting thus, that any economic entity —a group of nations with shared interests, a nation, a region, a firm, etc., can be represented as viable systems which perform the referred five sub–functions in every dimension of recursion. Naturally, this functional description can adopt quite different organisational structures in each particular case. The detailed mapping of economies as viable systems is out of the scope of this work and we shall refer only to the more general aspects which are related with our purposes[8].

At one of the higher levels of aggregation, let us say at the national level, the economic system is composed of several subsystems or production units which are

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6 In this context, variety is defined as the number of possible states of a system.

7 The structure and characteristics of the viable system model are too complex to be explained here. For a detailed analysis see the original sources (Beer 1972, 1979, 1985).

8 Examples of this can be found in (Lopez-Martinez 2006). We also remit the reader to the original sources of the viable system model which have been mentioned and to Espejo and Harnden (1989).

responsible of the reproduction of the whole system itself. From our perspective, these can be understood as producers of knowledge, either codified or embedded in products, processes or services. In a higher recursive dimension, several other organisations constitute the subsystems that are in charge of self–awareness and control, coordination, foresight and cohesion. We must remember that in each recursion we will find that the same functional structure is repeated, since they are also constituted of sets of viable systems. Therefore, a firm, which could be usually considered the lowest dimension of recursion in an economic system, is also composed of viable systems and has components that perform the functions of production, coordination, control, foresight and cohesion.

If we return to a hypothetical national level, the subsystem that is responsible of establishing the policies that give cohesion to the whole, can adopt different perspectives regarding the strength of its actions and its degrees of intervention. These depend mainly on the tension between internal values and beliefs, as well as in the models representing the system's operation that flow internally and externally and that are out of the scope of this work. However, what is important to remark is that the specific way in which states or governments determine their degrees of intervention in the operation of the whole system is a matter of choice. This defines the particular characteristics of economies that are usually referred as 'economic systems'. One of the aspects that differentiate them is precisely the degrees of intervention exerted through policies, based on specific visions of the system's future, in order to regulate and control the operation of the whole.

Since in cybernetics terms, every regulator must contain a model of that which is regulated, the characteristics of this model will determine the degrees of intervention assumed by the policy subsystem. In market and mixed economies, this model corresponds to a neoclassical interpretation of the economic system. Some heterodox economic interpretations, such as the Nelson & Winter evolutionary model (Nelson and Winter 1982), are from this perspective, of the same ‘family’. We shall explain the differences below, but first, let us have a look at their similarities. These models assume that the particular characteristics of economic processes occurring at the dimension of the subsystem of production, are to a certain extent autopoietic, i.e. the sustainability of the system is almost entirely provided by their interactions, and through these, the system produces the necessary means for its own reproduction. It is then assumed that the function of control is performed by the environment in which the production units operate, i.e. the market organisation. Therefore, state intervention is reduced to establish and fine–tune the regulatory measures that are necessary to guarantee that self–control and coordination occurs. Given that the underlying model is static, the future states of the system are not considered, and consequently, new variety (in this case, knowledge and technology), are also neglected. It is a model that represents the ‘inside and now’[9] of the system.

Nevertheless, this underlying abstract representation has limitations because its assumptions do not occur in the real world. Thus, in practice the state needs to increase its level of intervention in terms of regulatory measures as well as in terms of auxiliary control mechanisms that will help to compensate disturbances of the real world affecting the assumptions of the model that are hindering the self–control function of the system. It also happens that in real situations, governments are not

[9] Using Stafford Beer’s terms.

‘blind’ with respect to the future states of the system and this fact implies further reasons to increase its influence over the control and regulatory mechanisms.

These latter aspects make evident the differences between orthodox and heterodox interpretations of the economy when perceived from this systemic interpretation. Some of these latter, such as the neo–Schumpeterian explanations, are dynamic and oriented to understanding the changes of state of the economic system. Therefore, they focus on the system’s processes in charge of surveying the environment and generating change in the current operation of the system, i.e. in foresight, planning and innovation. Consequently, though they share the view of self–control through the market operation, these explanations provide detailed knowledge concerning the dynamics of change, which imply the introduction of variables not included in the neoclassical model. These considerations also imply different perceptions of the processes allowing self–control and their potential disturbances.

Up to this point, we have shown how systems principles can be used to describe some aspects of the operation of an economy. We have also briefly described the underlying model determining the balance and influence of the different functions that maintain the identity and stability of the system in market and mixed economies. From this we have derived a systemic explanation of the rationale for government intervention through policy measures in order to regulate the whole system and allow the market to perform its self–control function. In the next section we shall describe how innovation policies, which correspond to an area of government intervention in economic processes, constitute an auxiliary system to the self–control function.

4. Innovation policy as an auxiliary control mechanism

Since its inception, innovation policy has been perceived fundamentally as involving a problem of allocation of resources. Given the assumption that the market performs the self–awareness and control function in the economic system, it is natural that the solution for this allocation problem has relied primarily on elements taken from the dominant economic theory, i.e. the theory of general equilibrium, the Pareto optimum and consequently on the market failure argument.

The structuring of a purposeful system of innovation policies —of the type defined at the beginning of section 2.1, has then been implemented through the introduction of an auxiliary control or regulation mechanism. The general functional components of such a mechanism consist of a feedback cycle with two inputs: the goal —preferred values for the system's essential variables; and, the disturbances —processes in the environment affecting those variables and which are not under the system's control. In addition, the mechanism has instruments for perception or monitoring of the variables —memory or information storage capacity is associated with this function and it allows learning and adaptation, as well as a set of specific actions to affect part of the environment. As was mentioned above, the control mechanism also needs a model or simplified representation explaining the main processes taking place in the whole system —i.e. the neoclassical framework, to make sense of the behaviour of the essential variables and the perturbations that affect them[10].

[10] Compare this general structure with that of a decision problem which requires: (1) an objective function defining the desirability of different outcomes; (2) specification of the policy alternatives available to the decision–maker; (3) specification of the model that links the objective function or the variables with the policy alternatives; and (4) computational methods for choosing among policy alternatives those that perform best as measured by the objective function. See for example Arrow (1957a; 1957b).

The concrete function of the control mechanism has been, thus, to correct the imperfections of the market organisation in the allocation of resources for research and innovation activities. This derives from the realisation that the axioms that support the hard–core propositions of general equilibrium theory, do not occur in real situations involving R&D activities. Therefore, the actual economic system is inefficient in the absence of government intervention. The analysis of these imperfections, which are generally described as the presence of *indivisibility*, *uncertainties*, *externalities* and *collectivities*, has been carried out for decades, either within orthodox economics, or outside it, in this latter case mainly as part of the series of criticisms to the dominant model, and does not need to be repeated here (Bator 1958; Dasgupta and David 1994; Geroski 1995; Metcalfe 1995; Stiglitz 1988). Nevertheless, it is useful to recall that in our area of interest, the market failure argument is frequently referred to as the *Arrow–Nelson rationale*, since these scholars stressed the economic importance of financing basic research and innovation and suggested the economic justification to do so within the neoclassical framework (Arrow 1962; Nelson 1959a, 1959b).

From the sources of market failure, Richard Nelson, on the one hand concentrated on the analysis of the problems of externalities and inappropriability associated to performing fundamental research. He pointed out that since basic research is not a homogeneous commodity it is difficult to assert, based on welfare economics, whether the levels of expenditure for this activity are adequate or not. However, he clearly showed that the referred market failures would prevent socially desirable levels of expenditure in research and suggested the necessity of encouraging the growth of what he called a ‘basic research industry’.

Arrow, on the other hand, focused his attention on the problem of allocation of resources under uncertainty, pointing out that the economic system has imperfect and limited devices to deal with risk. His analysis was based on the treatment of knowledge as information and of invention as the process to generate information. Subsequently he addressed the problems arising when information becomes a commodity under conditions of uncertainty. With this method, he was able to demonstrate that a free–enterprise economy would:

> "… underinvest in invention and research (as compared with an ideal) because it is risky, because the product can be appropriated only to a limited extent, and because of increasing returns in use. This underinvestment will be greater for more basic research. Further, to the extent that a firm succeeds in engrossing the economic value of its inventive activity, there will be an underutilization of that information as compared with an ideal allocation" (Arrow 1962, p. 619).

He thus concluded that for optimal allocation to invention it would be necessary for the government or some agency not governed by profit–and–loss criteria to finance research and invention. Arrow also pointed out two arising problems associated with this intervention to correct market failures: determining the amount of resources devoted to invention, and encouraging efficiency in the use of those resources.

Considering that the limitations of the neoclassical model have been recognised for a long time, the structuring of a mechanism that corrects deficiencies of an imperfect model, implies a philosophy justified by cybernetics and operations research in as much as the ultimate aim of a mechanism is not understanding, but control, i.e. if a system is too complex to be understood, it may, nevertheless, still be controllable. The only thing that a controller needs to find is some action that gives an acceptable result

(Ashby 1958). Thus, in this case, the Arrow–Nelson rationale represents the identification of a flaw affecting the proper functioning of the control subsystem that has an important impact in the self–reproduction of the whole economic system. It not only determines particular perturbations violating the conditions imposed by the abstract model of the economy, but identifies a variable not included in the original model, which in turn is also affected by those perturbations. The inclusion of this variable also implies that the dynamic behaviour and properties of the system have been taken into account. Actions to correct the malfunction of this variable, allowing self–control and reproduction, are then necessary.

The simplified logic of the mechanism is as follows: given an accepted representation or model of the nature of the system, its general purpose is to maintain the system's essential variables stability close to a predefined goal To perform its task the mechanism needs a variety of actions affecting those variables, to compensate the variety of disturbances that cause the system's instability as well as monitoring instruments to provide feedback and make adjustments (see figure 2). In addition, this rationality implies that actions outside the limits of those established to compensate the perturbations are not permitted since they would cause further disturbances to the system. This consideration naturally implies that the whole is being taken into account within the limits of the framework used.

[INSERT FIGURE 2 ABOUT HERE]

The goals of control systems can be displayed across several hierarchical levels, however, since a higher number of layers could decrease its efficiency it is usually best to maximise the regulatory ability of a single layer. Thus, in our case, we have an ultimate goal which could be stated as: to increase the economic and social benefits of scientific and technological research. This goal assumes that there is a relationship between science, technology and social and economic benefits. It should be observed that the nature of these relationships could greatly affect the expected outcome, and thus, taking it into account increases the level of design complexity of the mechanism. For the sake of simplicity, let us say that this is an area of uncertainty that requires additional knowledge, but that the assumptions made in the design of the mechanism —and in fact this was the relationship considered by Nelson and Arrow in their articles, are that these relationships are linear, i.e. the more scientific research we perform, the greater the chances we have to advance technology and both combined have a positive effect in the economy and society.

The important aspect is that this ultimate goal is transformed into a resource allocation problem within the orthodox economic framework, i.e. maintaining a 'socially desirable' level of expenditure in R&D. However, as Nelson and Arrow observed, the determination of that level of expenditure is very difficult to estimate by means of welfare economics due to the presence of uncertainty, i.e. balancing marginal social benefits of resources devoted to research and alternative uses. In practice, this problem has been addressed by establishing international benchmarks or best practices concerning levels of expenditure, and by assessing the outputs of research in terms of impacts in competitiveness and innovation. Naturally all this implies indicators and methods of measuring performance which will be referred below.

The disturbances impact the stability of the system, by altering the behaviour of certain essential variables. In this case, these consist mainly of diverse inputs to R&D

activities, such as human, physical and financial resources. Consequently, the outputs of these activities, i.e. social benefits are also affected. As mentioned above, the perturbations that have been identified as impacting the system are derived from concrete conditions that occur in the real world and constitute a violation of the postulates that support the theoretical model that represents the economic system. Therefore, it is important to remark that the acceptance or rejection of this theoretical model does not imply that the conditions, which the dominant interpretation identifies as disturbances, do not exist. Once these conditions have been identified, it is necessary to count with the sufficient variety of actions (requisite variety) to compensate the alleged disturbances.

As different scholars have shown, these actions can be synthesised in two generic types of actions: lowering the cost of R&D activities and restricting the exploitation of knowledge. Our mechanism uses two methods to deliver these solutions: passive absorption of the disturbance and direct actions to compensate its effects. The former consist in the use of buffering to reduce the effect of disturbances, such as the case of intellectual property rights. The latter consists of the well known set of measures to correct market failures that include among others: the support of public research, direct subsidies to private research, indirect subsidies through tax mechanisms, provision of information, enhancing the links between users and suppliers of knowledge, etc.

The final basic component of the control mechanism involves the instruments of perception that are essential for feedback concerning the concrete determination of the goal and the efficiency of the overall system. These comprise generically, the structuring of a system of measures of performance; and, particularly involve the development of methods of evaluation, priority setting, forecasting and foresight of research activities. It is important to remark that the fact that the control mechanism is based on a neoclassical interpretation of the economic system does not prevent it to use sources of knowledge outside the limits of this framework; the only thing that is forbidden is the use of actions that are outside those limits. Therefore, the monitoring instruments are crucial to enhance the ability of the system to determine and fine–tune its goal as well as to refine its knowledge concerning the dynamics of the system, the particular characteristics of the disturbances and consequently the variety of actions needed.

4.1. Robustness and persistence of the control mechanism

In synthesis, this control mechanism puts together the dominant interpretation of the economic system and the supplementary knowledge it needs to operate but that is not offered by the simplified orthodox representation. The salient characteristics of the former are its reliance on the market mechanism, the disturbances that make the market inefficient, and the set of basic actions allowed to compensate the identified disturbances. The latter includes as fundamental component, means to increase the understanding of the dynamics of knowledge generation, diffusion and exploitation. All this knowledge is used in turn to fine–tune the detection of disturbances and their corresponding actions, as well as the role played by these in the achievement of the goal. Paradoxically, most of this knowledge has been systematically developed by heterodox economics. An additional characteristic is derived from systems theory and its own system properties: it can be generalised to economic systems displaying similar properties. This in turn is not an obstacle to make the necessary adjustments for particular situations, which are based on heterodox knowledge.

We argue that the basic components and structure of the mechanism have not changed since its inception. This occurs partly because the heterodox approaches have not offered yet an integral alternative to substitute the model and partly because to a certain extent they partially accept some of the basic components of the orthodox model. Thus, although they use radically different methods and offer more complex explanations concerning the operation of the economic system, they accept the function of the market as mechanism of allocation of resources as well as the existence of conditions of uncertainty, indivisibilities, collectivities and externalities in the production, diffusion and exploitation of knowledge, as can be shown by the following quotation from works within the evolutionary tradition:

> "There is a pragmatic case for market organization that I believe is richer and more persuasive than the neoclassical case. It is that while market organization as it actually is does not achieve 'Pareto optimality', market organization and competition often does seem to generate results that are moderately efficient" (Nelson 2003, p. 700).

> "Externalities and publicness have similar meanings in evolutionary theory and in orthodoxy, and are seen to pose requirements for regulation and collective–choice machinery" (Nelson and Winter 1982, p. 366).

Therefore, two fundamental aspects underlying the control mechanism are kept and despite the alternative approaches imply different relationships —from those of orthodox economics, between market operation and what we have been calling disturbances, from the point of view of the policy–maker it is easier to assume them as failures that reduce the efficiency of the market. In addition, the theoretical and empirical literature concerning the explanation of this market–disturbances relationship has not been able to provide convincing arguments invalidating the relative operative efficiency of the market failure rationale. For example, a careful analysis of what some authors call system failures (Carlsson and Jacobsson 1997; Smith 1998), or evolutionary traps, trade–offs and failures (Malerba 1996), as well as their remedies, reveals that in the last instance these disturbances could be accounted as problems of underinvestment resulting from uncertainty, externalities, etc. This however, does not prevent the control mechanism from adopting knowledge generated by these alternative studies which could be useful to increase the variety of the set of actions to correct the disturbances. There is thus, reciprocal complementarity between approaches while addressing concrete problems, inasmuch as each framework feeds on and extends the other.

In addition, heterodox approaches, at least those closely associated with innovation policies, have not offered yet an integral and generally accepted approach targeted at modifying the main functions of the control mechanism, i.e. one including a different model of the economic system, its factors of disturbance and consequently the actions and main goal of the mechanism.

Without these, policy–making activities have had no other alternative than to rely on the traditional ones to identify disturbances in the system, and consequently, the specific measures and goals of the overall control mechanism have remained without significant changes. This argument is reinforced by the fact that in practical terms, innovation policies are embedded in economic policies. If these latter are also based in the dominant framework of orthodox economics, we cannot expect significant changes in the former. This is reflected, for example in the fact that several international agreements and treaties involving trade relationships include regulations concerning state intervention for the support of innovation activities, and these are also based on the market failure rationale. Therefore, innovation policies at national levels have to comply in the last instance with this internationally agreed underlying principle.

This is not to say that the knowledge derived from the in–depth study of the dynamics of innovation processes has not been useful or incorporated into policy making. It is evident for example, that the linear model has been almost completely superseded and that this implies a great deal of refinement on the goals of the regulating system and on the variety of specific actions to achieve these. There are also innumerable advances in measures of performance and evaluation, priority setting and foresight methods, and many other areas of the process of innovation. However, despite these refinements, the ultimate goal of science and innovation policies is still stated in terms of achieving a relatively arbitrary and ideal level of expenditure on R&D.

5. Implementation and diffusion: the OECD system

The basic structure of the control mechanism to influence the generation of knowledge, which in turn was expected to have social and economic benefits, was shaped in the aftermath of World War II. The classic example of one of its earlier incarnations is the Bush report, *Science the Endless Frontier* (Bush 1945), which lead to the creation of the National Science Foundation and associated organisations in the United States. Despite it has been criticised as a linear approach mainly oriented to the funding of basic research, it included at least the following elements: firstly, goals which were equally distributed between the exploitation of knowledge for social and economic reasons as well as to guarantee the continuous provision of new knowledge. Secondly, sets of actions that included not only measures directly related with the organisation and funding of research, but also instruments concerning the creation of framework conditions to encourage industrial involvement in innovation. And finally, a clear definition and delimitation of diverse components interacting at different levels for the generation of knowledge and its commercialisation —the military and the industrial sectors, the research and educational apparatus, the international scientific resources, as well as the government bodies, programmes and financial resources.

The theoretical aspects of the application of this initial control mechanism were an important concern of economic theory by the late 1950s and early 1960s[11]. Subsequently, with these antecedents, the OECD set up a more powerful system to promote the generation of knowledge. We must remember that we have been referring to processes occurring in two dimensions: the control mechanism or purposeful system of policies and the production subsystem that is affected by the former. The power of the OECD system of policies rested on its clear perception of these two dimensions through systems analysis, and the consequent generic structure of its control mechanism that included[12]:

1. A clear definition of the goals to be achieved by the production subsystem and the performance measures to assess the influence of policies in the achievement of the goals. The ultimate goals concerned the continuing generation of a knowledge base and its exploitation in order to obtain economic and social benefits. These were transformed in a resource allocation goal. The measures of performance had a twofold role: while providing data

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11 See for example the already referred works of Arrow and Nelson or the contributions included in the volume edited by Richard Nelson (1962), .

12 A detailed analysis of the OECD system can be found in (Lopez-Martinez 2006).

for the evaluation of actions they also acted as means to redirect and shape the activities under scrutiny.

2. An analysis of the environment and constraints of the production subsystem. The OECD contemplated three environmental levels: the areas of social and economic activity influencing and influenced by knowledge generation, the national economic environment and the international economic and scientific environments

3. An identification of the main components of the production subsystem and their function concerning the achievement of the goals. This functional definition was centred on the agents performing research activities as well as their interaction with other areas of economic activity.

4. An analysis of the diverse types of resources used by the components. These, which included human, physical and financial assets, were translated into allocation of funds issues through the national research budget. The inadequacies of the market mechanism to allocate resources were implicit in several parts of the Piganiol report (OECD 1963/1965) —which can be considered as the initial version of the OECD system, and explicitly discussed in *Science, economic growth and government policy* (Freeman et al. 1965), presented in the First Ministerial Meeting of Science, in which the report constituted the main background document.

5. A management unit to coordinate the set of actions intended to influence the distribution of resources among the components of the production subsystem towards the achievement of the goals. The original recommendation consisted

in the creation of national advisory bodies responsible of: (i) the formulation of the policy for science and technology; (ii) the coordination of the various scientific and technological activities; and, (iii) the horizontal integration of science and technology measures with other areas of national policy. It was also emphasised that each country should design this advisory body according to its own political history, institutional structure, tradition and the nature, characteristics and complexity of its problems. The basic set of actions or policy measures is presented in table 2.

[INSERT TABLE 2 ABOUT HERE]

The OECD system was designed to operate at the national level and its complete structure was already present in the Piganiol Report (OECD 1963/1965). Simultaneously, other group of experts developed the supplementary set of performance measures known as Frascati Manual (OECD 1963/2002). It can be observed that the structure of the mechanism includes all the elements that characterise a purposeful system as defined at the beginning of section 2.1, where the OECD assumes the role of co–designer of the system. The adoption of systems methods is related with the wide diffusion of systems analysis during the 1960s, which had an especial impact in policy making activities in several areas. The OECD document known as Brooks Report makes an explicit reference to this influence: “The second phase [of the political climate of science] extended from about 1961 to 1967 and was characterised by the gradual emergence of economists and systems analysts as significant influences in science policy”[13].

[13] (OECD 1971b) p. 39; see also (Salomon 1977). For particular applications of systems analysis see (OECD 1972).

As discussed in the previous section, the structure of the control mechanism allows refinements in terms of the actions oriented to the achievement of the goals. These have been derived from the development of knowledge concerning the specific dynamics of science, technology and innovation, which has been carried out within several currents of economic thought. The assimilation of this knowledge into the OECD system is evident in the key documents that have revised the system (OECD 1965, 1971b, 1980, 1992) and in the evolution of the 'Frascati family' of performance measures. The adoption of the notion of 'national innovation systems' in the late 1980s, is therefore, one of such refinements. What we have called the generalised interpretation of systems of innovation is then, the result of the evolution of the control mechanism.

6. Conclusions

We have attempted to clarify several aspects concerning the use of the systems approach within economics and particularly in the analysis, design and implementation of science and innovation policies. Since the systems movement includes a broad range of disciplines and areas of research, some clarification of concepts was necessary to delimit the scope of our work. In this respect we should mention that our use of systems methods is not new to policy–making studies but it has been absent from innovation policy literature in recent years.

Our main proposal consisted in suggesting a systemic framework to understand the operation of policy–making activities within the economic system. This is intended to derive generic principles applicable to any system sharing the same functional properties. Within it, economies are perceived as sustainable or viable systems that perform two essential functions —current and long–term stabilisation, and five sub–

functions —production, regulation, control, foresight and cohesion. Both functions and sub–functions take place at two different dimensions of recursion.

The recursiveness of the model implies systems constituted by nested subsystems with the same functional characteristics and allows the mapping of activities from the lowest to the highest levels of aggregation, i.e. from basic production units to groups of nations. For our particular purposes, the basic production units are perceived as producers of embedded and codified knowledge.

Within this framework we have suggested that, in market and mixed economies, science and innovation policies constitute an auxiliary control mechanism that allows the control function of the whole to achieve the system's self–reproduction and control. The implementation of these policies requires the adoption of abstract representations of reality that in the case of knowledge generation has consisted in an orthodox economics framework whose operative representation corresponds to the so–called Arrow–Nelson rationale. We have also suggested that this adoption has implied the structuring of a purposeful learning system to control the disturbances of the market organisation within the economic system. The mechanism is characterised by a hybrid nature in the sense that its basic structure depends on a neoclassical model of the economy, but its components and methods feed on knowledge derived from heterodox economic approaches.

Therefore, this particular configuration has allowed evolution and refinement of the system without changing its basic structure. Our main conclusion in this respect is that the alternative approaches to mainstream economics have provided knowledge concerning partial aspects of the innovation policy–making mechanism. Nevertheless, they have not been able to promote a shift in the basic structure and rationale because they have not offered a comprehensive proposal to substitute the existing one. Such a proposal should include at least an operational alternative model of the economic system, means to establish the desired goals, and consequently, the disturbances affecting the achievement of the goals and the actions to compensate such perturbations.

Our interpretation has also made explicit a different hierarchical structure between some parts of the economic system and policy–making activities. These latter are naturally considered as part of the overall system, but they differentiate from the actual production system and its function is to constitute and shape part of the environment within which this operates.

The model that we have described is thus, analytically applicable to any economic system. Naturally, each one of them has its own particular characteristics, which imply different ways of understanding and performing the five sub–functions of the model and consequently different ways of variety engineering. These are exclusive and unique of each case. However, we have shown that the activities of innovation policy —originally conceived as science and technology policy, involved implicitly or explicitly systems methods. They were used as means to simplify complex problems and to implement transformations aimed at modifying reality. The underlying philosophy implied that it is not necessary to completely understand a complex phenomenon to be able to control it. This is to say that once that some goals had been established by politicians, scientists determined sets of basic actions to obtain acceptable results in the achievement of the goals.

We have also mentioned that the OECD has had a crucial role in the design of the control mechanism and its promotion among its members. Apart from the functional structure of the mechanism, the systems analysis methods used in its design account for its successful diffusion. One of the implications of our suggested model is that what we called the generalised interpretation of systems of innovation is precisely the successor or the latest version of the control mechanism developed since the mid–1960s. It corresponds to the incorporation of the synthesis made by the original proponents of systems of innovation into the logic of its structure.

A final implication which can be derived from our analysis is that the neoclassical framework is quite consistent with the systems approach and its philosophy, in contrast with some of the claims made by the original systems of innovation advocates. This assertion does not imply any judgement about this framework, apart from its systemic nature, or that we agree with the neoclassical explanation of the economic system. It is mainly oriented to promote further study of these issues as well as a deeper involvement of innovation policy studies within the systems approach.

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Table 1. Functions and dimensions of viable systems

Fundamental function	Local function	Dimension of recursion
Current stabilisation	Production	*n* (system)
Current and Long–term stabilisation	Regulation	Link between *n* and *n+1*
Current and Long–term stabilisation	Control	Link between *n* and *n+1*
Long–term stabilisation	Foresight	*n+1* (metasystem)
	Cohesion	*n+1* (metasystem)

Table 2. Basic policy actions of the OECD system

General Objective	Specific Actions
Coordination of policies across main government departments	Determination of priorities in the government programmes of oriented R&D
Creation of a general environment for innovation	Support for the 'scientific infrastructure' (education and fundamental research)
	Policies to encourage R&D and innovation in the business sector[14]
	Ad–hoc institutions to finance the development of inventions
	R&D loans
	Fiscal policies.
	Government procurement policies
	Encouraging cooperative research
	Improving technical communications and advisory services
	Training policies to improve management and expertise devoted to technical change
	Promotion of university–industry linkages
International cooperation	Standard indicators and information
	Exchange of experiences
	Harmonisation of policies
	International scientific cooperation
	Assisting countries in the process of development

Sources: Freeman et al. (1965) pp. 105-111; OECD (1963/1965) pp. 167-171; (1971b) pp. 89-108; and (1980) pp.93-107.

[14] From the 1970s onward, policies oriented to the business sector include two broad approaches: those of a general nature and specific sectoral policies.

Figure 1. The viable system model

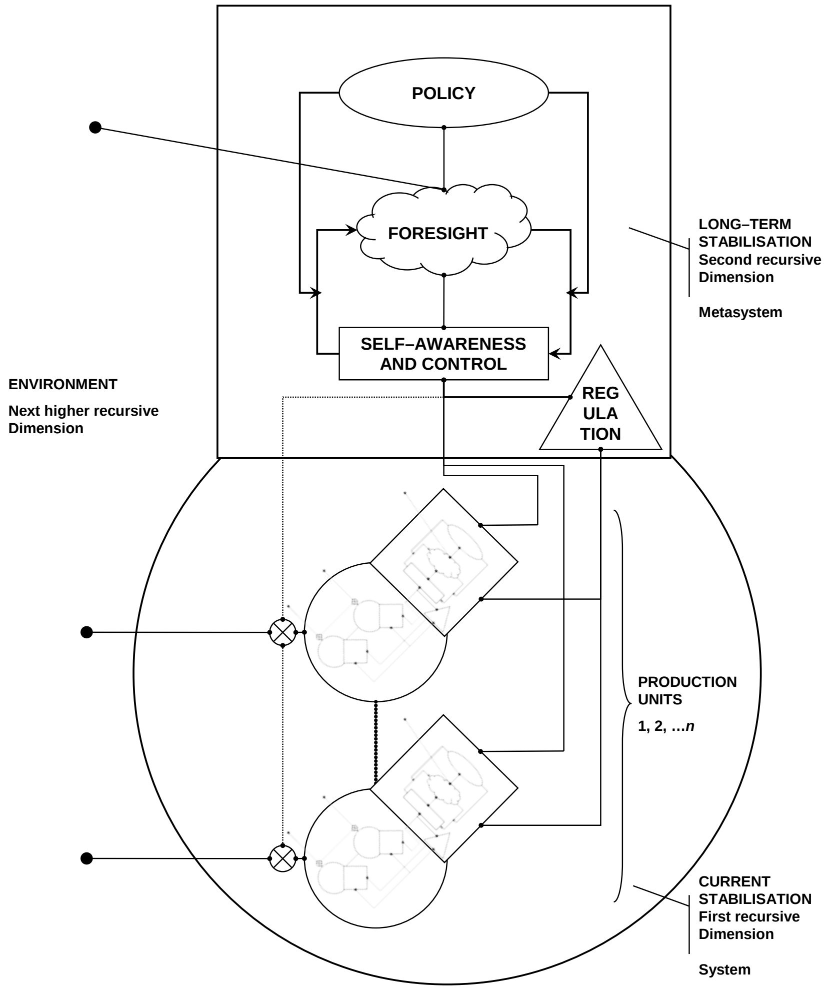

Figure 2. Innovation policy as a control mechanism