# Functionality of innovation systems as a rationale for, and guide to innovation policy

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# Functionality of innovation systems as a rationale for, and guide to innovation policy[1]

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## 1. Introduction

This chapter discusses an approach to the rationale and operations of innovation policy from a 'systems' perspective, focusing on functions performed by an innovation system. The systems approach stems from a key insight of innovation studies, which is that innovation by firms cannot be understood purely in terms of independent decision-making at the level of the firm. Firms' strategies are central to innovation, but strategic options are shaped and constrained by environmental factors: collaborative patterns, regulatory systems, customary practices, etc., are phenomena which persist in a systemic way and which inflect how innovation may occur. These environmental conditions are often specific to technological, regional or national contexts, but they are also dynamic: their forms of operation change with political conditions, changing technological opportunities, economic integration processes and so on.

The basic argument of systems theories is that system conditions have a decisive impact on the extent to which firms make innovation decisions, on the modes of innovation which are undertaken and on the success/failure of these. Much of the literature focuses on differences in the structure of systems, trans-national variation across e.g. institutions and organizations. However, from an innovation point of view, what also matters is functionality: that is, what do the components of an innovation system actually do, and what do they achieve? We argue that innovation processes involve various functions that need to be fulfilled – they must be initiated (usually by some perception of an opportunity), they must be financed, they must deploy capabilities that in turn have been created and maintained etc. Any evaluation of system performance should therefore rest in part on an account of what a system actually does in terms of such functions.

A first aim of this chapter is to formulate a taxonomy of system functions, as a step towards an understanding of how systems affect innovation. But we go further, suggesting that the functions of a system can form a framework for understanding the foundations and shaping the content of policies in support of innovation. The objective of this chapter therefore is to develop a framework that adds a functional level to the structural one, which may provide a tool for policy makers seeking a rationale for, as well as a guide to policy interventions. Illustrative empirical examples will be drawn from analyses of technological innovation systems (TIS), i.e. systems centred on specific technologies, products or industries, e.g. micro wave technology, solar cells or salmon farming (e.g. see Carlsson, 1997).[2] The approach does not, of course, have anything to say about the desirability of a particular TIS but assumes that such a decision has already been taken by policy makers.

The paper is structured as follows. In section 2, we discuss rationales for public policy, and how they are affected by the evolutionary dynamics of innovation systems, linking up to the chapter by Chaminade and Edquist. Section 3 outlines a set of functions in innovation systems that act as an intermediate between the structure of the system and its ultimate performance. We exemplify with the case of 'biomass gasification' in the Netherlands. In section 4, we proceed to analyse how a functional analysis can be used as a very practical tool to find not only a (partial) rationale for policy intervention, in terms of system weaknesses, but also a guide for finding the key policy issues to tackle. We illustrate here with the case of 'IT in home care' in Sweden. This section also further develops a rationale for intervention by assessing the nature of system weaknesses in relation to the opportunities for system-building activities by entrepreneurs. Section 5 contains our conclusions.

## 2. Policy rationales: beyond market failures

For a long time, the rationale for and scope of policy intervention in industry has been highly controversial. Yet it is clear that in industrially advanced countries policy intervention is widespread and part and parcel of larger transformation processes.[3] Contemporary policy intervention, however, rarely consists of 'orchestration' of overall development by governments, nor 'industrial policy' as conventionally understood (consisting of subsidies to specific industries to promote growth or offset decline). Rather, modern policy incorporates a wide range of industrially-relevant, loosely and sometimes disconnected measures including those found within science and technology policies, tax policies (including $CO_2$ and other pollutant taxes, but also

[2] This is so for two reasons. First, policy makers often have a particular product group/knowledge field as their responsibility. Second, at a higher system level, the framework probably looses some of its power to guide policy makers.

[3] See, for instance, Computer Science and Telecommunications Board (1999) for an exciting analysis of the US case and Jacobsson and Bergek (2004) for the case of renewable energy technology in Germany.

tax credits to R&D), venture capital provision, standardization measures, formation of early markets via e.g. procurement policies, measures to broaden the search space of firms etc.[4] In contrast to subsidies of dying industries, such measures are, on the whole, deemed to be legitimate. In a developing country context, it is also '… increasingly recognized that developing societies need to embed private initiative in a framework of public action that encourages restructuring, diversification, and technological dynamisms beyond what market forces on their own would generate' (Rodrik, 2004, p.1). In such a framework, it has not only been argued that the appropriate public action needs to be selective, i.e. differ across industrial fields (Katz, 1983; Carlson and Jacobsson, 1996; Rodrik, 2004), but also that it needs to change its content over time (Galli and Teubal, 1997; Katz, 2004).

Against the background of this complex array of measures, there is a need for a coherent conceptual approach that provides policy makers with a rationale for intervention as well as a guide to the central issues that a selective and time-specific policy should aim at resolving. Scholars on innovation and technology have almost completely rejected the market failure approach as a basis of policy action. It is argued repeatedly in the literature (e.g. Metcalfe, 1992; Malerba, 1996; Carlsson and Jacobsson, 1996, 1997; Smith, 2000b; Metcalfe, 2004) and by Chaminade and Edquist in this book, that the approach is flawed and insufficient. A systems approach to innovation is seen as more useful. Systems approaches have four basic conceptual underpinnings:

- Technologies should be seen as systemic at the technical level – that they consist of complex systems, and that the creation of complementary technologies, such as in electricity production and distribution, should be seen as a process of system building. The nature of the artefacts may, thus, matter which is not recognised as a problem in the market failure approach.
- Economic behaviour rests on institutional foundations, in the sense of legally or customarily established 'rules of the game', which limit and constrain choices but at the same time reduce uncertainty, which is important for investments. Different modes of

[4] A good overview of the range and complexity of relevant measures and instruments can be found on TrendChart, the European Commission's monitoring project on innovation policy: www.trendchart.cordis.lu

institutional set-up lead to differences in economic behaviour and outcomes. The market failure approach neglects the importance of institutions.

- Technological (and other) knowledge is generated by interactive learning, and technological knowledge in general takes the form of 'distributed' knowledge bases among different types of economic agents who must interact in some way if technological knowledge is to be applied. The market failure approach, however, assumes strong independence between firms (and indeed all economic agents), and hence clear boundaries between firms. The study of innovation, on the other hand, constantly presents phenomena of interdependence and blurred boundaries between actors.
- Competitive advantage results from variety and specialization, and that this has path-dependence-inducing effects characterised by increasing returns. That is, successful specializations are self-replicating, with system-building as an outcome – particularly around specific industrial structures. Increasing returns are, thus, an inherent feature of system formation and not a 'failure' – indeed, without increasing returns, systems will fail to develop.

These conceptual underpinnings have serious effects on the rationale for policy intervention. A central proposition in the systems literature is that just as the nature of actors/markets may block or obstruct the formation of a TIS, so can institutions and networks (e.g. Malerba, 1996; Carlsson and Jacobsson, 1997; Edquist, 1999; Jacobsson and Johnson, 2000; Unruh, 2000; Rotmans et al., 2001). Additionally, some scholars (e.g. Hughes, 1983, Sandén and Jonasson, 2006) point to the exclusion effects of specific artefacts (particularly in the energy field). The concept of 'system failure' (or better, system weaknesses) emerged to capture this broader rationale for policy intervention (Smith 2000b).[5] Carlsson and Jacobsson (1997, p. 303), for instance, argued that:

> "… firms, institutions and networks become 'locked in' to the 'old' technologies. Thus, the cumulativeness and path dependency of innovation lead to risks of lock-in into technological, institutional and networking cul-de- sacs".

[5] See Klein Woolthuis et al. (2005) for a recent overview of the system failure literature.

Here, all the four underpinnings are present and, combined, these may lead to a 'failure' at the level of the entire system, i.e. a system fails to develop or does so in a stunted way only.[6] Edquist (1999) suggested, similarly, that 'system failures' can be ascribed to characteristics of organisations, institutions or interactions (networks), i.e. in the nature of the components of a system. Metcalfe (2004, p. 18) argued that:

> "… 'government' takes responsibility for the ecology of organizations and institutions that facilitate business experimentation but recognises that without the necessary interconnections the ecology is not a system…because systems are defined by components interacting within boundaries, it follows that a system failure policy seeks to address missing components, missing connections…"

It follows that policy makers may find a rationale for intervention in a specific innovation system in the form of *system weaknesses* in structure.[7] Yet, the mere existence of system weaknesses is not necessarily a rationale for policy intervention since private actors may have the scope for repairing problems independently of government. As Smits and Kuhlmann (2004. p. 8) put it: "[O]ne should not overestimate the instrumental power of public policy vis-à-vis other actors in complex policy-making arenas." Individual firms, groups of entrepreneurs, industry association and other interest organization may very well identify and act upon system weaknesses in their own self-interest. For example, referring to the work of Van de Ven, Aldrich and Fiol (1994) emphasize the possibility for actors to jointly influence the institutional framework:

> "[A] small handful of actors can generate networks that, in the aggregate, result in institutional-legitimating events. If founders can overcome the barriers to effective collective actions, they can rise above the level of their individual ventures and run together 'in packs' …" (Aldrich and Fiol, 1994, p. 654; cf also Van de Ven, 2005)

However, such system-building activities may be in conflict with the interests of individual actors. For example, although variety creation may be necessary on a system level, individual firms will usually have to focus on developing one (or few) technological alternative(s) at a time and cannot be expected to support the development of competing substitutes. In addition, first-mover system builders may become victims of the "burnout of pioneers" phenomenon (Olleros, 1986), where the benefits of their system-level investments in an early phase are reaped by follower firms while they themselves perish. Indeed, "… there is an ongoing tension for each

[6] This is also emphasized in Smith (1996).
[7] Chaminade and Edquist in this book use the term 'systemic problems'.

industry participant to organize its own proprietary function and distribution channels as opposed to contributing to the creation of the industry's resources and institutional arrangements" (Van de Ven, 1993, p. 223). There are, therefore, strong reasons to expect that public policy makers may need to make interventions in order to secure developments on a system level.

Focusing on system weaknesses means that we have left the old and sterile debate over the ability of the state to 'pick winners' in the form of individual firms (Carlsson and Jacobsson, 1996). As Stewart and Ghani (1991) rightly pointed out many years ago, the systems view on the innovation process makes us instead focus on the conditions and processes whereby winners are created. However, even when the rationale for public policy intervention is clear, the question remains how to identify system weaknesses that should be tackled by public policy. Some have tried to address this policy problem by specifying a set of policy issues pertaining to possible 'generic' system weaknesses that may be particularly important to tackle in the process of emergence of a new system (Carlsson and Jacobsson, 1997; Jacobsson and Johnson, 2000; Jacobsson and Bergek, 2004), and require the application of *systemic instruments*, as distinct from those which primarily focus on individual organizations or bilateral relations (Smits and Kuhlmann, 2004, see also their chapter in this book as well as the chapter of Teubal et al.). Safeguarding of variety is such a key generic policy issue in the face of uncertainty[8]; formation of 'prime movers' is vital in an early phase; the formation of new networks may be required to enable an alignment of actors' expectations and coordination of their investment;[9] articulation of demand[10] is required to form markets and induce firms to enter etc.[11]

Potentially 'generic' policy issues are, however, of little guidance for policy makers dealing with a specific TIS, e.g. salmon farming in Chile or mobile data in Sweden. As Rodrik (2004, p. 14) argues, policy has to focus on specific activities, (e.g. a new technology, a particular kind of

[8] See also Malerba (1996) for a useful discussion on variety.
[9] Carlsson and Jacobsson (1993) discussed in terms of the role of networks in 'blending visions' or technological expectations.
[10] This point is emphasized in Frenken et al., (2004). See also Malerba (1996) and Edquist (1999).
[11] Others pointed to 'general' policy issues coming out of the application of an innovation system approach. Smith (1996) pointed to four (infrastructural provisions, 'transition failures', lock-in failures and institutional failures). Edquist (1999) mentions the last two and adds problems associated with interactive learning (networks) and demand side issues). Some of these policy issues are found in the chapter of Chaminade and Edquist in this volume.

training, a new good or service) rather than on a sector per se and should be thought of as "…a process designed to elicit areas where policy actions are most likely to make a difference.[12]
As noted above, these areas differ between TIS and change over time and, therefore, require the application of non-uniform and often a wide range of policies. Indeed, Katz (2004, p. 29) concludes from a study of the successful evolution of salmon farming in Chile that "…it is the diversity of roles the State has played affecting industry's behaviour what strikes as the major lesson". *The relevant issue then is how policy makers can identify those activities/areas that are of critical importance to the dynamics of a specific TIS.*

In the received literature on 'Policy and Innovation Systems', we find little guidance on how to do so – it stops at outlining general policy challenges. In the few cases where more concrete advice is given, policy makers and researchers are recommended to compare different innovation systems with each other: "In this rationale to government involvement the recommended methods of identifying failures are the use of comparative analysis, benchmarking and best practice" (Norgren and Hauknes, 2000, p. 4). However, very little guidance is given on which dimensions to compare. In the following section, we suggest that a functional analysis of a TIS constitutes a framework that allows us to identify system weaknesses and to develop (more systemic) policies to tackle these weaknesses in an emerging TIS.

## 3. System functions as key processes in the dynamics of innovation systems

In order to be able to find a rationale for intervention and to identify the central policy issues in a specific innovation system, we need to develop an understanding of the key processes in system evolution that policy makers may need to intervene in. A focus on key processes, rather than states, implies, of course, that our approach is about the dynamics of innovation systems (see chapters by Kuhlman et al. and Teubal et al. for a critique of the literature on innovation systems being static). The key processes can be identified at two levels. The first is structural and refers to the three components in a TIS: actors, networks and institutions. Dynamics can be analysed in terms of how actors enter into a TIS, networks are formed and institutions are changed (or not). The second level refers to 'what is achieved in the system' in terms of processes that have a more

[12] This does not imply that more generic systemic policy challenges are useless or that they can't be found at the level of national innovation systems.

direct and immediate impact on the ‘goal’ of the system, which could be stated as to generate, diffuse and utilise new technology (Carlsson and Stankiewicz, 1991). These processes are here labelled ‘functions’. We propose that if an innovation system is to successfully evolve, it has to perform well in seven dimensions. We derive these functions from contributions from the literature on innovation systems and evolutionary economics but also from political science, sociology, organization theory and related fields. Earlier versions of the framework have been applied to a number of TIS.[13] These functions are:

(1) Knowledge development and diffusion
(2) Influence on the direction of search and the identification of opportunities
(3) Entrepreneurial experimentation and management of risk and uncertainty
(4) Market formation
(5) Resource mobilization
(6) Legitimation
(7) Development of positive externalities

In what follows, we outline the content of these seven functions.[14] A brief illustrative case of biomass gasification in the Netherlands ends the section.

### 3.1 Knowledge development and diffusion

This is the function that is normally placed at the heart of an innovation system in that it is concerned with the knowledge base of the TIS (globally) and its evolution. The function captures the breadth and depth of the (scientific and technical) knowledge base of the TIS and how that knowledge is diffused and combined in the system. It is, thus, closely related to the concept of “learning”, which is at the core of the innovation system approach.

Learning and knowledge creation happen across innovation systems at different levels. Firstly, there is the level of the firm, where highly specific forms of expertise and knowledge are created, relevant to the products and process around which the firm seeks to compete. Secondly, there is knowledge shared within an industry or sector: broader forms of knowledge (often codified in the form of disciplines such as chemical engineering). Thirdly, there are general scientific or social

[13] See Bergek and Jacobsson (2003), Jacobsson and Bergek (2004), Jacobsson et al., (2004), Bergek et al., (2005) and Hekkert et al., (in press).
[14] The description of the seven functions draws heavily but not exclusively on Bergek et al., (2005).

forms of knowledge that make up an even broader background to production and innovation. Enterprises very rarely innovate on the basis solely of their internal knowledge bases. Key reasons for this include technological complexity and technological dynamics. Technological complexity means that firms can rarely command all relevant knowledge internally. Technological dynamics means that knowledge is often evolving in directions that firms cannot master as a whole. A prevalent solution to this is technological cooperation or collaboration.

A key site of such collaboration and support is the sub-system of organisations that make up the knowledge infrastructure: universities, government labs, standards-setting organisations, research institutes, etc. A major issue in system functioning is how these organisations maintain and diffuse elements of scientific knowledge bases or specific industry-relevant knowledge bases. Moreover, as argued elsewhere in this book (see chapters by Polt and Smits et al., in part V), such organisations form part of a Strategic Intelligence infrastructure that is concerned with perceptions of technological opportunities, possible applications as well as consequences of realising these and what strategies are required to do so.

### 3.2 Influence on the direction of search and the identification of opportunities

If a TIS is to develop, a whole range of firms and other organizations have to perceive new opportunities and enter into it. In much economic theory, the problem of recognizing an innovation opportunity is in effect assumed away – the assumption is that the market mechanism leads to the taking up of all profitable opportunities. This idea rests on assumptions of costless and instantaneous access to new information and of identical interpretation of the very same information by all firms.

However, opportunities rarely present themselves in a clear and transparent way and this applies in particular to those associated with technologies that disrupt existing technological knowledge. As Metcalfe (2004) argues, firms (individuals within these) read and interpret the same information in very different ways and "here we find one of the principle sources of variation in the innovation process, innovations are conceived in individual minds and these minds differ".[15]

[15] In the classic book on Korean industrialisation, Jones and Sakong (1980, p. 83) explained how government attempted to increase variety and experimentation through influencing the direction of search. The means was to manipulate the perceived opportunity set of business – 'field augmentation' – so that they would *enter into new*

Identification of opportunities and related demand articulation is therefore a problematic characteristic of a TIS and there must be sufficient incentives and/or pressures for firms to search for opportunities and undertake investments in an emerging TIS.

The second function is the combined strength of factors influencing this search and investment behaviour. This function also covers the mechanisms influencing the direction of search *within* the TIS, in terms of different competing technologies, applications, markets, business models etc. Examples of influencing factors are beliefs in growth potentials (e.g. Raven, 2005), changes in the 'landscape' (Geels, 2002), e.g. the climate debate, regulations, articulation of demand by leading customers (e.g. von Hippel, 1988; Carlsson and Jacobsson, 1993) and technical bottlenecks (e.g. Rosenberg, 1976; Hughes, 1983). It ought to be recognised that this is not simply a matter of firm behaviour. We noted above that 'infrastructural' organisations have often played an important role in shaping major new technologies: these too have a role in identifying opportunities. For example, the development of mobile telephony in the Nordic countries was mainly the result of an opportunity envisaged by state telecoms laboratories that carried out an extended development effort which was only transferred to firms at a late stage.

### 3.3 Entrepreneurial experimentation and management of risk and uncertainty

The origin of a TIS can be traced back to a whole range of factors and circumstances, such as an abundance of skilled labour (Breschi and Malerba, 2001; de Fontenay and Carmell, 2001), unique university research expertise, competence in related industries (Porter, 1998), advantageous geographic location (Feldman and Schreuder, 1996) or abundance of natural resources (Katz, 2004). These 'triggering factors' operate, however, only if there are entrepreneurs that conduct experiments, delving into uncertain markets and technologies and challenging institutions.

Entrepreneurial uncertainties are a fundamental feature of technological and industrial development and are not limited to early phases in the evolution of a TIS but is a characteristic of later phases as well (Rosenberg, 1996). After all, innovation is by definition a novelty, and we do not know what the nature and impact of novelty might be. Innovation, thus, involves both serious

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*areas for business*: "Field augmentation…operates through expanding information about existing opportunities. The controller/the firm/considers his perceived opportunity set that includes only a finite number of feasible alternatives, due to limited information. The controller/the government/can expand the decision-maker's perceived opportunity set by filling this information gap."

risk and serious uncertainty, both in technological and in economic terms. Risk here refers to the fact that potential outcomes of an innovation may be known but show very large variability in results. Uncertainty means that we do not even know what the potential outcomes might be – indeed, it has very rarely been possible to predict the path of innovation, even in general terms. The identification and management of uncertainty and risk is therefore central to any TIS and systems differ sharply in how they do that. The policy issues here relate to the long-standing and well-recognised role of government is reducing, shifting or diversifying risk.

From a social perspective, a fundamental way to handle uncertainty and risks is to ensure that many entrepreneurial experiments take place. These refer, of course, to the activities of the entrepreneurial firm, but include also actions by others, e.g. policy makers that experiment with new ways to promote a technology. These experiments imply a continuous probing into new technologies and applications, where many will fail, some will succeed. A TIS without vibrant experimentation will stagnate and, indeed, without the initial experiments, it will not be formed.

As emphasised in Strategic Niche Management (e.g. Raven, 2005) a multi-dimensional social learning and search process will unfold through the course of these experiments. As mentioned above, Strategic Intelligence (see chapters by Polt and Smits et al.) plays an important role here. Strategic Intelligence provides the tailor made information about the potential of a new technology, possible applications and the consequences of turning options in concrete products and services that actors need in order to develop their strategies and action plans.

Where experiments take place, knowledge formation is of a more applied nature than that captured under the first functional heading. Entrepreneurial activity always involves a range of activities related to business that have little to do with technological capabilities – this includes business planning, investment programming, strategic marketing, and human resource policies. In turning inventions into economic outcomes the crucial ‘middle term’ is business development, which involves a range of complementary assets (skills and capabilities) that are crucial for, but not necessarily directly related to, innovation. These include the ability to finance capital investment programs, the ability to create efficient production systems on an adequate scale, the ability to recruit and coordinate appropriately skilled labour forces, the ability to construct and use marketing channels, and the ability to create and deploy logistics systems.

From a company perspective, experimentation always leads to risk and uncertainty problems. Whereas these are also the source of business opportunities, profit-seeking companies may be very hesitant to invest in longer-term and high risk projects, in particular those requiring large scale commitments. Historically, such projects have been managed by such means as government subsidies (e.g. for biotech development), military procurement systems (e.g. for semiconductor development and computing, or for the GPS system), income-contingent loans (e.g. the launch-aid system for Airbus),[16] through research institute funding (for the world-wide web), or through the independent labs of state-owned companies (for mobile telephony). Risk and uncertainty management is central to innovation, but is rarely openly acknowledged or addressed. An economic system that cannot bear or diversity risk, or meet the challenges of uncertainty, is likely to fail to innovate.

### 3.4 Market formation

For emerging TIS, markets may not exist, or be greatly underdeveloped. Market places may be absent, potential customers may not have articulated their demand, or have the competence to do so, price/performance of the new technology may be poor, standards may not exist, uncertainties may prevail in many dimensions. As regards the latter, Rosenberg (1976, p. 195) puts it like this:

> ”Most innovations are relatively crude and inefficient at the date when they are first recognized as constituting a new innovation. They are, of necessity, badly adapted to many of the ultimate uses to which they will eventually be put; therefore, they may offer only very small advantages, or perhaps none at all, over previously existing techniques.”

Consequently, it is important that smaller “nursing markets” (Erikson and Maitland, 1989) evolve so that a learning space is opened up in which the TIS can find a place to be formed (Kemp et al., 1998).[17] Within such an environment, actors can learn about the new technology and expectations

[16] The creation of Airbus, for example, required major long-term financing in the face of serious technological and economic risk, financing that was well beyond the scope of even the largest banks or consortia of banks. In effect governments assumed this risk, financing the company via income-contingent loans that diversified risk across governments, reduced risk to the shareholders, and through this made a major technological development possible.

[17] Strategic Intelligence is, of course, also relevant here.

and beliefs be formed. Nursing markets may eventually give way to ‘bridging markets” (Andersson and Jacobsson, 2000) that allow for volumes to increase and for an enlargement of the TIS in terms of number of actors. Finally, in successful TIS, mass markets may evolve, often decades after the formation of the first market.

### 3.5 Resource mobilization

Innovating is much more than creating knowledge or learning. As noted above, it always involves a range of assets and abilities that are not necessarily related directly to innovation. These include the ability to finance investments, to create efficient production systems and to recruit appropriately trained staff. As a TIS evolves, a range of different resources therefore need to be mobilized including human and financial capital. In some areas, resource mobilisation also entails building a physical infrastructure, in addition to a knowledge infrastructure. Clearly, because of the diversity of resources required for a major new technology (or major upgrade of an existing technology) there are potential coordination failures in resource mobilization.

### 3.6 Legitimation

Legitimacy is a matter of social acceptance and compliance with relevant institutions; the new technology and its proponents need to be considered appropriate and desirable in order for resources to be mobilized, for demand to form and for actors in the new TIS to acquire political strength. Legitimacy also influences expectations among managers and, by implication, the function ‘influence on the direction of search’.

As is widely acknowledged in organization theory, legitimacy is a prerequisite for the formation of new industries (Rao, 2004) and, we would add, for the formation of new TIS. Legitimacy is not given but is formed through conscious actions by organisations and individuals in a process of legitimation, which eventually may help the new TIS to overcome its ‘liability of newness’ (Zimmerman and Zeitz, 2002). This process may take considerable time and is often complicated by a requirement of the new TIS to relate to and often compete with a number of established TIS (Van de Ven and Garud, 1989). Regardless of whether the new TIS may become part of the incumbent regime or threaten to overthrow it, vested interests may oppose this force of “creative destruction” and defend the existing TIS’ and the institutional frameworks associated with them. In that case, “political networks” or advocacy coalitions, (e.g. Smith, 2000a) may function as catalysts by engaging in wider political debates in order to secure institutional alignment. The scale and success of such coalitions are though directly dependent on the available resources and prevailing expectations of the future of the new technology.

### 3.7 Development of positive externalities

As markets go beyond the first niches, there is an enlarged space in which the emerging system can evolve and the functions be strengthened via a generation of positive external economies. Structural change in the form of entry of firms is central to this process. First, new entrants may resolve at least some of the initial uncertainties with respect to technologies and markets (Lieberman and Montgomery, 1988), thereby strengthening the functions ‘influence of the direction of search’ and ‘market formation’. Second, new entrants may, by their very entry, legitimate the new TIS (Carroll, 1997). New entrants may also strengthen the ‘political’ power of advocacy coalitions that, in turn, enhances the opportunities for a successful legitimation process. An improved legitimacy may positively influence four functions: ‘resource mobilisation’, ‘influence of the direction of search’, ‘market formation’, and ‘entrepreneurial experimentation’. Further externalities may arise due to the co-location of firms. Marshall (1920) discussed economies that were external to firms but internal to a location:[18]

- Emergence of pooled labor markets, which strengthens the function ‘knowledge development and diffusion’ in that subsequent entrants can recruit staff from early entrants (and vice versa as time goes by).
- Emergence of specialized intermediate goods and service providers; as a division of labour unfolds, costs are reduced and further ‘knowledge development and diffusion’ is stimulated by specialization and accumulated experience.
- Information flows and knowledge ‘spill-over’, contributing to the function ‘knowledge development and diffusion’.

[18] To these, we may add that the greater the number and variety of actors in the system, the greater are the chances for new combinations to arise, often in a way which is unpredictable (Carlsson, 2003). An enlargement of the actor base in the TIS therefore enhances both the opportunities for each participating firm within in the system to contribute to ‘knowledge development and diffusion’ and for the firms to participate in ‘entrepreneurial experimentation’.

Hence, new entrants may contribute to a process whereby the functions are strengthened, benefiting other members of the TIS through the generation of positive externalities. This function is therefore not independent, but rather one which indicates the dynamics of the system.

Drawing on Negro et al., (2006), the next sub section applies the functions approach to the development of the TIS for biomass gasification in the Netherlands as a brief illustrative case in point.

### 3.8 The case of biomass gasification in the Netherlands

Biomass gasification technology converts biomass into electricity (and heat) or into feedstock for the production of chemicals and liquid bio fuels. Despite the promises of high-energy conversion efficiency and the wide variety of applications, biomass gasification has not yet been successfully developed and implemented in the Netherlands.[19]

When biomass gasification came onto the political agenda for large-scale production of electricity in the early 1990s, the development of the knowledge base could build on experience with gasification of coal in the Netherlands and with building small scale biomass gasification plants for developing countries. However, the first initiatives in ‘knowledge development’ were not so much focused on technology development as on energy systems studies to identify the potential contribution of biomass gasification to the energy sector and the available biomass resources. These desktop studies presented such a positive picture for biomass gasification that it greatly raised expectations. This influenced the ‘direction of search’ towards biomass gasification. Further desktop studies confirmed the initial expectations, which increased expectations and positively ‘influenced the direction of search’ even more. In a very short time period, biomass gasification was considered to be on par with other renewable energy technologies. The high expectations were reflected in reports in media that large-scale demonstration projects could be realised quickly and that no unsolvable technological problems were expected.

[19] Also in other countries this technology is still in an emerging stage.

The expectations led to an interest by some parties to actually build a biomass gasification plant (‘entrepreneurial experimentation’) which triggered the initiation of R&D projects (‘knowledge development’ as well as some ‘resource mobilisation’). The EU contributed financially to several projects, energy companies invested in feasibility studies and experiments and the Dutch government included biomass gasification in their R&D program to produce energy from biomass and waste. Also, biomass gasification projects were able to obtain financial resources from more general (renewable) energy R&D subsidies.

Two major ‘entrepreneurial experiments’ with biomass gasification dominated. The first was an energy company that added a biomass gasification unit to a coal fired power plant. The unique feature was that it used waste wood as biomass resource. This combination (waste wood in a biomass gasification plant) resulted in many technological problems.  The other project was a coalition of local authorities, energy companies and R&D institutes. The two experiments attracted much attention in the energy community and the first phase of the projects boosted many other system functions: in particular they ‘influenced the direction of search’ and ‘knowledge creation’ since they initiated several feasibility studies and enhanced the ‘process of legitimation’ of biomass gasification.

The process of legitimisation led to a drastic change in perception of this technology; from a relative unknown technology to a building block in the transformation of the energy sector. Since very influential actors became part of the ‘advocacy coalition’, successful lobbying activities took place, leading to the start of a specific publicly financed research program on biomass gasification.

The function ‘market formation’ was, however, never well fulfilled. The high technological risks were not compensated by specific market stimulation measures and no “nursing market” was created. The effect of this poorly developed function became immediately visible after the liberalization of the Dutch energy market in 1998. The key words for electricity companies after the liberalization were ‘low costs’. Without specific market formation policies in place, the technological uncertainties resulted in an abortion of all projects. Without these, positive externalities could not emerge and the TIS around biomass gasification never became really entrenched in the larger energy innovation system. Indeed, the emerging TIS stalled and declined rapidly, as indicted in Figures 1 and 2 which shows the rise and fall in the functions ‘knowledge formation’ and ‘influence the direction of search’. Note that Figure 2 also negative events are recorded; this implies that guidance away from biomass gasification took place.

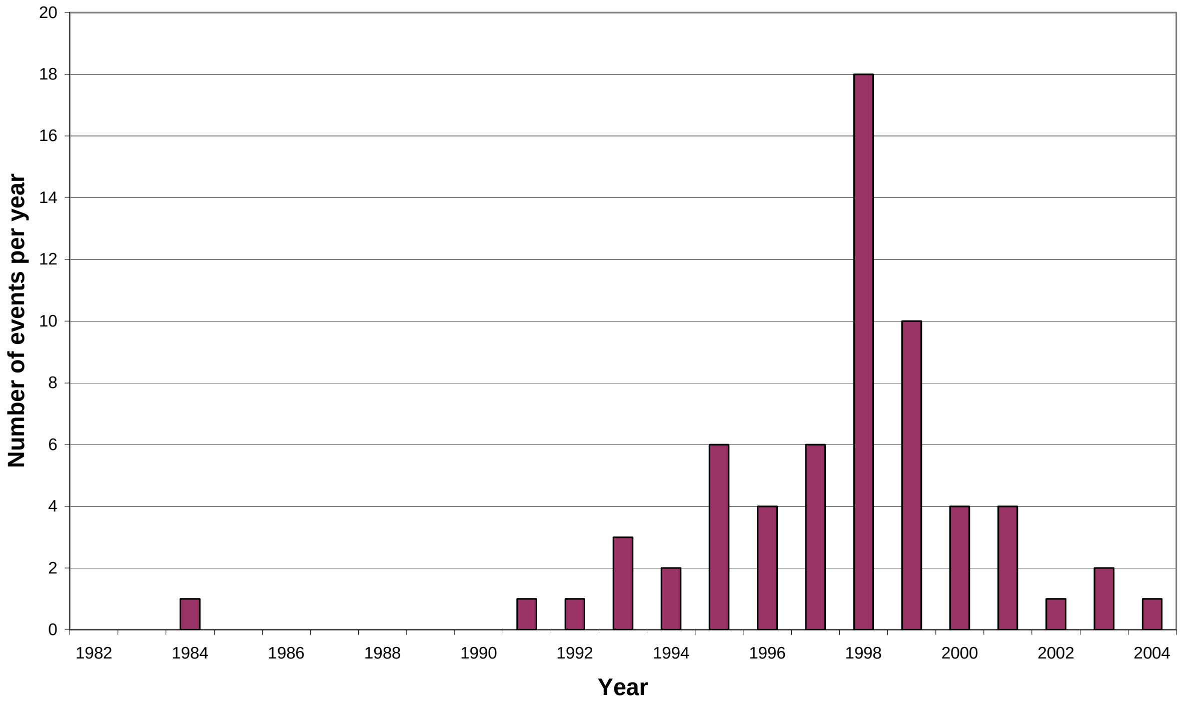


*Figure 1 Activity pattern of the function ‘Knowledge development and diffusion’*

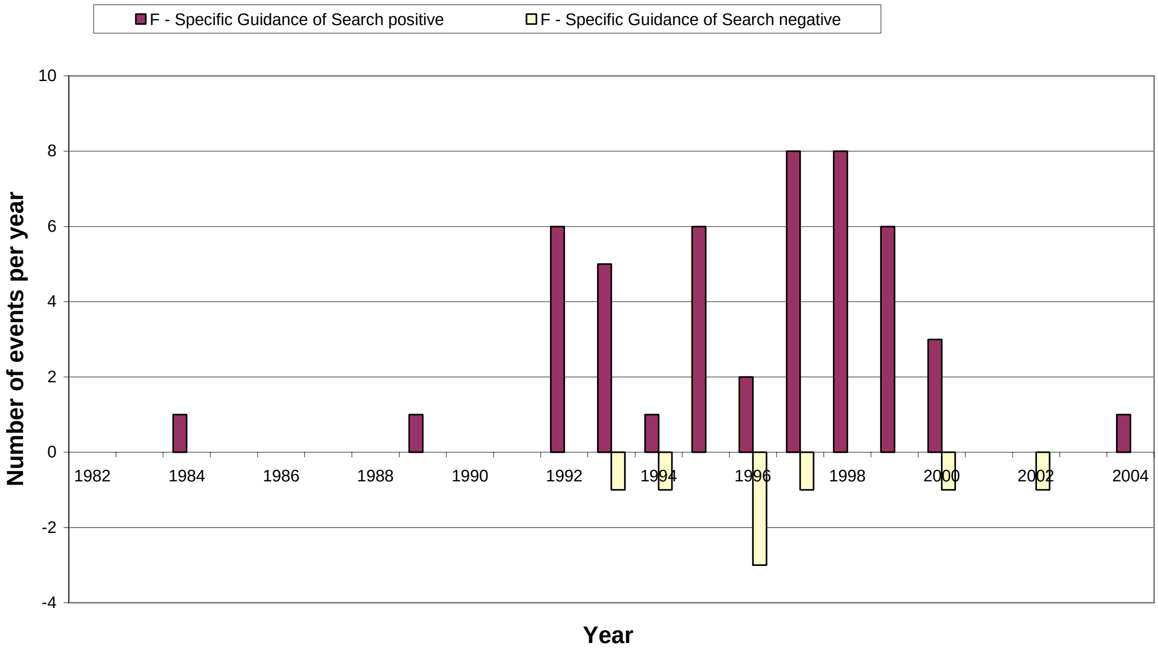


*Figure 2 Activity pattern of the function 'influence the direction of search'*

# 4. Functional analysis as a guide and rationale for policy

Having described and illustrated the seven functions, we will now proceed to analyze how a functional analysis can be used as a tool to find the key policy issues to tackle (4.1) and a further rationale for doing so (4.2).

## 4.1 System weaknesses in functional terms: A guide for policy

As mentioned above, most of the literature discussing innovation system weaknesses (or failures) has tended to focus on perceived weaknesses in the structural composition of a system. For example, all the four types of system failures identified by Klein Woolthuis et al., (2005) in their recent synthesis and re-categorization of previous system failure literature are related to structural components: infrastructural failures (related to actors and artefacts), institutional failures (related to institutions), interaction failures (related to networks) and capabilities' failures (related to actors).

However, it is difficult, if not impossible, to evaluate the ‘goodness’ or ‘badness’ of a particular structural element or combination of elements without making references to its effects on the innovation process.[20] For example, how do we know whether the existence of a strong network constitutes a weakness rather than a strength of a particular system, e.g. a source of synergy rather than of lock-in or ‘group-think’ (cf. Klein Woolthuis et al., 2005), without identifying its influence on the innovation process and its key sub-processes? Therefore, an attempt to find system weaknesses at the structural level only is fraught with difficulties. Hence, an assessment of rationale and options for policy in a specific TIS should rest, in part, on the dynamics of what the system achieves rather than on the nature and evolution of its structural components.

This is, indeed, the main benefit of the functional analysis: It allows us to separate structure from content by adding the second level – functions – to the structural one. With a functional analysis, the prime focus is on the dynamics of ‘what is actually achieved’ in the TIS rather than on the dynamics in terms of the structural components of the TIS. This does not mean that a policy analysis should neglect structural factors. These contribute to how the functions are performed and any intervention has, of course, to focus on structural elements. It is, however, through a functional analysis that specific system weaknesses in a given TIS can be sought out.

The *functional pattern*, i.e. *what is achieved* in terms of the seven key processes, can be analysed empirically. This was first demonstrated in Johnson and Jacobsson (2001).[21] In later work, we used this framework to trace the dynamics of functional patterns. In Bergek and Jacobsson (2003) and Jacobsson et al., (2004), for example, analyses of functional patterns were used to understand the evolution of two TIS in the energy field (wind power and solar power). Empirical analyses of this nature not only improve our understanding of dynamics but can provide policy makers with a specification of which the weak functions are. It follows that we can also formulate policy problems in functional terms, i.e. ‘what do we think should be achieved that is not’, which

[20] Mowery’s (2005) analysis of the differences in paths followed by Korea and Taiwan in the semiconductor industries clearly demonstrates that industrial development does not involve following one structural path only but is achieved in different ways in different contexts.
[21] In that analysis, we restricted ourselves to five functions.

implies that *system weaknesses can be expressed in functional terms*.[22] A functional analysis can therefore not only provide a rationale for intervention but also constitute the focusing mechanism for policy makers (and others who desire to influence the dynamics) in their efforts to specify the key policy issues. In here we differ from more structural approaches focusing on system failures or systemic problems (e.g. Chaminade and Edquist (this volume) and Klein Woolthuis et al., (2005)).

How can we then explain why certain functions are weak in a particular TIS? Each TIS has a degree of uniqueness in terms of its structural components. Yet, for emerging TIS, many of the components are shared with other TIS, incumbent as well as other emerging ones (Johnson and Jacobsson, 2001). For instance, institutional change in the form of tradable emission permits influences many TIS using or supplying energy.[23] Within the boundary of the TIS there are, thus, both technology-specific components and those that are part of also other TIS.

An innovation system evolves in part as a result of its internal dynamics. As noted by Myrdal (1957), in a rapidly developing system, a chain reaction of positive feedback loops may materialise setting in motion a process of cumulative causation. In such a process, the boundary alters and impacts on the dynamics in functional terms (what is being achieved). However, the internal dynamics is only part of the picture. Factors that are exogenous to a TIS may have an impact on its structural evolution and functional dynamics. Myrdal (1957, p. 18) showed a keen understanding of the interplay between internal and external sources of dynamics and even suggested that "… the main scientific task is…to analyse the causal inter-relations within the system itself as it moves under the influence of outside pushes and pulls and the momentum of its own internal processes". Hence, the determinants of system development are both endogenous and exogenous (Sandén and Jonasson, 2006).[24]

[22] Assessing the goodness of a specific functional pattern – the functionality of a TIS – is a challenge that requires more work to meet. For initial discussions, see Bergek and Jacobsson (2003) and Bergek et al., (2005).
[23] Indeed, the whole notion of functions was developed to handle an integration of technology-specific and more general influencing factors, see Johnson and Jacobsson (2001, p.93). See also Geels' (2002) discussion of a multi-level framework.
[24] This means that within our framework, we incorporate determining factors found at the levels of 'regimes' and landscape' in Strategic Niche Management.

An endogenous driving force, or inducement mechanism, may be demand from a leading-edge customer and an exogenous one may be the climate debate or accidents like that in Chernobyl.[25] From the perspective of an emerging TIS, it is particularly vital to identify *blocking mechanisms*, i.e. factors that provide obstacles to the development of functions and, therefore tilt the selection environment in favor of incumbent technologies.[26] An endogenous blocking mechanism may, for instance, be poorly developed learning and 'political' networks that limit knowledge diffusion and legitimation. An exogenous blocking mechanism may come in the form of highly organized incumbents that defend their markets and investments and make sure that institutions are continued to be aligned to the dominant technologies.[27] Further blocking mechanisms may be traced to the emergence of other TIS that compete for space both in the market and in the political arena. A case in point is that of fossil gas in Sweden where a 'battle of institutions' is taking place with the proponents of biomass CHP.[28]

The functional pattern and the dynamics of a TIS can, thus, be empirically linked to and explained by a set of driving forces and blocking mechanisms. System weaknesses in the emerging TIS, as expressed in functional terms, can then be traced to structural features of the TIS or to exogenous factors. *This means that the key policy issues are readily definable as and when such an analysis has been completed.*

We will illustrate this with the example of the emerging Swedish TIS for 'IT in home care' which is defined by the application of a generic technology (IT) to a particular application: care of elderly and ill people in their homes instead of in a hospital. For a number of reasons (demographic, public sector funding restrictions, technological opportunities etc), this is a TIS

[25] Raven (2005) has a useful discussion of 'destabilization' of regimes which opens up windows of opportunities for new 'niches'. This was, for instance, the case in Germany where the current regime (power sector) lost much legitimacy after the Chernobyl accident (Bergek and Jacobsson, 2003). The stabilization and destabilization of the regime (and the dominant TIS making up that regime), should perhaps be included as a key process.
[26] See Johnson and Jacobsson (2000), Unruh (2002) and Jacobsson and Bergek (2004).
[27] Setting the boundary of a system that is emerging is very difficult. It could be argued that incumbents should be included in the system as their behavior is possible to influence by the growth of the new TIS. In functional analysis, the issue of setting boundaries (in terms of the structural elements of the TIS) is, however, of lesser importance. The focus is on the functions and how these are influenced by structural elements found at different system levels (Johnson and Jacobsson, 2001).
[28] We don't exclude that the relationship between emerging TIS can be complementary. For instance, small-scale hydropower proponents and the advocacy coalition for wind power teamed up to influence the German legislation so that it would favour renewables (Jacobsson and Lauber, 2006). Sandén and Jonasson (2006) discuss how competition and collaboration evolved among emerging TIS in alternative fuels in Sweden.

which is thought of as having a large growth potential. However, it is still in an early phase, as judged by, e.g., the following structural features:[29]

- There are many competing experiments that are linked to specific IT platforms (no standards and high technical uncertainty).
- The number of firms supplying IT solutions is small.
- Markets are small, with high uncertainties, e.g. with respect to applications and choice of software
- The ’advocacy coalition’ for the TIS is weak
- The demand is poorly articulated by customers with poorly developed competences

In this early phase, the functional pattern can be summarized as follows:

- ’Knowledge development and diffusion’: pilot projects in only some of the 290 counties and 21 county councils
- ’Market formation’: local pilot projects constitute a small and fragmented ‘nursing markets’
- ’Influence on the direction of search’: some government R&D funding, opportunities, although unclear, to find new markets, awards
- ’Entrepreneurial experimentation and management of risk and uncertainty’: a few IT firms only have developed solutions – risks are high
- ’Resource mobilization’: EU and government R&D funding, some co-funding by firms, poor adjustment by the higher educational sector
- ’Legitimation’: partly underdeveloped legitimacy, especially among care providers
- ’Development of positive externalities’: early stage of cluster formation in three cities

This pattern is shaped by both inducement and blocking mechanisms (see Figure 2). There are two significant *inducement* mechanisms: belief in growth potential and government R&D policy. The former is driven by a range of factors, as was mentioned above[30] and has a bearing on the function ‘influence on the direction of search’ among both care providers (e.g. county councils) and suppliers (IT firms), as well as on the functions ‘market formation’ (nursing markets) and ‘entrepreneurial experimentation’. The latter inducement mechanism both signals attractiveness and provides some resources for research and experiments. Hence, it strengthens the functions

[29] This case was developed together with Cecilia Sjöberg at VINNOVA.
[30] These include demographic changes with a larger share of elderly people in the population, public sector funding restrictions and emerging technological opportunities.

‘influence on the direction of search’ and ‘legitimation’ as well as ‘resource mobilization’ and ‘knowledge development and diffusion’.[31]

In spite of these two inducement mechanisms, there are several *system weaknesses in functional terms*. In particular, we would single out ‘market formation’, ‘entrepreneurial experimentation’, ‘influence on the direction of search’ and ‘legitimation’. The *blocking* mechanisms are here strong and manifold. ‘Market formation’ is blocked by an absence of standards (which leads to a fragmented market), two factors that reflect poor awareness and competence among potential customers (leads to poor articulation of demand) and an associated lack of knowledge among suppliers of IT solutions of customer needs.

‘Entrepreneurial experimentation’, ‘influence on the direction of search’ and ‘legitimation’, are blocked by two factors each. These three have a common blocking mechanism in the form of a ‘lack of competence and a poor articulation of demand’. This is strengthened by an additional but different factor in each case (uncertainties of customer needs, lack of markets for standard software solutions and a weak advocacy coalition).

Functions are not independent, but tend to reinforce each other (dotted lines in Figure 2). A poor ‘market formation’, thus, affects negatively both ‘entrepreneurial experimentation’ and ‘influence on the direction of search’, whereas little ‘entrepreneurial experimentation’ negatively influences ‘resource mobilization’ and ‘knowledge development and diffusion’. This means that the impact of blocking mechanisms is magnified by such interdependencies. Clearly, it could be argued that policy must focus on reducing the strength of the blocking mechanisms that have such a pervasive effect. In the fourth column in Figure 2, we list six specific policy issues connected to removing or reducing the strength of the blocking mechanisms. The first three of these focus on the potential customers (care providers) and are aimed at removing the most pervasive blocking mechanisms. These policy issues can be specified as

- how to raise user competence so that demand is articulated and uncertainties reduced for potential suppliers

[31] Indirectly, it also strengthens ‘entrepreneurial experimentation’ as a consequence of its positive influence on the direction of search.

- how to support users in order to (a) increase their knowledge of the benefits of IT in home care and of ways to distribute the costs and benefits over organizational boundaries and (b) diffuse knowledge of the outcome of early experiments in order to reduce uncertainties further
- how to support experimentation with new applications in order to reduce the level of uncertainty of needs[32]

A fourth policy issue refers to

- how to develop standards in order to move from a fragmented market of 290 local councils and 21 county councils

In addition to these four issues, we can also deduce two additional ones which are

- how to alter research and education at universities in order to allow for 'resource mobilization' in terms of staff with relevant background
- how to support a weak advocacy coalition so that it can improve the process of 'legitimation'

Hence, by analyzing the functional pattern of the TIS ('what is actually going on'), we can point out the key system weaknesses in functional terms. By specifying the main endogenous and exogenous determinants of these weaknesses, in particular the main blocking mechanisms, we arrive at the central policy and/or strategy issues.

[32] It would be interesting to analyse how a well developed Strategic Intelligence infrastructure could support the identification of solutions to these three issues.

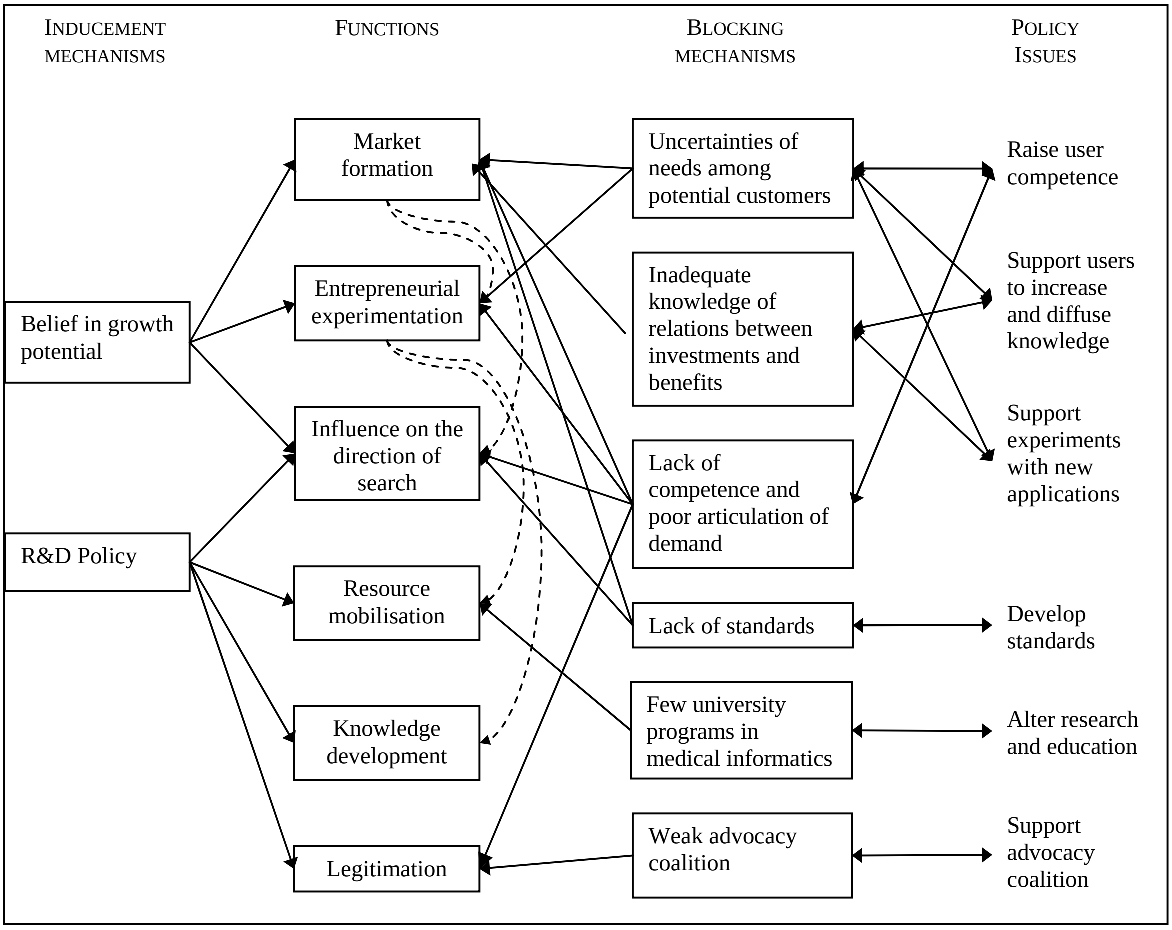


*Figure 2: Inducement and blocking mechanisms, functions, and policy issues in the case of "IT in home care".*

### 4.2 The nature of blocking mechanisms: An additional rationale and widened scope for policy

As mentioned in section 2 above, the mere existence of system weaknesses is not necessarily a rationale for policy intervention; individuals and groups of entrepreneurs may act on system weaknesses without any support from policy (and often do, as shown in the case of solar cells in Germany, see Jacobsson and Lauber (2006)). However, the very nature of blocking mechanisms may set limits to entrepreneurial influence on system dynamics and, thus, justify public policy intervention.

First, entrepreneurial experimentation does not necessarily come about automatically. Hausmann et al., (2005) argue that markets are good at signalling the profitability of already existing activities but not of uncovering profitability of those that might exist – firms may get 'locked in'. Hence, the blocking mechanism may be of a nature where there are no or very few entrepreneurial experiments going on which, of course, severely restricts the opportunities for these firms to influence system functionality.[33]

Second, blocking mechanisms may be quite many and come in a wide variety with different features. In the case of 'IT in home care', blocking mechanisms ranged from poorly articulated demand to institutional misalignment, such as the lack of standards. Individual actors, as well as networks of actors, can only be expected to allocate a smaller part of their investment budgets to improve system functionality and, therefore, to take on a limited number of roles and influence a limited number of mechanisms simultaneously. This implies that policy makers may need to lessen the burden of firms and other actors. This is particularly so in early phases in system evolution where firms are often small and lack resources.

Third, some blocking mechanisms may simply be out of reach of entrepreneurial actors. A few examples can be given:

- Entrepreneurs – on their own or in 'packs' – do not have the opportunity to reduce uncertainties and shift risks. The importance of this is currently seen in the success of the feed-in-law used in Germany (and Spain) in promoting the development of TIS centred on wind and solar power. A key feature of that institutional change is that it reduces risks for investor.
- Even though firms may act through advocacy coalitions to stimulate institutional alignment in a case where market formation is blocked by current legislation (or lack thereof), legislative changes in the end still require the participation of policy makers.
- Other blocking mechanisms than those requiring legislative changes may also be beyond reach. In the case of 'IT in home care', an alteration of research and education at universities is needed in order to allow for 'resource mobilisation' in terms of staff with relevant background. This is clearly not a problem easily solved by entrepreneurial actors alone. Nor would we expect that the issue of lack of software standards could be solved by

[33] This means that there are ample opportunities for policies that aim at 'influencing the direction of search' of firms. For example, Katz (2004, pp 29-30) argues that: "In the case of salmon, the *perception* that large natural rents are potentially present … required the public sector to take a proactive stance in favour of inducing the erection of salmon farming production capacity…it certainly exercised a crucial catalytic role…showing that '*it could be done'*" (our emphasis). This involved, inter alia, starting the first commercial salmon farming operation in Chile.

entrepreneurial IT suppliers alone, although it is conceivable that care providers could agree on standards without policy intervention.

- There may be a need for coordination of parallel initiatives by different actors and actor groups. Such coordination may be very difficult for firms to achieve – especially when many actors or types of actors are involved – and policy makers may, therefore, need to step in. For instance, a shift to fuel cell powered automobiles requires a simultaneous investment in development and production of fuel cells, fuel cell driven cars, production of energy carriers for fuels cells, 'petrol stations' for fuel cells, etc. Coordination then requires that a range of firms supplying complementary products/services are influenced in their respective search and investment processes (Frenken et al., 2004).

To conclude, by analyzing the nature of blocking mechanisms we may specify the rationale for public policy interventions and shed light on possible interventions. The ability of firms and other market actors to influence the functionality of a TIS may be particularly limited when (a) these do not perceive the opportunities; (b) functions are blocked by factors that for some reason are out of reach for firms, (c) there is a wide range of blocking mechanisms, or (d) there are many different initiatives that need to be coordinated. Policy makers, thus, need to understand the nature of the blocking mechanisms that shape the functional dynamics and identify those blocking mechanisms that individual actors or any foreseeable collaboration between actors cannot be expected to handle.[34]

These four issues do not only specify the rationale for public policy intervention in TIS formation but may also point at a broadened scope for policy intervention in comparison with a 'conventional' innovation system perspective. We have already argued that an analysis of functions in innovation systems can develop the notion of 'system weaknesses' from its conventional focus on structural factors only, to an identification of weak functions and the

[34] This is, however, not an easy task. As was evident from the case of "IT in home care", the 'picture' of a functional patterns and the mechanisms influencing it may become quite complex. It is more common than not for functions to be influenced by several blocking mechanisms and for blocking mechanisms to influence several functions simultaneously. The prevalence of feedback loops between functions increase complexity further (Jacobsson and Bergek, 2004). The co-existence of endogenous and exogenous (in the sense described above) blocking mechanisms may make the picture even more confusing. As a consequence of this complexity, even what may appear to be a 'simple' issue (such as what blocks the formation of markets) may be obscure (Jacobsson and Bergek, 2004) and the task of identifying, tracing and assessing the strength of various blocking mechanisms requires highly competent staff.

mechanisms causing weaknesses. It is reasonable to ask though if a 'conventional' innovation system analysis would not have identified the same functions (although termed differently), blocking mechanisms, and associated policy issues, particular since our list of functions draws heavily on previous innovation system literature. Reviewing the "Policy and innovation system" literature of the 1990s (largely) generates some interesting observations.

First, although many of 'our' functions were indeed mentioned in this literature, there was a clear focus on three functions only: 'knowledge development and diffusion' (especially learning),[35] 'resource mobilization' (especially knowledge and competence building in individuals)[36] and 'influence on the direction of search' (especially general incentives for innovation[37] and the phenomenon of lock-in,[38] but also the building of visions and awareness[39]).[40] The functions 'market formation' and 'entrepreneurial experimentation' were mentioned by a few authors only, primarily in terms of demand articulation and variety creation respectively.[41]

Second, two of 'our' functions were either mentioned only in passing or completely left out. That 'positive externalities' were only mentioned by a few (and primarily in terms of learning) was perhaps most surprising, since we consider this to be one of the central features of a well-functioning innovation system. The main exception was Malerba (1996), who discussed "dynamic complementarities" at some length. With the exception of Carlsson and Jacobsson (1997), 'legitimation' was not mentioned, which is also somewhat puzzling since its importance has been noted in several strands of literature, including organisational science and sociological analysis of technology development.

[35] See, e.g., Malerba (1996) and Smits and Kuhlman (2004).
[36] See, e.g., Hauknes (1999), Malerba (1996) and Metcalfe (2004).
[37] See, e.g., Malerba (1996), Smith (1996) and Teubal (2001).
[38] Malerba (1996), Smith (1996), Carlsson and Jacobsson (1997)
[39] Malerba (1996), Smits and Kuhlman (2004), Teubal (2001).
[40] Related to this function were also discussions of the trade off between variety creation and selection (see Malerba, 1996). The first two functions were often mentioned together, for example in terms of "too low level of R&D" or as a "learning failure" (Malerba, 1996).
[41] See, e.g., Malerba (1996) on trial-and-error and variety creation and Malerba (1996), Smits and Kuhlman (2004) and Teubal (2001) on market formation issues. Carlsson and Jacobsson (1997) put more emphasis on entrepreneurial experimentation.

The main observation, however, was that *none of the policy literature we reviewed mentioned all functions at the same time*. Instead, policy researchers seemed to focus on a few functions or general policy problems to be solved.[42] They, moreover, tended to mix functions with structural elements. Here lies the main difference between the functional analysis and ‘conventional’ innovation system analyses: Explicitly stating and including all functions allows for the systematic identification of policy problems, as illustrated by the case of ‘IT in home care’, at the same time as it avoids the pitfall of focusing on the structural characteristics of the system. As a consequence of the latter, policy makers are informed on the basis of what is actually achieved by the system, and in explaining the pattern exogenous blocking mechanisms are included in addition to endogenous ones.

The wide range of possible policy challenges coming out of a functional analysis implies that traditional policy instruments such as R&D support, education programmes or taxes are not enough. Depending on the functional patterns and associated blocking mechanisms in particular cases, public policies may need to work through all types of structural components simultaneously, including different types of actors, different types of networks within and between actor groups (e.g. standard setting groups, user-supplier learning networks and advocacy coalitions) and different types of institutions (not only regulatory, but normative and cognitive as well), in order to strengthen the system’s functionality. Due to this widened focus, there may be a need to develop novel policy instruments, in particular aiming at e.g. legitimation (e.g. support of emerging advocacy coalitions). Indeed, the functional analysis further strengthens the innovation system perspective’s tendency to open up for more rich and difficult innovation policies (see also the chapter Teubal et al., in this book).

## 5. Conclusions

The purpose of this chapter was to develop a framework that provides a tool for policy makers seeking a rationale for, as well as a guide to policy interventions in a TIS. It rests on a set of systemic interdependencies in terms of technologies (artefacts and knowledge), institutions, networks and industrial structures that co-evolve in a process characterised by increasing returns. Whereas the literature on ‘Policy and Innovation Systems’ has made progress in terms of

[42] Malerba (1996) and Carlsson and Jacobsson (1997) are the main exception, covering most of our functions.

focussing on system weaknesses, it has largely been limited to defining these in terms of the nature of the structural components in a system and to identifying an associated set of 'generic' policy challenges. What also matters though for policy is functionality: that is, what is achieved by the system and, moreover, policy makers in charge of a specific TIS need a tool that identifies the unique policy issues pertaining to the dynamics of that system.

We suggested that policy makers may focus on a set of key processes in the evolution of a system. In addition to those at the structural level (entry of actors, formation of networks and institutional alignment), we argued that there are seven additional ones at the functional level. This second level refers to processes that have a more direct and immediate impact on the 'goal' of the system and can be seen as indicators of 'what is achieved by the system'. The functional pattern, i.e. what is achieved, can be analysed empirically and system weaknesses can, therefore, be specified in functional terms. These weaknesses (and strengths) can then be empirically linked to and explained by a set of driving forces and blocking mechanisms for each TIS. This means that the key policy issues are readily definable as and when such an analysis has been completed.

Some of these blocking mechanisms may be, and often are, addressed by individual firms or groups of firms. Yet, the very nature of blocking mechanisms may set limits to entrepreneurial influences on system dynamics and justify public policy intervention. The nature of these therefore needs to be carefully assessed by policy makers. Policy makers also need to think much more broadly than in terms of issues pertaining to R&D support, education and tax changes. With a functional analysis, a wide range of policy challenges is identified, some of which may be in need of new types of instruments (see chapters in this book by Smits and Kuhlman as well as Teubal et al.]. The approach also opens up for a systematic process for policy learning. Although it is clear that there are no 'one size fits all' policy implications; there is presumably no infinite variety in the evolution of different TIS. It is therefore possible for policy making bodies to repeat the analysis, with a given framework, and develop a typology of the evolution of functional patterns and associated policy challenges. A typology of that nature would be expected to be a useful guide for policy makers in their search to find the key policy issues in specific TIS.

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