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Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars

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Systemic policy instruments are receiving increased attention among innovation scholars as a means to stimulate sustainability oriented technological innovation. The instruments are called systemic in the expectation that they will improve the functioning of entire (innovation) systems. A first step in designing systemic instruments is an analysis of the systemic problems that hinder the development of a specific technological trajectory. This paper argues that two approaches to studying innovation systems—structural and functional analyses—can be combined in a systemic policy framework that helps to first, identify the systemic problems; and second, to suggest the systemic instruments that would address these problems.

Keywords: innovation policy, systemic instruments, systemic problems, technological innovation system, functions of innovation system.

1. Introduction

Current pathways of economic development are not sustainable. Most developed and developing economies are heavily dependent on fossil fuels, leading to enormous negative environmental effects. These economies are characterised by a huge throughput of materials, chemicals and products that lead to depletion of resources, loss of biodiversity and pollution of the environment. According to Rockström et al. (2009) the world is no longer functioning in a safe operating space. Policy makers are trying to change the direction of technological change by innovation policies that address society's grand challenges (European Commission 2011)

Systemic instruments are receiving increased attention among innovation scholars and policy makers as novel means that can bring about these processes of change and stimulate sustainability oriented technological innovation (Smits and Kuhlmann 2004; Raven et al. 2010; Voss et al. 2009; van Mierlo et al. 2010). According to Smits and Kuhlmann (2004) systemic instruments are tools that focus on the level of the innovation system instead of focusing on specific parts of innovation systems and support processes that play a crucial role in the management of innovation processes. The basic idea behind systemic instruments is that they aim to address problems that arise at the innovation system level and which negatively influence the speed and direction of innovation processes. These problems are often referred to as systemic weaknesses or systemic failures. They hinder the operation and development of the innovation system as a whole and the presence of these system failures is often considered to be a new policy rationale, replacing the neoclassical market failure (Edquist 1997). Examples include: innovation networks that are either too weak or too strong, and poorly articulated demand for innovation or institutional capacity problems (Smith 2000; Jacobsson and Johnson 2000; Klein-Woolthuis et al. 2005). While the literature is rich in various categorisations of systemic problems, not much is being said about how to systematically identify them and what type of tools will best address them. Even more surprisingly, the literature on systemic instruments is poorly linked to the literature on systemic problems. The key article on systemic instruments by Smits and Kuhlmann (2004) does not build further on the systemic failures identified in the above literature.

This paper argues that two approaches to study innovation systems—the structural and functional analyses—can be combined together and provide analytical building blocks of a systemic policy framework that helps to: (1) identify systemic problems; and (2) suggest systemic instruments to address the obstacles that are identified. Structural analysis has long been used to evaluate and compare the composition of mostly national innovation systems in an attempt to clarify the determinants of varying rates of innovation (Nelson 1993; Freeman 1988, 1995; Schmoch et al. 2006). However, structural analysis has proved insufficient for the analysis of technological innovations. Thus, the functional approach emerged to highlight the processes (rather than the structure) that are important for a good performance of technological innovation systems (TISs). The processes are categorised as functions of innovation systems (e.g. entrepreneurial activities, knowledge development, market formation), and they aim to clarify how well an innovation system is functioning (Johnson 2001; Bergek 2002; Hekkert et al. 2007; Bergek et al. 2008).

The structural and the functional analyses, as well as the systemic problems and systemic instruments concepts, all have the same systemic–evolutionary foundations but they were developed separately from each other and they are therefore poorly aligned. They are also used rather individually to inform the policy process. Each is of a different kind and concerns different aspects of the policy process (analysis, identification of problems, design of policy tools). If linked together into a consistent policy framework, they could show a much more complete picture of the system being analysed and its problems, and thus lead to more effective policies to accelerate the process of sustainable technological change.

The best attempt so far to integrate the different concepts is that presented by Bergek et al. (2008). The authors incorporated elements of structural analysis into a functional analysis of innovation systems to better explain the inducement and blocking mechanisms in technological innovation systems, to identify key policy issues and to set policy goals. Their contribution, however, criticises systemic problems for their structural characteristics; it does not refer to the currently most advanced categorisation of systemic problems by Klein-Woolthuis et al. (2005) and instead proposes inducement and blocking mechanisms, without clarifying how they differ from systemic problems. There is also a lack of theoretical clarity with regards to the typology of the inducement and blocking mechanisms. Being derived from empirical cases they encompass a mix of endogenous and exogenous factors which hinder innovation systems and it is not clear whether all possible mechanisms have been identified or whether the list can further be extended. In the case of mapping the structural components, the paper emphasises the importance of the presence of actors, networks and institutions. It does not, however, elaborate on the issue of the actors' capabilities or institutional capacities and it gives no thought to infrastructure as an element of an innovation system, despite some studies that show that missing infrastructure may also cause a systemic problem (Klein-Woolthuis et al. 2005; Chaminade and Edquist 2010). Finally, Bergek et al. identify key policy issues without any reference to the work on systemic instruments, or to how useful such tools might be in addressing the obstacles that are identified.

This paper aims to address these gaps. In particular it shows why structure is so important for explaining systemic problems. It also clarifies the relationship between systemic problems and blocking mechanisms and proposes a method to methodologically link the structural and functional analyses with systemic problems and systemic instruments into a consistent policy framework. Before proposing the framework, however, this paper reflects on the various conceptualisations of structural elements, functions and systemic problems, and identifies categorisations which reinforce their mutual complimentarity and thus help to build a consistent policy framework. Such a reflection is necessary because the concepts are not fully agreed upon in the communities that use them.[1] Since systemic instruments (Smits and Kuhlmann 2004) are not very clearly defined in the literature either, this paper draws some preliminary implications for their desired characteristics.

The rest of this paper consists of five sections. Section 2 reviews the structural elements of innovation systems. Section 3 focuses on the functions of innovation systems and proposes a way to link them with the structure. Section 4 defines and categorises systemic problems. Section 5 reflects on the characteristics of the systemic instruments and their relationship with the systemic problems. Section 6 presents the systemic policy framework and explains how it can be applied by policy makers. The paper closes with some concluding remarks on the methodological choices made in Sections 2–5 and on the further research that will be necessary to improve and test the framework.

2. Structural elements of innovation systems

2.1 Structural elements in the literature

'Systems of innovation' has been proposed by innovation scholars predominantly in reaction to the shortcomings of the neoclassical attempts to explain innovation and technological change (Edquist 1997). Since its identification, there have been a number of categorisations of innovation systems: national (Freeman 1988; Lundvall 1992;

Nelson 1993) or regional innovation systems (Doloreux 2002) when a geo space is a unit of analysis; sectoral innovation systems (SISs) that often go beyond national borders (Malerba 2002); and TISs that are not confined to national borders either, but are more specific in scope than SISs and are the most dynamic of these conceptualisations (Carlsson and Stankiewicz 1991; Carlson et al. 2002).

With regards to elements of innovation systems, Lundvall (1992: 12) distinguishes between a narrow and a broad definition. The narrow definition includes organisations and institutions involved in searching and exploring: such as R&D departments, technological institutes and universities. The broad definition comprises all the parts and aspects of an economic structure and the institutional set up affecting learning, searching and exploring: the production, marketing and finance system. Johansson and Johnson (2000) are more specific and name three types of elements of TISs: actors and their competences, networks and institutions, including legislation, capital market, educational system, as well as culture. This is along the lines of Carlson and Stankiewicz (1991), who define a TIS as a social network composed of actors and institutions (rules of the game) constructed around a specific technology. Kuhlmann and Arnold (2001), however, uses the modified technopolis structure encompassing: demand, framework conditions, industrial system, intermediaries, education and research system, political system and infrastructure meant as policies and institutions.

Comparisons of the structure of various (mostly national) innovation systems have for long been a source of information about the reasons behind the success or failure of a specific innovation system. However, policy makers cannot easily learn from the structures of other innovation systems because local specificities make it difficult to transfer elements of one system to another in the expectation that they would perform equally well. Also the great diversity of perspectives on the concept and composition of innovation systems is quite challenging when it comes to practical applications or to designing a framework for the analysis of systems, identification of problems and the design of policies.

We address these issues in three ways. First, we narrow our focus to TISs. We do this because of the advances in the literature in defining the elements and functions of TISs, and because the present authors were interested in testing the framework empirically, in the context of sustainability transition pathways that are built around specific technologies. A TIS is a global system with strong regional variations in terms of structure and functioning. It can be analysed at a global level but a regional delineation is also possible. Secondly, we propose that the structural analysis of a system is based on mapping its elements and evaluating their capacity to stimulate innovation rather than on comparing different systems. As will be shown later (see Section 4.2), the structural elements, their presence or absence as well as their capacities, are critical to the functioning of the innovation systems. Thirdly, we link structural analysis with the functional analysis (in Section 3.2).

The following paragraphs discuss four structural elements of the TIS identified in the literature: (i) actors, (ii) institutions and (iii) interactions, operating within (iv) a specific infrastructure.

2.2 Structural dimensions of a TIS

There is no disagreement in the literature that actors play a role in innovation systems. Various sources emphasise the role of users (von Hippel, 1988), universities (Mowery and Sampat 2005) or multinationals (Narula and Zanfei 2005). The differences between the various sources are rather in the categorisation of the actors who are under scrutiny. Some present them from the perspective of a role they play in the innovation process: users, producers, intermediary and supportive organisations (Smits and Kuhlman 2004). Sometimes these categories are complemented with classifications from the perspective of the role actors play in the economic activity such as: companies, consumers or knowledge institutes (Klein-Woolthuis et al. 2005). Given the current systemic phase of innovation, where the difference between producers and users is increasingly blurred (Smits and Kuhlman 2004), the distinction made on the basis of actors' roles in the innovation process is not the most useful. For analysing TIS we therefore delineate categories of actors (individuals, organisations and networks) based on their role in the economic activity: civil society, government, non-governmental organisations (NGOs), companies (start-ups, small and medium-sized enterprises (SMEs), multinationals, large firms), knowledge institutes (universities, technology institutes, research centres, schools), and other parties[2] (legal organisations, financial organisations/banks, intermediaries, knowledge brokers, consultants). These different actors can all fulfil different roles.

Institutions encompass a set of common habits, routines and shared concepts used by humans in repetitive situations (soft institutions) organised by rules, norms and strategies (hard institutions) (Crawford and Ostrom 1995). Institutional set-ups and capacities are determined by their spatial, socio-cultural and historical specificity (Lipsey et al. 2005) and are different from organisations (such as firms, universities, state bodies etc.) (Edquist 1997). Organisations of various kinds are considered in this paper as a type of actor.

Since *interaction* is dynamic, it is difficult to consider it as a structural element. A 'network' has been used in some literature positions (Johansson and Johnson 2000) to describe the cooperative relationships and links between actors but a 'network' can also be seen as a higher form of actors' organisation. However, interactions are not

Table 1. Structural dimensions of TISs

Structural dimensions	Subcategories
Actors:	• Civil society • Companies: start-ups, SMEs, large firms, multinational companies • Knowledge institutes: universities, technology institutes, research centres, schools • Government • NGOs • Other parties: legal organisations, financial organisations/banks, intermediaries, knowledge brokers, consultants
Institutions:	• Hard: rules, laws, regulations, instructions • Soft: customs, common habits, routines, established practices, traditions, ways of conduct, norms, expectations
Interactions:	• At level of networks • At level of individual contacts
Infrastructure:	• Physical: artefacts, instruments, machines, roads, buildings, networks, bridges, harbours • Knowledge: knowledge, expertise, know-how, strategic information • Financial: subsidies, fin programs, grants etc.

restricted to occurring within networks. In the early stages of the development of a system there are no networks, but bilateral interactions between actors can be traced. The focus here is on relationships and they can be analysed at the level of networks and of individual contacts.

Infrastructure does not have a steady position as a structural element of innovation systems and there is no conclusive agreement in the key literature positions as to what the term infrastructure covers. Kuhlmann and Arnold (2001) or Schmoch et al. (2006) use infrastructure to encompass what has, in this paper, been defined as 'institutions', namely so-called 'framework conditions', institutional set-ups (rules, norms and social conduct), public utilities and policies. O'Sullivan (2005) uses the term infrastructure in connection with the availability of finance for innovation in the form of venture capital, funds, subsidies or programmes. Link and Metcalfe (2008) analyse the whole set of dimensions of 'technology infrastructure' such as physical and virtual tools, methods and data. Smith (1997) emphasises the importance of the tangible physical and knowledge infrastructure. He argues that physical infrastructure such as buildings, (rail-)roads, bridges, harbours, airports, telecommunication networks, but also existing technologies meant as artefacts, instruments or machines play an important role in establishing the dominance of technologies and in shaping the technological trajectories, which have an effect on the overall performance of innovation systems. Some empirical studies explicitly show the significance of physical infrastructure (such as rail-tracks) for the functioning of innovation systems and refer to its deficiency as a systemic problem (Klein-Woolthuis et al. 2005). Under the knowledge infrastructure Smith (1997) includes: universities, research labs, training systems, libraries etc.: those public and private organisations whose role is the production, maintenance, distribution, management and protection of knowledge. This conceptualisation has some characteristics of physical infrastructure but most importantly it emphasises the soft part of it: the skills, the expertise and the know-how it generates and stores. Building on this literature but given the definitions of institutions and actors above, this paper proposes to consider three categories of infrastructure: physical, financial and knowledge as structural components of the innovation systems. The physical infrastructure encompasses: artefacts, instruments, machines, roads, buildings, telecom networks, bridges and harbours. The knowledge infrastructure includes: knowledge, expertise, know-how and strategic information. The financial infrastructure includes: subsidies, financial programs, grants etc. Table 1 summarises all the structural 'dimensions' of a TIS.

3. Functions of innovation systems

3.1 Functions in the literature

Functional analysis (Johnson 2001; Bergek 2002; Hekkert 2007; Bergek et al. 2008) focuses on the processes that are important for innovation systems to perform well. The processes are categorised as functions of innovation systems and they clarify the dynamics of the systems. Originally Johnson (2001) proposed six functions. Hekkert et al. (2007) tested the list empirically and suggested seven functions: F1 (entrepreneurial activities), F2 (knowledge development), F3 (knowledge diffusion), F4 (guidance of the search), F5 (market formation), F6 (mobilisation of resources), F7 (creation of legitimacy). Bergek et al. (2008) also list seven functions but their phrasing and order is slightly different. The functions show the state of a specific innovation system in a defined moment of time. Answers to a set of diagnostic questions provide a basis for evaluating the quality of the functions (Hekkert et al. (2010), see also Section 6).

Table 2. Functions seen through structural elements of innovation systems

System function	Structural element
F1: entrepreneurial activities	Actors
	Institutions
	Interactions
	Infrastructure
F2: knowledge development etc.	Actors
	Institutions
	Interactions
	Infrastructure

3.2 Functions and structure

The functional approach has been used in the literature to identify the so-called 'blocking mechanisms' and has served as a framework to identify emerging policy issues (Bergek 2002).We would like to argue, however, that functions alone are not a sufficient basis on which to develop successful systemic innovation policies for two reasons. First, functions cannot be influenced without altering a structural element. For example, a precondition for knowledge diffusion (function F3) is the presence and interactions of actors. Policy-wise the function of knowledge diffusion cannot be influenced other than by stimulating the participation of the relevant actors or by creating stimulating conditions for their interaction. Lack of occurrence or 'weakness' of any of the functions should therefore be a signal and a reason for policy makers to look at the structure of the innovation system. Secondly, if the functions are used as the sole basis for policy, then uncertainty emerges with regard to the completeness of the identified list of blocking mechanisms and thus, of the policy issues.

To address the concerns we propose that once the functional pattern of a system has been established, as in Bergek et al. (2008) or Hekkert et al. (2007), each function is examined through the perspective of four structural elements for either explanatory (e.g. why entrepreneurial activities do not take place?) or policy reasons (how to alter entrepreneurial activities?). Thus, the reasons why a certain system function is absent or weak can be related to the structure of the innovation system and more specifically to actors, interactions, institutions and infrastructure. Similarly, by altering the structural elements policy can create circumstances in which functions can take place or 'strengthen' (see Table 2).

That implies that structure makes functions meaningful while a coupled functional–structural analysis gives quite a good overview of what happens in the systems and in particular what goes wrong and why. Such analysis also provides a much more precise and complete basis for suggesting policy than does classical functional analysis.[3] From the analytical perspective the number and exact phrasing of the functions are very important but do not seem to have an impact on establishing the connection between the functions and the structural elements.

4. Systemic problems

4.1 Systemic problems in the literature

The innovation literature refers to problems that hinder the development of innovation systems as systemic problems, failures or weaknesses. While their existence and the need to consider the systemic problems as a new innovation policy rationale is widely recognised in most 'systemic' innovation literature, the number of publications that attempt to define and classify these problems can be reduced to a few: Jacobsson and Johnson (2000) in their analysis of the Swedish renewable energy system identified a number of factors that block the development and/or diffusion of a new technology. The blocking factors are identified per element of the analysed TIS and include on the actors' and markets' side: poorly articulated demand or market control by incumbents; on the network side: poor connectivity or wrong guidance with respect to future markets; on institutions: legislative failures or failures in the educational system. These are quite in line with the list provided by Chaminade and Edquist (2010) which includes: infrastructure provision and investment problems; transition problems; institutional problems (hard and soft); lock-in problems; capability and learning problems; network problems; unbalanced exploration–exploitation mechanisms; and complementary problems. Smith (2000) lists four systemic 'failures': failures in infrastructural provision and investment; transition failures; lock-in failures; and institutional failures. The early OECD report (1997) lists: lack of interaction between actors; mismatch between basic and applied research; malfunctioning of the technology transfer institutions; and information and absorptive deficiencies on the part of enterprises as systemic failures. Klein-Woolthuis et al. (2005) revised the various listings and proposed four general categories: infrastructural, institutional, interaction and capabilities problems. They removed 'lock-in' problems from the list arguing that this is not a reason but an outcome of other problems on the list.

4.2 Problems versus structure

The different classifications of systemic problems in the literature are difficult to compare. Their diversity may also create confusion among policy makers interested in using the concept in practice. In this section we attempt to define systemic problems, develop their generic typology and explore how they compare with the listings in the literature.

We start by referring to a system studies perspective (Carlsson at al. 2002), according to which a system is made up of: components (operating parts of a system), relationships (links between components) and attributes (properties of the components). Carlsson et al. (2000) consider that the attributes are only properties of the components. We argue, however, that relationships, links or interactions may also have properties: for example, they can be either strong or weak. We therefore consider attributes to be properties of not only the components, but also of the relationships.

In the case of an innovation system, four structural dimensions have been identified (see Section 2): actors, institutions, infrastructure and interactions. The first three, namely actors, institutions and infrastructure can be easily considered to be the components (operating parts) of the system. In the language of system studies, interactions are relationships or links between the components. All four can have specific attributes. Carlsson et al. (2002) also argue that a system does not function as a system if there is a problem with any of these aspects. By analogy an innovation system may not function well when there is a problem: (1) with any of its structural elements—when for example they are missing (presence issue); or (2) with their attributes (properties)—e.g. they are too intense as in the case of interactions or they lack capacity when we talk about actors (capacity/capability issue). That means that if the innovation system does not function well (and we know that that is the case because the functions are absent or weak) we can analyse why by looking at each of the structural elements in two ways: whether it is because of its presence/absence or because of its properties. Thus, for problems which arise in the context of an innovation system, the systemic problems can be conceptualised as relating to:

- The presence or capabilities of the actors.
- The presence or quality of the institutional set up.
- The presence or quality of the interactions.
- The presence or quality of the infrastructure.

To express the properties/attributes of the various structural elements terms like capacity, quality or intensity are used in both the positive and a negative sense. For example an interaction can be too intense or too weak. An institution can be too stringent or too weak[4] etc.

Following these lines and using insights from Klein-Woolthuis et al. (2005), systemic problems can be defined as factors that negatively influence the direction and speed of innovation processes and hinder the development and functioning of innovation systems. We suggest that they are classified into the following categories:

4.2.1 Actors' problems.

These are often inadequately referred to as capabilities problems. They may be of two types:

- Presence related: relevant actors (within the categories listed earlier) may be absent.
- Capacity related: actors may lack competence, capacity to learn or utilise available resources; to identify and articulate their needs; and to develop visions and strategies. Thses are sometimes termed transition problems (Smith 2000; Chaminade and Edquist 2010).

4.2.2 Institutional problems (hard and soft).

These may be of two types:

- Presence related: when specific institutions are absent.
- Capacity related: when there is a problem with their capacity/quality:
  - Stringent institutional problems may result in the so-called appropriability trap and favour incumbents.
  - Weak institutional problems may hinder innovation, for instance by insufficiently supporting new technologies or developments.

4.2.3 Interaction problems.

These are sometimes referred to as lock-in problems (Smith 2000) or network problems (Chaminade and Edquist 2010). They may be of two types:

- Presence related: interactions are missing because of cognitive distance between actors, differing objectives, assumptions, capacities, or lack of trust.
- Quality related: there is a problem with the quality/intensity of the interactions:
  - Strong network problems—when some actors are wrongly guided by stronger actors and fail to supply each other with the required knowledge. This may be caused by:
    - Myopia: internal orientation favouring the incumbent set-up and relationships and thus blocking the necessity to open up to external forces.
    - Over strong involvement of incumbent actors (Kemp and Nill 2009).
    - Lack of (external to incumbents) weak ties, valuable for breaking through an over strong internal organisation.
    - Dependence on dominating partners due to assets specificity.
  - Weak network problems which are caused by weak connectivity between actors, which hinders interactive learning and innovation. These are also referred to as complimentarity problems by Chaminade and Edquist (2010).

4.2.4 Infrastructural problems.

These refer to physical, knowledge and financial infrastructure. They may be:

- Presence related when specific type of infrastructure is absent.
- Quality related when infrastructure is inadequate or malfunctioning.

This typology does not suggest that in practice all possible actors, all types of infrastructure or all existing institutions, need to be 'present' in every system or otherwise there is a danger that a systemic problem will occur. Such a suggestion would contradict the emergent nature of innovation. It is also possible that the involvement of specific actors or the presence of some regulation can hinder the operation of the system. Who to involve and in what capacity they should be involved, is therefore dependent on the system being analysed and its socio-economic and political environment. The complete overview of all system dimensions and all possible problems that may arise should be helpful for policy makers to first, thoroughly analyse the system, and secondly, to stimulate such combinations of elements that in their view have the greatest chances to stimulate innovation and the desired (e.g. sustainable) orientation of the system.

From a theoretical perspective, the above typology can be useful for assessing the various listings of systemic problems available in the literature. Table 3 provides a comparison and reveals several gaps and a couple of overlaps in the classifications of systemic problems from the literature. Overall, all the analysed sources attempt to present generic categorisations of systemic problems, but in most cases they name specific types or aspects of problems. A good example is the case of *lock-in problems* from the list by Chaminade and Edquist (2010) and Smith (2000). Lock-in is an outcome of over strong interactions (caused by various reasons as explained above) and can therefore be classified as an *interaction/intensity problem* and in particular it is one of the types of strong network problems. *Complementarity problems* as defined by Chaminade and Edquist (2010) refer to a lack of connection and compatibility between competencies within the system. They can therefore be regarded as a type of *interaction/intensity problem* corresponding with weak network problems or *interaction/presence problems* when there is no interaction at all. In addition, the same authors list a more general category of *network problems* which includes linkages within the system that are either too strong or too weak, which in our typology also corresponds with *interaction/intensity problems*. Similarly, *infrastructural problems*—different types of infrastructure are highlighted by different sources: physical (Smith 2000; Klein-Woolthuis et al. 2005; Chaminade and Edquist 2010), knowledge/research (OECD 1997; Jacobsson and Johnson 2000; Chaminade and Edquist 2010) and financial/investment (Smith 2000; Chaminade and Edquist 2010). Only Chaminade and Edquist (2010) highlight all three types. No new type of infrastructure is mentioned in the analysed literature, which gives us a sense that we defined infrastructure well (as including physical, knowledge and financial aspects) and most important of all, that we included it as a structural element of the system. Very few of the authors cited in Table 3 take the presence aspect into account (OECD 1997; Jacobsson and Johnson 2000). Most focus on the capability/capacity aspect of the problems, although it is difficult to judge whether the *legislative failures* of Jacobsson and Johnson (2000) or *institutional failures* of Smith (2000) refer also to missing institutions and thus the *institutional/presence* type of problem. However, the use of the term 'failure' by both sources, suggests rather 'malfunctioning' of institutions or their 'insufficiency' which makes us categorise these problems as *institutional/capacity problems*. Unbalanced exploration and exploitation mechanisms[5] (Chaminade and Edquist 2010) are difficult to classify because, as in the case of lock-in, unbalanced exploration and exploitation is an outcome of a problem. It can be caused by the incapability of the actors or can result from interactions that are either too strong or too weak. We therefore do not include it in Table 3.

One more note needs to be sounded when discussing systemic problems. In the literature discussing these problems, terms like systemic 'failure' (OECD 1997; Bergek et al. 2008), 'weakness' or 'imperfection' are used (Klein-Woolthuis et. al. 2005; Smith 1997). According to the major dictionaries, failure is defined as a lack of success in something, or an unsuccessful attempt at doing something: something that falls short of what is required or expected. Similarly, imperfection or weakness falls short of something that should be perfect or optimal. It is now widely recognised in innovation studies that when technology changes endogenously and in conditions of uncertainty, there is no optimality and no equilibrium (Lipsey et al. 2005) so it is impossible to talk about a failure, a weakness or imperfection. This paper therefore (in line with Chaminade and Edquist (2010)) refers to these systemic failures and weaknesses as systemic problems.

4.3 Functions, structure and systemic problems

Table 4 shows how a coupled functional–structural analysis could be used to identify the above-defined systemic problems. Following the explanation in Section 3.2 (functions and structure), once it is established whether or not the weakness of the function has something to do with actors, institutions, interactions or infrastructure, one can further explore whether the problem occurs because any of these are missing (e.g. specific entrepreneurs are not involved, there is no regulation that allows registering a novelty, or there are no funds to support pilot projects) or there is a problem with their capacity (e.g. actors' capabilities to innovate and to identify their strategies are insufficient, thus their choices are not leading to any successful outcomes, or some actors dominate over others, or despite there being a lot of knowledge about a specific technology it is not easily available to the actors). Such an analysis can be carried out for all functions in order to identify where exactly the problem is.

Table 3. Comparison of systemic problems classifications from literature with typology identified in this paper

Systemic problem	(Type of) systemic problem	OECD (1997)	Smith (2000)	Jacobsson and Johnson (2000)	Klein-Woolthuis et al. (2005)	Chaminade and Edquist (2010)
Actors' problems	Presence	-	-	-	-	-
	Capability	Information and absorptive deficiencies of enterprises	Transition failures	Poorly articulated demand	Capabilities' failure	Capability and learning problems Transition problems
Institutional problems	Presence	-	-	-	-	-
	Capacity	Malfunctioning of technology transfer institutions	Institutional failures	Legislative failures	Hard institutional failures Soft institutional failures	Institutional problems (hard and soft)
Interaction problems	Presence	Lack of interaction between actors	-	Poor connectivity	-	-
	Intensity/quality	-	Lock-in failures	Wrong guidance Market control by incumbents	Interaction failures: weak/strong network failures	Network problems Lock-in problems Complementarity problems
Infrastructural problems (physical, knowledge, finance)	Presence	-	-	-	-	-
	Quality/capacity	Mismatch between basic and applied research	Failures in infrastructural provision and investment	Failures in educational system	Infrastructural failures	Infrastructure provision (physical, scientific, network)[a] and investment problems

[a]Where 'network' encompasses IT and telecom network. This paper however lists the two under physical infrastructure.

4.4 Blocking mechanisms and systemic problems

Some authors (Bergek et al. 2008; Hekkert et al. 2007) focus on identifying the mechanisms blocking the functions. Careful consideration of these mechanisms reveals that they can be categorised as systemic problems even though the latter are criticised by the same authors for their static basis. For example the blocking mechanisms identified by Bergek et al. (2008) based on specific empirical case such as: *lack of actors and resources in the middle of the chain* can be categorised as an actors/presence problem and infrastructure/presence issue. *Weak advocacy coalition* is an interaction/quality problem. *Lack of integration of sub-elements of the system* is an interaction/presence problem. *Lack of standards* refers to the absence of institutions. *Lack of standard software* concerns the absence of infrastructure. *Lack of competence/poorly articulated demand* is a problem with the actors/capabilities, while *inadequate knowledge* is a knowledge infrastructure/quality or presence issue etc.

We therefore suggest that the application of the typology of systemic problems developed in this paper can significantly enhance such empirical analyses by assisting policy makers and innovation scholars in structuring the outcomes of the coupled structural–functional analysis and, most importantly, in a systematic mapping of all possible 'blocking mechanisms' that may occur in a specifically defined innovation system. The comparison above also validates the existence of a relationship between functions and the systems structural elements, confirming that an intervention in the function without an alteration in the structure of the system is not possible.

5. Systemic instruments

5.1 Systemic instruments for systemic problems

The identification of the type of systemic problems should be a precondition for a selection of strategies and tools that would target them and thus influence the overall functioning of the innovation system. Smits and Kuhlman (2004) called such tools 'systemic instruments' and suggested five processes that systemic policies should aim to achieve:

- Building and organising innovation systems.
- Providing a platform for learning and experimenting.
- Providing an infrastructure for strategic intelligence and stimulating demand articulation.
- Managing interfaces.
- Developing strategy and vision.

How do these five processes correspond with the typology of systemic problems outlined in Section 4.2?

Building and organising innovation systems seems to refer to ensuring the presence of the relevant actors, institutions or infrastructure. It could be made more specific depending on the problem it is supposed to address. For the actors' problem, it could be formulated as 'stimulating and

Table 4. Systemic problems based on functional–structural analysis of an innovation system

System function	Structural element	Systemic problem	(Type of) systemic problem
F1: entrepreneurial activities	Actors	Actors problem	Presence? Capabilities?
	Institutions	Institutional problem	Presence? Capacity/quality?
	Interactions	Interaction problems	Presence? Intensity/quality?
	Infrastructure	Infrastructural problems	Presence? Capacity/quality?
F2: knowledge development etc.	Actors	Actors problem	Presence? Capabilities?
	Institutions	Institutional problem	Presence? Capacity/quality?
	Interactions	Interaction problems	Presence? Intensity/quality?
	Infrastructure	Infrastructural problems	Presence? Capacity/quality?

Table 5. Goals of systemic instruments per (type of) systemic problem

Systemic problem	(Type of) systemic problem	Goals of systemic instrument
Actors' problems	Presence?	Stimulate and organise participation of relevant actors (1)
	Capabilities?	Create space for actors capability development (2)
Interaction problems	Presence?	Stimulate occurrence of interactions (3)
	Intensity?	Prevent too strong and too weak ties (4)
Institutional problems	Presence?	Secure presence of hard and soft institutions (5)
	Capacity?	Prevent too weak and too stringent institutions (6)
Infrastructural problems	Presence?	Stimulate physical, financial and knowledge infrastructure (7)
	Quality?	Ensure adequate quality of infrastructure (8)

organising the participation of relevant actors'. For the institutional problem it could be defined as 'stimulating the presence of hard and soft institutions'. For infrastructural problems one could think of 'stimulating physical, financial and knowledge infrastructure'. *Providing a platform for learning and experimenting* could be seen as a way to address problems with actors' capabilities related to learning about new technological options. *Providing an infrastructure for strategic intelligence* and *stimulating demand articulation* links with two types of issues: the capacity aspect of infrastructural (knowledge) problems and actors' capacity problems. Ability to articulate demand, however, is just one specific aspect of capability building. *Management of interfaces* is a way to stimulate the interactions within the system while *developing strategy and vision* is again about developing actors' capabilities.

The processes that systemic instruments should focus on proposed by Smits and Kuhlmann (2004) seem incomplete and not sufficiently structured to be of much help to policy makers. Most importantly, they do not correspond with many of the problems that may occur within innovation systems (for example none of the goals refers to the capacity aspect of institutional or interaction problems while provision of adequate physical and financial infrastructure is totally omitted). That suggests that in order to be able to address all eight types of systemic problems, systemic instruments should focus on one or more of the following eight goals (Table 5):

(1) Stimulate and organise the participation of various actors (NGOs, companies, government etc.).
(2) Create space for actors' capability development (e.g. through learning and experimenting).
(3) Stimulate the occurrence of interaction among heterogeneous actors (e.g. by managing interfaces and building a consensus).
(4) Prevent ties that are either too strong or too weak.
(5) Secure the presence of (hard and soft) institutions.
(6) Prevent institutions being too weak or too stringent.
(7) Stimulate the physical, financial and knowledge infrastructure.
(8) Ensure that the quality of the infrastructure is adequate (strategic intelligence serving as a good example of specific knowledge infrastructure).

Table 6. A systemic innovation policy framework

System function	Structural element	Systemic problem	(Type of) systemic problem	Systemic instrument goals
F1: entrepreneurial activities	Actors	Actors problems	Presence?	Stimulate and organise the participation of relevant actors (1)
			Capabilities?	Create space for actors capability development (2)
	Interactions	Interaction problems	Presence?	Stimulate occurrence of interactions (3)
			Capacity?	Prevent too strong and too weak ties (4)
	Institutions	Institutional problems	Presence?	Secure presence of hard and soft institutions (5)
			Intensity?	Prevent too weak and too stringent institutions (6)
	Infrastructure	Infrastructural problems	Presence?	Stimulate physical, financial and knowledge infrastructure (7)
			Quality?	Ensure adequate quality of infrastructure (8)
F2: knowledge development etc.	Actors	Actors problems	Presence?	Stimulate and organise participation of relevant actors (1)
			Capabilities?	Create space for actors capability development (2)
	Interactions	Interaction problems	Presence?	Stimulate occurrence of interactions (3)
			Intensity?	Prevent too strong and too weak ties (4)
	Institutions	Institutional problems	Presence?	Secure presence of hard and soft institutions (5)
			Capacity?	Prevent too weak and too stringent institutions (6)
	Infrastructure	Infrastructural problems	Presence?	Stimulate physical, financial and knowledge infrastructure (7)
			Quality?	Ensure adequate quality of infrastructure (8)

5.2 Goals versus functions

The difference between the functions of innovation systems and the above goals of systemic instruments is that the functions (together with structural analysis) are *descriptive* and provide an *analytical* tool to determine a system's performance at a specific moment in time and to identify the systemic problems that this system faces. The goals of systemic instruments are *prescriptive* and meant to support *policy design* and the selection of tools that can address the problems that are identified in an integrated manner. The relationship of the goals of systemic instruments with the structural elements is useful in targeting specific elements in a way that it improves the functioning of the system as a whole. We therefore suggest that, while the functions of innovation systems are processes that need to take place to ensure that a system performs well, the goals of systemic instruments describe what the instruments should do to create the circumstances under which the innovation system functions have the highest chances of occurring.

6. A systemic policy framework proposal

The link between systemic problems and the systemic instruments' goals allows for the systemic policy framework to be completed (see Table 6). Within this framework the functions are analysed through the perspective of the structural elements. Such analysis leads to a very precise identification of the factors that block specific functions and thus hinder the development of the system. Different types of problems need to be addressed with different instruments. The goals of systemic instruments guide the selection of individual tools in a way that allows for their mutual reinforcement, coherence and orchestrated impact. The purpose of such an integrated instrument is to create opportunities for system development by influencing those elements and connections within the system that would not emerge spontaneously.

6.1 Application of the framework

Since policymaking is a cyclic process and functional analysis shows just a particular moment of the system development, the effectiveness of the designed instrument can be evaluated over a period of time by applying the same framework. Fig. 1 shows the framework as a cyclic process. Fig. 1 also presents the consecutive stages of the framework application. We describe them briefly in the following paragraphs.

6.1.1 Stage 1: mapping structural dimensions and their capabilities. The analysis starts with mapping the structural dimensions of the analysed innovation system: actors, institutions, interactions and infrastructure as well as their capabilities. Sources of information include the literature, internet searches and interviews with actors. The results can be presented in a table like Table 1.

6.1.2 Stage 2: coupled functional–structural analysis. This stage starts with a functional analysis of the TIS at hand. The functions are evaluated by policy makers in cooperation with other actors using the 5-level

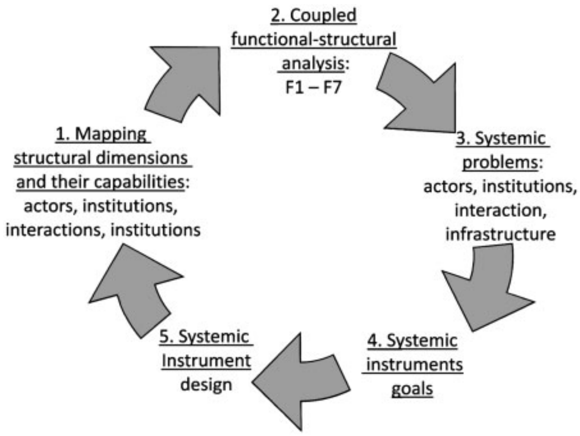

Figure 1. A systemic innovation policy framework.

scale (0 = absent, 1 = weak, 2 = very weak, 3 = moderate, 4 = strong, 5 = very strong) and based on responses to a set of diagnostic questions (Hekkert et al. 2010).[6]

Function 1, entrepreneurial activities:

- Are there enough entrepreneurs?
- What is the quality of entrepreneurship?
- What types of businesses are involved?
- What are the products?
- To what extent do entrepreneurs experiment?
- What variety of technological options are available?
- Are any entrepreneurs leaving the system?
- Are there new entrepreneurs?

Function 2, knowledge development:

- What is the knowledge base in terms of quality and quantity?
- Is the knowledge basic or applied?
- Are there many projects, research, patents and articles?
- Is there a leading international position, trigger programmess, many cited patents?
- Which actors are particularly active?
- Who finances the knowledge development?
- Does the technology receive attention in national research and technology programs?
- Are there enough knowledge users?

Function 3, knowledge dissemination:

- Are there strong partnerships?
- Between whom?
- Is the knowledge development demand-driven?
- Is there space for knowledge dissemination?
- Is there strong competition?
- Does the knowledge correspond with the needs of the innovation system?
- Have any licenses been issued?

Function 4, guidance of the search:

- Is there a clearly articulated and shared goal for the system?
- Is it generic or specific?
- Is it supported by specific programs, policies, who are the system's frontrunners?
- Is the objective inducing government activities?
- What are the technological expectations (negative/positive)?
- Does the articulated vision fit in the existing legislation?

Function 5, market formation:

- What does the market look like?
- What is its size (niche/developed)?
- Who are the users (current and potential)?
- Who takes the lead (public/private parties)?
- Are there institutional incentives/barriers to market formation?
- Must a new market be created or an existing one be opened up?

Function 6, resources mobilisation:

- Are there sufficient financial resources for system development?
- Do they correspond with the system's needs?
- What are they mainly used for (research/application/pilot projects etc.)?
- Is there sufficient risk capital?
- Is there adequate public funding?
- Can companies easily access the resources?

Function 7, creation of legitimacy:

- Is investment in the technology seen as a legitimate decision?
- Is there much resistance to change?
- Where is resistance coming from?
- How does this resistance manifest itself?
- What is the lobbying power of the actors in the system?
- Is coalition forming occurring?

A coupled functional–structural analysis is based on studying each function through the perspective of the four structural elements either for explanatory (e.g. why do entrepreneurial activities not take place?) or policy reasons (how to alter entrepreneurial activities?) It is important to identify which structural element causes the weakness or absence of the function.

6.1.3 Stage 3: identification of systemic problems. The coupled structural–functional analysis and the identification of the reasons why certain functions perform better and other worse should allow for precise and systematic identification of problems that hinder the development of the systems. The final results of the analysis are presented in Table 7.

Table 7. Scheme for presenting results of coupled functional–structural analysis and identification of problems per function

Function	Functions evaluation (absent/very weak, etc.)	Reasons why the specific function is absent/weak/strong etc. ('blocking mechanism')	Systemic problems (presence/capability)
F1: entrepreneurial activities			
F2: knowledge development			
F3: knowledge diffusion			
F4: guidance of search			
F5: market formation			
F6: mobilization of resources			
F7: creation of legitimacy			

Table 8. Potential of individual policy tools to contribute to systemic instruments goals

Goals of systemic instruments	Examples of individual instruments
1. Stimulate and organise participation of actors	Clusters; new forms of Public Private Partnerships, interactive stakeholder involvement techniques; public debates; scientific workshops; thematic meetings; transition arenas; venture capital; risk capital
2. Create space for actors' capability development	Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programmes; technology platforms; scenario development workshops; policy labs; pilot projects
3. Stimulate occurrence of interactions	Cooperative research programmes; consensus development conferences; cooperative grants and programmes; bridging instruments (centres of excellence, competence centres); collaboration and mobility schemes; polic evaluation procedures; debates facilitating decision-making; science shops; technology transfer
4. Prevent too strong and too weak ties	Timely procurement (strategic, public, R&D-friendly); demonstration centres; strategic niche management; political tools (awards and honours for innovation novelties); loans/guarantees/tax incentives for innovative projects or new technological applications; prizes; Constructive Technology Assessment; technology promotion programmes; debates, discourses, venture capital; risk capital
5. Secure presence of (hard and soft) institutions;	Awareness building measures; information and education campaigns; public debates; lobbying, voluntary labels; voluntary agreements
6. Prevent too weak/stringent institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms
7. Stimulate physical, financial and knowledge infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs
8. Ensure adequate quality of infrastructure	Foresights; trend studies; roadmaps; intelligent benchmarking; SWOT (strengths, weaknesses, opportunities and threats) analyses; sector and cluster studies; problem/needs/stakeholders/solution analyses; information systems (for programme management or project monitoring); evaluation practices and toolkits; user surveys; databases; consultancy services; tailor-made applications of group decision support systems; knowledge management techniques; Technology Assessments; knowledge transfer mechanisms; policy intelligence tools (policy monitoring and evaluation tools, systems analyses); scoreboards; trend charts

6.1.4 Stage 4: goals of systemic instruments. Systemic problems that have been precisely identified can easily be aligned with the goals of systemic instruments and followed by a policy suggestion on how to support the development of the entire system. The identified systemic problems and corresponding goals of systemic instruments are summarised in Table 5.

6.1.5 Stage 5: design of systemic instruments. To fulfil the goals of systemic instruments, a set of traditional, individual tools already present in the policy field may be of use. An overview of them is presented in Table 8. These tools have a supportive task in the creation of a systemic instrument for the innovation system being analysed. Their selection, however, is dependent not only on the identified problems but also on the instruments' mutual interactions, the socio-political and economic conditions of the surrounding environment, the impact of other, perhaps competing TISs. They need to be selected in a way that allows for their effectiveness, common reinforcement and orchestrated action. A systemic instrument is thus an integrated coherent set of tools designed for a specific innovation system (or part of a system). Its purpose is to create opportunities and conditions for system formation by influencing elements and connections within the system that would not otherwise emerge spontaneously. It is expected that the application of a well-designed systemic tool will be manifested in the development of a system and higher rates of innovation. Analytically, this should be seen in strengthening of the previously weak or absent functions.

7. Conclusions

Building on recent insights from innovation studies, this paper brought together four approaches which have been developed on the basis of the systemic, evolutionary view of innovation that aims to inform the policy-making process: the structure and functions of innovation systems, systemic problems and systemic instruments into a systemic policy framework to analyse and stimulate technological innovation.

The paper showed that both the structural and functional analyses are promising analytical tools to evaluate the performance of a system. The view presented in this paper on the relationship between the two is that the functional analysis complements the structural one by being a manifestation of the way in which an innovation system is organised. Linking functions to the structure of innovation systems is necessary not only for analytical purposes, but also for practical reasons. Functions can only be influenced by policies through alterations of the structural components. By 'signalling' problems functions help facilitate the design of a systemic instrument that can address the problems in an integrated manner. The structural characteristic of the systemic problems facilitates the problems' connection to the functional pattern which is responsible for innovation levels. The systemic problems identified on the basis of such coupled structural–functional analysis therefore express both structural problems as well as their effect on innovation processes. The mechanisms blocking the systemic functions can easily be expressed in terms of the categories and types (presence, capacity) of systemic problems and therefore also link to the structural components of innovation systems. The advantage of the typology for systemic problems that has been proposed in this paper is that it provides a complete 'checklist' of all possible problems that may occur within a specifically defined system.

This theoretical exercise also confirmed the appropriateness of considering actors, institutions, interactions and in particular the physical, knowledge and financial infrastructure as explicit structural dimensions of innovation systems. By discouraging negative elements, securing the presence of positive ones and by increasing their capacities, policy makers not only have the chance to provide a better environment for innovation but they may also influence the direction of technological change towards objectives such as more sustainable goals. The proposed systemic policy framework should therefore be seen as a decision support tool for a new breed of policy makers who deal with such complex systemic problems as climate change or loss of biodiversity.

Notes

1. The inconsistencies in the literature are natural for a new scientific field, but to grow and prosper more consensus is needed on the concepts and how they relate to each other. We hope that this paper will contribute toward this goal.
2. Miscellaneous category of parties that contribute to the innovation process.
3. The reasons may also lie outside the innovation system (exogenous factors) but since they are often beyond the immediate influence of policy makers, we only focus on endogenous system factors that policy makers have the ability to alter directly.
4. Broekel and Boschma (2009) and Nooteboom (2000) discuss geographical and institutional proximity or optimal for innovation cognitive distance between agents. They argue that a high degree of proximity (strong ties) between agents does not necessarily increase their innovative performance, and may possibly even harm it.
5. According to Chaminade and Edquist (2010): '. . . the system might be capable of generating diversity but not having the mechanisms to be able to make the adequate selections or it may have very refined selection procedures but no capability to generate diversity. Policy makers might support the emergence of spin-off companies, for example . . .'
6. Another method to evaluate the functions and in particular their historical development is event analysis as proposed by (Hekkert et al, 2007). The method is useful for innovation scholars but policy makers may find it too tedious and too broad for their needs.

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