



# **Analysing the Dynamics and Functionality of Sectoral Innovation Systems – A Manual for Policy Makers**

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**ANALYSING THE DYNAMICS AND FUNCTIONALITY  
OF SECTORAL INNOVATION SYSTEMS – A MANUAL FOR  
POLICY MAKERS**

**Anna Bergek, Staffan Jacobsson, Bo Carlsson, Sven Lindmark, Annika Rickne**

Various researchers and policy analysts have experimented with empirical studies of sectoral innovation systems (SIS),<sup>1</sup> in which attempts have been made to understand the current structure of various innovation systems and trace their dynamics. We have captured the dynamics in terms of not only the structural components of a SIS but also pioneered such an analysis in terms of functional patterns (as well as functionality).<sup>2</sup> It is now time to make explicit a scheme of analysis, or a manual, that is based on the literature and on our experience in developing and applying functional thinking. Such a manual will be useful both for teaching/training purposes and as a mechanism for us to identify and focus on those parts that still need development.

A scheme of analysis, a manual, is a description of a number of sub-analyses – in the following referred to as ‘steps’ – that need to be taken by the analyst. We have identified eight such steps. This should not, however, be construed as suggesting that the analysis will proceed in a linear fashion from step one to step eight; the analyst has to expect a great number of iterations between the steps in the process of the analysis. For reasons of simplicity, however, we will discuss the eight steps one at a time as if they were sequential.

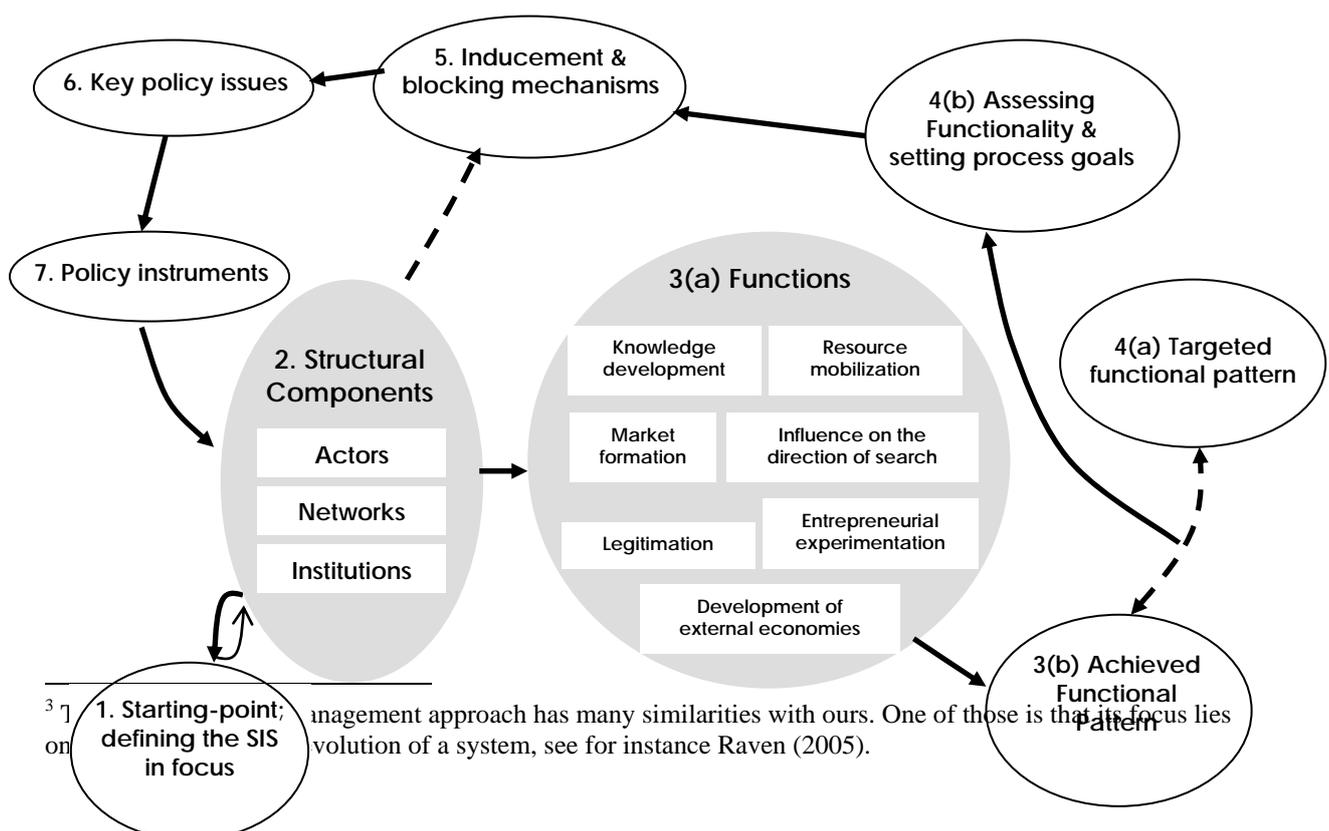
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<sup>1</sup> In our earlier work (e.g. Carlsson, 1997; Rickne, 2000; Bergek and Jacobsson, 2003) we have used the concept of ‘technological system’. In this manual, we let the concept of SIS include technological systems as well as more conventional sectoral innovation systems (see, e.g., Malerba, 2002).

<sup>2</sup> It should be noted here that we use the concepts of ‘functions’ and ‘functionality’ without any reference to the sociological concepts of ‘functionalism’ and ‘functional analysis’, in which ‘function’ refers to the effect of a social phenomenon on a social system. Our analogy is, instead, technical systems, with ‘hard’ system components filling different technical functions, thereby contributing to the system’s overall functionality. For our earlier work on functional analysis, see e.g. Johnson (1998), Rickne (2000); Johnson and Jacobsson (2001); Bergek and Jacobsson (2003) and Jacobsson and Bergek (2004).

The scheme of analysis is captured in Figure 1: The first step involves setting the starting point for the analysis, i.e. defining the SIS in focus. In the second step, we identify the structural components of the SIS (actors, networks and institutions). In the third step, we move from structure to functions, or to key processes in the evolution of a TS. With a functional analysis we first desire to describe what is actually going on in the TS in terms of these key processes<sup>3</sup> (a descriptive analysis) where we come up with a picture of an ‘achieved’ functional pattern. The subsequent fourth step is normative; we assess how well the functions are fulfilled and set ‘process goals’ in terms of a desired functional pattern. In the fifth step, we identify features in the structure that either induce (drive) or block a development towards a desirable functional pattern. At that point, we can specify the key policy issues as features of the structural components that either promote or block such a development; and this is the sixth step. The seventh step involves evaluating the expected impact of different policy instruments on inducement/blocking mechanisms and functional patterns. The final step (not shown in Figure 1) is reflection, learning and improvements in the manual.

Some of the steps build on an extensive literature that we simply cannot give full credit to – the manual would then turn into a book. Yet, in order to be useful, we need to articulate the analytical content as well as methodological opportunities and problems for each step. In particular, uncertainties need to be highlighted.



*Figure 1: The scheme of analysis. (Adapted from Olander and Perez Vico (2005)).*

Before we proceed with the manual, we need to make three fundamental points. First, the emergence of an innovation system is a process that usually takes at least a couple of decades. Given such a distant time horizon, decision makers face a great deal of uncertainty.

Second, the policy problem is not one of optimization; it is not feasible to specify all possible outcomes, rank them in terms of desirability, list all possible policy alternatives and then choose among them. Instead, the policy problem is one of “muddling through”: the goals and outcomes are fuzzy at best, and the policy steps necessary to achieve desirable goals are unclear. As pointed out by Charles E. Lindblom many years ago

“[p]olicy-making is a process of successive approximation to some desired objectives in which what is desired itself continues to change under reconsideration... Making policy is at best a very rough process. Neither social scientists, nor politicians, nor public administrators yet know enough about the social world to avoid repeated error in predicting the consequences of policy moves. A wise policy-maker consequently expects that his policies will achieve only part of what he hopes and at the same time will produce unanticipated consequences he would have preferred to avoid. If he proceeds through a *succession* of incremental changes, he avoids serious lasting mistakes in several ways.” (Lindblom, 1959, p. 86)

Third, policy makers are neither the only decision makers in an innovation system, nor the most important ones. In the words of Smits and Kuhlmann (2002) "... one should not overestimate the instrumentalist power of public policy vis-à-vis other actors in complex policy-making arenas. 'State' authorities in (regional, national, transnational) multi-actor arenas of innovation policy play an important, but not a dominant role /.../" (p. 12). Policy makers, thus, have to realize that identifying and solving the problems of an innovation system may not necessarily be their task; "[i]n many cases they perform more the function of a 'mediator', facilitating alignment between stakeholders /.../ rather than operating as a top-down steering power" (Smits and Kuhlmann, 2002, p. 12).

## **1. THE STARTING-POINT FOR THE ANALYSIS-DEFINING THE SIS IN FOCUS**

From an analytical point of view, the overall goal of an innovation system is to develop, diffuse and utilize innovations.<sup>4</sup> Taking a system approach implies that there is a system with related components (actors, networks and institutions) working together – deliberately or in an unplanned manner – to achieve this overall goal. We do not see, however, the system's components as directed or orchestrated by any specific actors.

In this manual we primarily think of *sectoral* innovation systems (SIS) as analytical constructs. This implies that the analysis does not require the focal SIS to exist in reality as a system (with fully developed links between the components etc.) – an emerging SIS may be analyzed as well. Indeed, as the case of 'Biocomposites' shows (see appendix B), it may even be possible and fruitful to analyze a SIS that only exists as an idea: Today, the biocomposite SIS in Sweden only exists in the form of a number of separate sub-systems, closely related to one application each. From a policy perspective it seems to make sense to work towards integrating these into one overall SIS, since this may increase learning, knowledge development and, thereby, the rate of development of the system as a whole.

In any analysis of a SIS, it is important to make clear and explicit the starting-point of the analysis. Indeed, as we will see below, the analyst faces several choices when he/she decides on the unit of analysis – or focus of the study. The ones made depend on the purpose of the study and the interests of policy makers and other stakeholders involved. The choice will determine what particular SIS is captured, and what components are to be included.

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<sup>4</sup> This definition has been inspired by Bergek (2002), Carlsson and Stankiewicz (1995) and Galli and Teubal (1997).

Therefore, it is crucial to make a *deliberate* choice, to *re-evaluate* this throughout the analysis, to *draw conclusions* as to how the choice of starting-point has affected the picture painted, and to *communicate* the unit of analysis clearly to the recipients of the analysis.

In what follows, we will outline the nature of these choices: the choice between technology or product as a focusing device, the choice between breadth or depth, the choice of some or all applications, and the choice of spatial inclusion. In this, there are no ‘correct’ choices, but, again the starting-point depends on the aim of the study.

In a sectoral innovation system (SIS), the focus of our attention is either a particular technological field or product area (or even an industrial sector), and the analysis first involves choosing between these two as the starting point. Thus, one common – and straightforward – starting point for the analysis is in terms of a *product, or product group*, for instance a wind turbine (Bergek and Jacobsson, 2003) or a machine tool (Carlsson and Jacobsson, 1993). A second way to think of a SIS is start the analysis in a *knowledge field or technological field* (Holmén and Jacobsson, 2000).

Having decided on product versus technology, we also need to choose the level of aggregation and the specificity/ breadth of the study. This choice is relevant for both alternatives, but is most prominent when dealing with a particular knowledge field/technology. In addition, focusing on a knowledge or technological field involves the choice of inclusion of some or all applications/product areas/industries/market segments in which the knowledge field is relevant. Let us elaborate on these two points.

First, a decision on the level of aggregation and the specificity/ breadth of the study means that we choose between including much to get a broad picture, and being specific and, therefore, able to go more into detail. Certainly, the definition of the knowledge/technological field to study may be very narrow (e.g. stem cells) or much broader (e.g. IT). It may also be defined as *one* specific knowledge/technology (e.g. microwave technology, see Holmén and Jacobsson, 2000) or as a *set of related* knowledge fields/technologies (e.g. biocompatible materials, see Rickne, 2000).

Technical change often involves the combination of many knowledge fields and complementary products/services. For instance, the use of fiber optics in telecommunication required the development of laser technology (Granberg, 1988). Indeed, major technological innovations, i.e. ones which have, in the end, a very high social value, often form a vital part

of a new technical system comprising a whole range of technologies which need to evolve for the value of the initial innovation to materialize. These technologies may be developed in adjacent industries or along the value chain. For example, in order to understand the dynamics of mobile Internet application and service innovations, complementary sub-sectors such as mobile infrastructure and terminal suppliers, operators, content providers etc. need to be taken into consideration. This implies that, no matter how narrow or broad the starting point of the analysis is, the analyst needs to be aware of and include such related dynamics.

Second, there is a choice of the range of applications of the technological field in question that should be included in the study. The analysis may be limited to the use of the technology in *specific* products or industries. This is the case in our study of 'IT in home care' (see appendix B), where a certain customer segment dictates what actors, networks and institutions will be included in the analysis. In other cases, the study may include *all possible applications/products*. This was done by Holmén and Jacobsson (2000) for microwave technology and we refer to appendix B for the cases of mobile data and biocomposites.

To illustrate, we may take the case of an analyst interested in the emerging technologies of biocompatible materials and the associated products of bio-implants, drug delivery and artificial organs. Such a SIS may be defined in terms of the products or by the underlying technologies. If the second alternative is chosen, the analysis could be focused on some of the underlying technologies (e.g. some types of biopolymers) or on all of them. Furthermore, the boundaries of the system could be set to some specific applications (e.g. medical applications) or all (e.g. include also environmental applications, etc., see Rickne, 2000). Depending on the choices made, different sets of actors, networks and institutions will be incorporated, and we capture, thus, different SIS or see different parts of the overall picture.

Finding the appropriate focus may not always be straightforward. First, when the analyst is new to a case, it may be necessary to have a broad starting point, and narrow it down as the understanding of the SIS increases and more narrow potential foci are identified. For example, in an earlier study two of us analyzed the overall Swedish innovation system for renewable energy technology (including, e.g. wind turbines, solar cells, solar collectors and bioenergy) (see Johnson and Jacobsson, 2001), after which we narrowed our focus and analyzed the Swedish innovation system for wind turbines (see Bergek and Jacobsson (2003)). The first step was necessary for us to begin to understand the features of the field of renewable energy

in general, without which we would not have been able to continue with our in-depth case study of wind turbines.

Second, given the large uncertainties involved when the analysis concerns an emerging SIS, a focus may be difficult to choose and may have to be changed subsequently. Sometimes, the initial expectations may prove to be quite wrong. For instance, the early development of laser technology was expected to find its main application in space warfare, while later the main application proved to be in CD players. Any early focus should therefore be seen as a ‘snapshot’ valid only at a particular point in time. As the analysis unfolds, and as time passes, we may learn that the initial focus needs to be altered.

Having made the choices specified above, the study may also – as a complement – have a spatial focus. While a SIS in general terms is global in character, at least to some extent, there may be reasons to limit the specific analysis to a spatially limited part of that system in order to capture other aspects, perhaps those most relevant for a particular set of actors in a national or regional context.<sup>5</sup> However, a geographical delimitation should not be used alone. Moreover, an analysis always need to have a strong international component simply since a spatially limited part of a global TS can neither be understood, nor assessed without a thorough understanding of the global context.

## **2. IDENTIFYING THE STRUCTURAL COMPONENTS OF THE SIS**

Having decided on the focus of the SIS (in a preliminary way), the next step is to identify and analyse the structural components of the system, i.e. the *actors*, *networks* and *institutions* of the system (Carlsson and Stankiewicz, 1991).

First, the *actors* of the SIS have to be identified. These may include not only firms along the whole value chain (including those up- and downstream), universities and research institutes, but also public bodies, influential interest organisations (e.g. industry associations and non-commercial organisations), venture capitalists, organisations deciding on standards, etc.

To identify actors in a specific industry, there are a number of available sources and methods. Several of these normally need to be used.

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<sup>5</sup> In practise, analyses of SIS are almost always limited geographically, if only due to resource constraints; we have yet to see a truly ‘global’ SIS analyzed in the literature.

- *Industry associations* are a good source, as are exhibitions, company directories and catalogues.
- A *patent analysis* may reveal the volume and direction of technological activity in different organizations and among individuals and may, thus, be a useful tool to identify firms, research organizations or individuals with a specific technological profile (see e.g. Rickne, 2000; Andersson and Jacobsson, 2000 and Holmén and Jacobsson, 2000). Identification may take place even if the various organizations are not linked in any form (by markets, networks or common institutions) and could then help us to identify the organizations in a potential system. Such a system may be delineated around a well-developed technology (e.g. microwave technology) or an embryonic one (such as biocomposites). Patent analysis is, however, not an unproblematic method. The link between patent classes and products is very shaky and a patent analysis is probably more useful if we choose a knowledge field/technology as the starting point.<sup>6</sup> Yet even here, we cannot conclude that a firm with patents in a particular class necessarily belongs to a knowledge field, which we, in general, associated with that class.<sup>7</sup>
- *Bibliometric* analysis (volume of publications, citation analysis, etc.) will provide a list of the most active organisations in terms of published papers etc., and these organisations will include not only universities but also institutes and firms.
- Interviews and discussions with *technology or industry experts* (gurus) as well as with firms, research organizations, financiers etc. is a good way to identify further actors. This may be called a ‘snow-ball’ method to identify actors, where each actor may point to additional participants (see Rickne, 2000).

The second structural component of interest is that of *networks*, informal as well as formal ones. A number of different types of networks are of relevance. Some are orchestrated to solve a specific task, such as standardization networks, technology platform consortia, public-private partnerships or supplier groups having a common customer. Other networks evolve in a less orchestrated fashion around a specific industry or firm, and include buyer-seller relationships and university-industry links. In this, some networks are oriented around technological tasks or market formation and others have a political agenda of influencing the

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<sup>6</sup> Bergek et al. (2004) tried to link patent classes to products with the help of industry specialists.

<sup>7</sup> For instance, Holmén and Jacobsson (2000) carefully scrutinised patents referring to microwave antennas and found that some patents certainly did not reveal any deep knowledge in the knowledge field in question.

institutional set up (see e.g. Sabatier, 1998; Smith, 2000; Rao, 2004; Suchman, 1995). Also social communities, such as professional networks and associations or customer interest groups, may be important to map.

Formal networks are often easily recognized, where, for example, the character of the mobile data SIS made obvious that standard setting committees and industry associations were influential for knowledge diffusion. On the other hand, the identification of informal networks may require discussion with industry experts or other actors, or analysis of co-patenting, co-publishing or collaboration (e.g. joint ventures and joint university-industry projects). In the case of mobile data, a thorough understanding of the history of the SIS showed that networks between the two leading firms (Ericsson and Telia) and academic research groups had been prominent and contributed to knowledge formation and diffusion. Sometimes, analysts have to look for subtle signs pointing to the existence or non-existence of networks. For example, given that academia and industry failed to communicate on a specific technical solution to an urgent industrial problem, we could conclude that learning networks were weak in the pellet burner industry in Sweden (Johnson and Jacobsson, 2001).

Third, *institutions* such as culture, norms, laws, regulations and routines need to be identified (North, 1994). Generally, institutions need to be adjusted, or ‘aligned’, to a new technology, if it is to diffuse (Freeman and Louca, 2002). Institutional alignment is, however, not an automatic and certain process but rather the opposite. Firms compete not only in the market but also over the nature of the institutional set-up (Davies, 1996; Jacobsson and Lauber, forthcoming).

Institutions may come in a variety of forms and may influence the SIS in different ways. For example, in the case of “IT in home care”, a key institution is the procurement policies of the county councils, which discriminate against smaller suppliers. In the case of “Biocomposites”, the emerging SIS is influenced by a number of EU regulations and directives concerning broad areas such as chemical substances and recycling. This implies that analysts need to have a broad perspective when mapping relevant institutions.<sup>8</sup> Sometimes, it is the lack of institutions that is of interest. Again, in the case of “IT in homecare”, a lack of standardization has led to fragmented markets and poor incentives for firms to innovate.

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<sup>8</sup> Institutional factors may be even more external to the focal SIS. Geels (2004) uses the concept of ‘technological landscapes’, which changes slowly but influences many different SIS. Examples include the greenhouse effect discussion and demographic changes.

For SIS that are only just emerging there are inherent uncertainties implying that the identification of the structural components is thorny and many of the indicators mentioned above may be difficult to use. It may prove hard to recognize the relevant actors when directories are scarce, no industry associations exist or if the actors themselves are not aware of belonging to a certain SIS. This was the case for early studies of the emerging system for biomaterials (Rickne, 2000). Moreover, in early phases networks are usually undeveloped and/or informal and SIS-specific institutions may not yet exist. Again, in the case of biomaterials, regulation was unclear for a long time, and regulators did only partly address the issues specific to the emerging SIS. In instances like this, the structural mapping must then be an iterative process, in which additional pieces of information are added incrementally as the analysis proceeds.

Identifying the structural components of the system provides a basis for the following step, which constitutes the core of analysis: analyzing the SIS in functional terms.

### **3. MAPPING THE FUNCTIONAL PATTERN OF THE SIS**

As described above, a system has components that in some sense contribute to the system's overall goal. The contribution of a component or a set of components to the overall goal is here referred to as a 'function' (Bergek, 2002; Johnson, 2001). A function is, therefore, a key process in the evolution of a TS. There is not a one-to-one connection between functions and components; each function may be filled by many different (types of) components and each (type of) component may influence several functions. Moreover, the functions may influence each other through various positive and negative feedback loops.

The first step of a SIS analysis in functional terms is to describe the 'functional pattern' of the SIS, i.e. to what extent the functions are currently filled in that SIS. This step has no normative features; assessing the 'goodness' of the current functional pattern will be dealt with later in the manual. The functional pattern of a SIS is likely to differ from that of other SIS and is also likely to change over time. Thus, the concept should not be interpreted as implying that the pattern is either repeated or optimal.

The main advantage with a functional analysis is that we can separate structure from content – the focus is more on what is actually happening in the SIS in terms of processes that have a direct influence on the performance of the system rather than on what the components are (the 'goodness' of which is difficult to evaluate). A further advantage is that we can formulate

both policy goals and policy problems in functional terms. We will return to this point later on in the manual.

As far as we know, there have been seven attempts to identify a set of functions that need to be filled for an innovations system to evolve and perform well: Johnson (1998), Rickne (2000), Johnson and Jacobsson (2001), Bergek (2002), Bergek and Jacobsson (2003), Hekkert et al., (2004) and Carlsson and Jacobsson (2004). Some of these are closely related, whereas some have been developed more independently. The seven functions described in this manual have been derived through a scrutiny of the functions described by these authors (see Appendix A). In addition, Edquist (2004) lists a number of ‘activities’, defined as “those factors that influence the development, diffusion, and use of innovation” (p. 190), which is based on a similar comparison as ours and which are included in our comparison in Appendix A.

In the following, we will explain each of these functions. We begin by explaining the content of the function. We will then give a brief illustrative example from various case studies that we have undertaken and examples of typical ‘diagnostic questions’. Finally, we will suggest some indicators that may reflect the extent to which the function is fulfilled.

### **1. Knowledge development and diffusion**

This is the function that is normally placed at the heart of a SIS in that it is concerned with the knowledge base of the SIS (globally) and how well the local SIS performs in terms of its knowledge base and, of course, its evolution. The function captures the breadth and depth of the knowledge base of the SIS and how well that knowledge is diffused and combined in the system. We can distinguish between the type and source of knowledge development:

- Type: scientific, technological (e.g. system integration), production, market, logistics, application specific, design, etc.
- Source: R&D, learning from new applications, imitation, import, etc.

An illustrative case is that of the emerging SIS for solar cells in Germany (Jacobsson et al., 2004). Initially, the type of knowledge development was limited to ‘scientific/technological’ and the source was R&D experimentation with various competing designs for solar cells. The knowledge base was subsequently added to by enlarging the system along the value chain. First, downstream, ‘application specific knowledge’ was developed as firms experimented

with using solar cells as a building element. A part of the knowledge development took place in Schools of Architecture where ‘solar architects’ developed new design concepts. Second, upstream technological knowledge was enhanced in the industry that produces capital goods by conducting R&D. A significant aspect of that knowledge development was, however, also a very practical and problematic learning process to build automated production lines for the manufacturing of solar cells.

Diagnostic questions for this function are typically of the following type: Wherein lies the knowledge related competitive edge of the SIS? How broad or narrow is the knowledge base? What is the degree of variety in the knowledge base? To what extent does the knowledge base cover the whole value chain? What kind of application specific knowledge is generated?

The function could be measured by a range of indicators:

- Bibliometrics (citations, volume of publications, orientation)
- Number, size and orientation of R&D projects
- Patents (in different competing designs, applications and along the whole value chain)
- Assessments by managers and others
- ‘Learning curves’

## **2. Influence on the direction of search**

If a SIS is to develop, a whole range of firms and other organizations have to enter into the SIS. There must then be sufficient incentives and/or pressures for the organizations to be induced to do so. The second function is the combined strength of such factors. It also covers the mechanisms influencing the direction of search *within* the SIS, in terms of different competing technologies, applications, markets, business models etc. These factors are not, of course, controlled by one organization – and definitively not by the state (apart from the case of regulations etc.) – but their strength is the combined effect of, for example:

- Visions, expectations, belief in growth potential
  - incentives from changing factor and product prices
  - growth occurring in SISs in other countries
  - changes in the ‘landscape’ (Geels, 2004), e.g. demographic trends

## climate debate

- Actors' perceptions of the relevance of different types and sources of knowledge<sup>9</sup>
- Regulations and policy
- Articulation of demand from leading customers (e.g. von Hippel 1988; Carlsson and Jacobsson, 1993)
- Technical bottlenecks, or 'reverse salients' (Rosenberg, 1976; Bijker, 1995; Hughes, 1983)
- Crises in current business

Wind turbines in Germany (in the early phase of system evolution) is an illustrative case in point where firms experienced a range of incentives to enter the industry (Bergek and Jacobsson, 2003). In several cases, the firms' existing markets were in recession at the same time as there was a California wind turbine boom and an associated expansion of the Danish wind turbine industry. These latter developments gave clear signals about the attractiveness of the future wind turbine market (i.e. expectations of future markets). Locally, there was a 'green' demand from some utilities and environmentally concerned farmers (articulation of demand). Federal R&D policy subsidized not only R&D in many competing designs but also investment in wind turbines in a number of demonstration programs (regulation).

The types of diagnostic questions asked refer to the strength and character of this function: Is there a belief in the growth potential of the new field? Are there any customers experimenting with or articulating a need for new solutions? What is the combined effect of regulations? Hence, we suggest that this function can be measured, or at least indicated, by factors of the following type:

- Belief in growth potential (interviews)
- Incentives from factor/product prices, e.g. taxes and prices in the energy sector (secondary data)
- The extent of regulatory pressures, e.g. regulations on minimum level of adoption ('green' electricity certificates etc) and tax regimes (study of regulatory frameworks, secondary data)
- The articulation of interest by leading customers

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<sup>9</sup> For example, actors are more likely to look for new knowledge (especially technology) within its current technological frame (McLoughlin et al., 2000) or paradigm (Dosi, 1982).

Of course, it is not possible to come up with an exact figure but the analyst has to make a composite judgment based on both qualitative and quantitative data. Exactly how that is done must be made explicit.

### **3. Entrepreneurial experimentation**

A SIS evolves under uncertainties in terms of technologies, applications and markets. This uncertainty is a fundamental feature of technological and industrial development and is not limited to early phases in the evolution of a SIS but is a characteristic of later phases as well. From a social perspective, the way to handle this uncertainty is to ensure that many entrepreneurial experiments take place. These experiments imply a probing into new technologies and applications, where many will fail, some will succeed and a social learning process will unfold through the course of these experiments. A SIS without a vibrant experimentation will stagnate. So, an analyst needs to ask diagnostic questions to the material that centers on the number and variety of experiments taking place:

- Number of entrepreneurial experiments, i.e. number of new entrants and diversifying established firms (interviews, trade fairs, catalogues, trade journals)
- Variety in entrepreneurial experiments, i.e. number of different types of applications, the breadth of technologies used and the character of the complementary technologies employed (interviews, trade journals)

To continue with the German wind turbine case in the early phase of its evolution, it is clear that the diversity in experiments undertaken was its main characteristic (Bergek and Jacobsson, 2003). The experiments were aided by a federal R&D program that was large enough to finance most projects applied for and flexible enough to finance most types of projects. In the period 1977-1991, a large number of industrial firms and a range of academic organizations received funding for the development or testing of a large variety of turbine sizes and designs. Many of these experiments resulted in entry of at least 14 firms into wind turbine production, including academic spin-offs, diversifying medium sized mechanical engineering firms and large aerospace firms etc., all of which brought different knowledge and perspectives into the industry.

### **4. Market formation**

For an emerging SIS, or one in a period of transformation, markets may not exist, or be greatly underdeveloped. Market places may not exist, potential customers may not have

articulated their demand, or have the competence to do so, price/performance of the new technology may be poor, uncertainties may prevail in many dimensions. Institutional change, e.g. the formation of standards, is often a prerequisite for markets to evolve.

Market formation normally goes through three phases with quite distinct features. In the very early phase, ‘nursing markets’ need to evolve so that a ‘learning space’ is opened up, in which the SIS can find a place to be formed. The size of the market is often very limited. This nursing market may give way to a ‘bridging’ market which allows for volumes to increase and for an enlargement in the SIS in terms of number of actors. Finally, in a successful SIS, mass markets may evolve, often several decades after the formation of the first market.

To understand the sequence of the formation of markets, we need to analyze both actual market development and what drives the formation of markets (and here is an overlap with the function ‘influence of the direction of search’). Actual market formation is normally quite easy to measure, i.e. timing, size and type of markets formed (e.g. wind turbines installed in 1989 with an effect of 12 MW, 75% farmers) – often statistics are assembled by industry associations. It is more difficult to analyze what drives that formation and, again, the analyst needs to have in-depth knowledge of the SIS to do so.

We will illustrate the multitude of factors that may drive or hinder market formation with the case of “Mobile data”. In this case, markets are global, but the home market is still strategically important to test new concepts and products, to learn, and to get early revenues. A swift market formation is, therefore, of essence to the Swedish SIS. However, on the Swedish market, demand is unarticulated, and there is great uncertainty as regards current or future user needs. Corporate and governmental use is low, the latter partly due to sluggish procurement procedures. Likewise, on the dominating consumer market Sweden lags behind countries such as Japan and Korea and has been unsuccessful in creating prerequisites for market growth. Indeed, today Sweden has a low rate of SMS use and insufficient usability, much due to unwillingness to cannibalize current cash cows within mobile telecom, inflexible pricing systems, lack of standards for platforms, problems with complementary technologies and proprietary solutions. Thus, while Swedish actors were early in introducing applications and services, such first-mover advantages were subsequently lost.

The main diagnostic questions concerning market formation are: What phase is the market in (nursing, bridging, mature)? What is the degree to which experiments are made with new

applications? Who are the users and what do their purchasing processes look like? Has the demand profile been clearly articulated and by whom? Are there institutional stimuli for market formation or is institutional change needed? What hinders use? What uncertainties are facing potential buyers?

Indicators to trace this development include readily available facts (as indicated above) on market size, customer groups, and time frames, but also qualitative data on actors' strategies, the role of standards, purchasing processes, and lead users, as given in interviews and industry analyses.

## **5. 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 by relevant actors in order for resources to be mobilized, for demand to form and for actors in the new SIS to acquire political strength. Legitimacy also influences expectations among managers and, by implication, their strategy (and, thus, 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, new SIS. Legitimacy is not given, however, but is formed through conscious actions by various organisations and individuals in a process of legitimation, which eventually may help the new SIS to overcome its 'liability of newness' (Zimmerman and Zeitz, 2002). However, this process may take considerable time and is often complicated by competition from adversaries defending existing SISs and the institutional frameworks associated with them.

Although the process of legitimation is often closely associated with institutional alignment, 'manipulation' of the rules of the game is only one of several possible alternatives; legitimation may for example also imply 'conformance' (following the rules of the existing institutional framework, e.g. choosing to follow an established product standard) and 'creation' (developing a new institutional framework) (Zimmerman and Zeitz, 2002). With respect to the latter, however, a new SIS seldom emerges in a vacuum, but instead is often subjected to competition from one or more established SIS. In such cases, some type of 'manipulation' strategy is usually needed.

Mapping the function ‘legitimation’ includes analyzing both the legitimacy of the SIS in the eyes of various relevant actors and stakeholders (not least the ones you would expect to engage in the development, e.g. potential capital goods suppliers and buyers), and the activities within the system that may increase this legitimacy. So, we need to understand:

- The strength of the legitimacy for the SIS
- What (or who) influences legitimacy and how
- How legitimacy influences demand, legislation and firm behaviour

The current legitimacy of a SIS can be measured with questionnaires, interviews and secondary data. Diagnostic question may include, for example: Is there alignment between the SIS and current legislation? Is the technology/product following current standards? What visions and expectations of the SIS exist among different stakeholders? Is it legitimate to make investments in the technologies, products etc. of the SIS? How is the SIS depicted in newspapers and other media?

In the case of “Biocomposites”, the legitimacy of these new materials is unclear; potential buyers have difficulties understanding how they fit the existing institutional framework. First, it is not clear if these new materials have unique characteristics or if they are merely direct substitutes for established materials. Second, they do not correspond well to the established categorization of materials into wood materials and plastic materials since all currently existing biocomposites are based on plastic matrices. Third, established standards and materials classifications are not applicable.

The process of legitimation is more complex, but may be studied by the political debate in parliament and media and by the actions of individual firms, pressure groups etc. Diagnostic questions may include, for example: Are there any official gatherings, e.g. workshops and conferences, related to the SIS (number and ‘weight’)? Are any lobbying groups active in promoting the SIS and/or influencing policy makers to its benefit (size and strength)? Are there any financially or reputationally strong actors that may ‘transfer’ some of their legitimacy to the SIS? How legitimation influences demand, legislation and firm behavior can be revealed through interviews, trade press, studies of various types etc.

Again, in the case of “Biocomposites” it is difficult to imagine standard systems for both wood and plastic materials to be aligned to the needs of the emerging biocomposite SIS,

which leaves only the creation of new biocomposite-specific standards as a viable legitimation strategy. However, we have seen no indications of such activities among standardization organizations or other actors.

A perhaps more interesting illustration of legitimation is provided by the case of solar cells in Germany (see Jacobsson and Lauber, forthcoming). After unsuccessful efforts to convince the Federal Government to launch a nationwide regulatory change in favour of the diffusion of solar cells in the early 1990s, a number of activists and interest organization began a lobbying work at the *Länder* and local levels. After much effort, most *Länder* expressly allowed cost-covering contracts between suppliers of solar power and local utilities. Several dozen cities subsequently opted for this model which revealed a wide public interest in increasing the rate of diffusion – the legitimacy of solar power was made apparent. Various organizations could later point to this interest when they lobbied for a program to develop yet larger markets for solar cells, now at the federal level.

## **6. Resource mobilization**

As a SIS evolves, a range of different resources needs to be mobilized. These resources are of different types, technical, scientific, financial, etc. and include also resources that may be complementary (in the case of a narrow delineation of the SIS). Hence, we need to understand the extent to which the SIS is able to mobilize:

- Human capital through education in specific scientific and technological fields, but also in entrepreneurship, management and finance
- Financial capital (seed, VC, diversifying firms, etc.)
- Complementary assets (complementary products, services, network infrastructure, etc.)

As an illustration of this function, we will use a recent analysis of the Swedish security sensor innovation system (Oltander and Perez Vico, 2005). The mobilization of human resources was found to be strong, partly following the recent reduction of personnel at Ericsson. However in specific technological fields, such as radar and sonar technology there was a resource shortage, explained by an absence of university education in these fields. The mobilization of financial resources was more troublesome. In addition to a generally weak Swedish seed capital market, there are also difficulties in attracting venture capital, resulting from (a) a cautious VC market in general, and (b) a belief that Swedish start-ups will have problems competing internationally with US firms. In larger organizations (e.g. Saab Bofors

Dynamics, FOI and Ericsson Microwave) there were some perceived difficulties to raise funding for internal R&D projects, because of an absence of strong customers and the ongoing transition from military to civilian customers.

There are various ways in which an analyst can measure resource mobilization:

- Volume of capital (interviews, trade journal, annual reports etc, number of new entrants)
- Volume of venture capital (industry associations, interviews, trade journals, annual reports etc)
- Volume and quality of human resources (interviews, educational data)
- Complementary assets: (interviews, trade journals)

In the analysis referred to above, Oltander and Perez (2005) used quantitative measures, such as the number of graduates from sensor-related education (absolute and per capita) in comparison to Germany and Israel and the number of venture capital firms with holdings in the security sensor sector, together with qualitative data based on interviews, such as perceptions on the supply of human resources and the VC firms' interest in the Swedish security sensor sector. Breaking down the resource base into different technological classes proved useful for the analysis.

However, especially in emerging systems these types of data may not be readily available and may, furthermore, be difficult to compare internationally due to differences in accounting principles.

## **7. Development of positive externalities or 'free utilities'**

As markets go beyond the first niches, there is an enlarged space in which the emerging system can evolve and the functions be strengthened. Entry of firms is central to this process. First, each new entrant brings knowledge and other resources into the SIS, strengthening the function 'resource mobilization'. Second, 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'. Third, new entrants may, by their very entry, legitimate the new SIS (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 mobilization’, ‘influence of the direction of search’, ‘market formation’, and ‘entrepreneurial experimentation’.

By resolving uncertainties and improving legitimacy, new entrants may confer ‘free utilities’, or positive externalities on other firms, established as well as new entrants. Further ‘free utilities’ may arise due to the co-location of firms. Marshall (1920) discussed economies that were external to firms but internal to a location. Developing his ideas, Audretsch and Feldman (1994) and Krugman (1991) outlined three sources of such economies:<sup>10</sup>

- 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 times go 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.<sup>11</sup>
- Information flows and knowledge ‘spill-overs’, contributing to the function ‘knowledge development and diffusion’.

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 SIS 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 all the six previous functions are strengthened, benefiting other members of the SIS through the generation of ‘free utilities’. This function is therefore not independent, but rather one which indicates the dynamics of the system.<sup>12</sup> The analyst needs to capture the strength of this dynamics by finding indicators of the sources of external economies specified above. That is, the analyst needs to ask his/her material diagnostic questions about the existence and evolution of these ‘free utilities’.

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<sup>10</sup> In addition to these, they also mention provision of non-tradable inputs specific to an industry.

<sup>11</sup> See Smith (1776; Young (1928); Stigler (1947); Rosenberg (1976); Maskell (2001). For a case study of mobile data in Western Sweden, see Holmén (2001).

<sup>12</sup> We are grateful to Professor Ruud Smits and Dr. Marko Hekkert on this point. The dynamics is, of course, enhanced by the interdependencies of the functions, as was pointed out above. As the system moves into a growth phase characterised by positive feed-back loops, these interdependencies are clearly seen.

- Political power (interviews, documents, newspapers etc.)
- Legitimacy (see above)
- Resolution of uncertainties (interviews, trade journals)
- Pooled labour market (labour market data, interviews)
- Specialised intermediates (catalogues, interviews)
- Information and knowledge flows (questionnaires, interviews)
- Combinatorial opportunities (interviews, trade journals)

To refer again to the German wind turbine case, we will mention two forms of ‘free utilities’. First, new entrants into the wind turbine industry, as well as into wind power production, increased the political power of the advocates of wind energy so that they could win against opposing utilities in several courts and defend a favorable institutional framework (Jacobsson and Lauber, forthcoming). Second, as the market increased, specialized suppliers emerged with the consequence that barriers to entry for yet more firms were lowered.

#### **4. ASSESSING THE FUNCTIONALITY OF THE SIS AND SETTING PROCESS GOALS**

The analyst now has a description of these seven functions, as well as a tentative assessment of their strengths and weaknesses. However, the functional pattern does not in itself tell us whether the SIS is well-functioning or not; that a particular function is weak does not necessarily constitute a problem, neither is a strong function necessarily an important asset. In order to assess system functionality – i.e. not *how*, but *how well* the system is functioning – we need ways to evaluate the relative ‘goodness’ of a particular functional pattern. This is one of the major challenges for analysts and policy makers, a challenge that probably needs to be dealt with further in research and in a learning process among practitioners. So far, we have identified two bases for an assessment, both of which are associated with different types of problems. In order to balance each other’s weaknesses, they should probably be used in combination: (1) industry lifecycle models and (2) system comparisons.

According to *industry life cycle models*, industries go through various phases in their evolution, phases that are common to most industries (e.g. Utterback, 1994; Klepper, 1997). We suggest that this notion may be extended to include SIS. However, we want to emphasize that this does not imply that all innovation systems follow the exact same development

pattern. Indeed, the whole point of the functional analysis is that SISs differ so much that there are no 'one size fits all' policy implications. Thus, although we claim that some features in innovation system development are common to most innovation systems, we fully acknowledge that the determining factors, time frames etc., differ between cases.

We have earlier suggested that it is particularly useful to distinguish between a formative phase and a growth phase (Jacobsson and Bergek, 2004). The former is characterized by high uncertainty in terms of technologies, markets and regulations; by institutional change, small niche markets; entry of many firms; and the formation of 'political networks' or advocacy coalitions. At some point in time, the SIS may be able to 'change gears' and begin to develop in a self-sustaining way as the SIS moves into a growth phase. At a later stage, the system may move into a mature phase, characterized by stability in both technological and structural terms. Usually, a few actors dominate the (mass) market in this phase, and market growth has declined. Most uncertainties have been resolved.

Having this in mind, we suggest that it is plausible that the definition of 'functionality' differs between phases. Since we are primarily concerned with an emerging SIS, we will here focus on the two first phases. *In the formative phase*, the key words are experimentation and variety creation. This requires extensive 'entrepreneurial experimentation' in such a way that 'knowledge development' occurs within a number of different technological approaches and applications. For this to occur, 'influence on the direction of search' and 'resource mobilization' must stimulate ventures into many directions. Moreover, a process of 'legitimation' must start, helping to overcome the 'liability of newness' associated with new actors and technologies. Finally, 'knowledge development' is to a large extent dependent on cooperation between actors, especially between suppliers and buyers, which require 'market formation'. Thus, either established markets need to be open to new technologies/products, or new niches need to be identified and stimulated.

*In the growth phase*, the focus has to shift to large-scale diffusion, expansion and cost reductions through, e.g. economies of scale. For this to occur, 'mass market formation' is necessary. Yet, it is normally not self-evident which applications that will generate 'mass markets' so a 'breadth in entrepreneurial experiments' must be kept up at the same time as 'influence on the direction of search' must sustain variety creation in 'knowledge development'. 'Legitimation' becomes even more important, since the growing SIS may be

expected to catch the attention of actors in competing SISs. Finally, the need for ‘resource mobilization’ for product and process development is increasing as well.

Each system may, at any given moment in time, be characterized as being in a particular phase. The analyst can then raise the question if functionality matches the needs of that particular phase or the need of the next phase (if it is judged to be desirable that the SIS is to move into that). In other words, the functional pattern, i.e. how the functions are performed, can be analyzed with respect to the requirements of each phase. The strength and weaknesses of functions may be related to the particular needs of the different phases.

Relating each specific SIS to a certain phase is of considerable importance when current functionality is assessed. A common error made by analysts is to judge a SIS that is in a formative phase with criteria that are more suitable for evaluating a system that is in a growth phase. Above, we outlined some key characteristics of a formative phase. One of those is *not* a rapid rate of diffusion or rapid growth in economic activities. On the contrary, the volume of activities is small and many experiments take place – the SIS is in a process of formation. Yet, in several cases we know of (renewable energy technologies and wood manufacturing) an emerging SIS was evaluated by the volume of economic activities. Of course, this led to a great deal of frustration and a feeling of disappointment and failure. Yet, by applying other criteria, more suited for a formative phase, a quite different interpretation would be made.

Ascertaining what phase a SIS is in is, of course, not straightforward. Yet, the analyst can use a number of indicators to know whether or not a SIS is in a formative stage, for instance:

- the time dimension, where we rarely escape formative periods that are shorter than a decade (yet they can last for many decades, as in the case of solar cells)
- large uncertainties prevail as regards technologies, markets and applications
- price/performance of the products is not well developed
- a volume of diffusion and economic activities, that is but a fraction of the estimated potential
- the whole value chain is not populated, or at least not densely
- demand is unarticulated and a supplier industry is only being formed

- the absence of powerful self-reinforcing features (positive feed-backs) and insignificant ‘free utilities’

Whereas the case of ‘Biocomposites’ was quite straight forward in this respect – the system can hardly be characterized as anything but formative (or even ‘pre-formative’) – our judgment in the other two cases may need to be explained further. In the case of ‘IT in home care’, we judged that the SIS is still in a formative phase for the following reasons:

- There are many competing experiments that are linked to specific platforms (no standards and high technical uncertainty).
- The number of firms supplying solutions is small.
- Markets are small, with high uncertainties and no standard software.
- The demand is poorly articulated by customers with poorly developed competence.
- An absence of powerful positive feed-backs and ‘free utilities’.

Yet, Sweden seems to be at the forefront internationally so the system appears to be in a formative phase also abroad.<sup>13</sup>

In the “Mobile data” case, the variety of entrepreneurial experimentation, slow market formation, slow reduction of uncertainty and lack of self-sustaining growth so far, suggest that mobile data is in a late stage of a formative phase. International comparisons suggest that there are systems abroad that have already entered into an early growth phase.

*Comparing the focal SIS with other SISs* is the second basis for assessing system functionality. We would argue that comparative analyses between different SISs, across regions or nations, are a powerful way of improving the understanding for decision makers (see e.g. Rickne (2000) for biomaterials in Sweden, Massachusetts and Ohio and Bergek and Jacobsson (2003) for wind turbines in Sweden, the Netherlands and Germany). A company that is contemplating introducing a new product tries to find out as much as it can about the market (existing or potential) in terms of existing products and how they are positioned, as well as competitors and their strategies (and therefore what responses might be expected). Perhaps a patent search is conducted to locate the knowledge frontier and who is active in its vicinity. A market survey of potential customers may also be done.

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<sup>13</sup> This observation is not, however, based on solid empirical analyses of SIS in other countries.

In a similar fashion, policy makers involved with a particular innovation system need to perform analyses of similar systems being developed elsewhere or of systems in related areas: What particular user or consumer needs are being addressed? Who are the actors involved? What resources are available? What obstacles have been encountered and how have they been overcome? Most importantly, policy makers need to address the question of how these other systems are performing (in order to get the right gauge in an assessment in terms of what development is reasonable to expect of the SIS), and relate this to their functional patterns (in order to identify critical functions and/or different ways to achieve the same level of functionality).

In the case of “Mobile data” two types of comparisons with other systems were made. First, the SIS was compared with the exceptionally strong, large and rapidly growing Swedish mobile telephony innovation system of the 1980s and 1990s. Mobile data communication largely builds on, converges with and cannibalizes on that system. Thus, one part of the assessment was a comparison with a historical Swedish innovation system with which the focal SIS is interlinked. Second, the assessment partly drew on a comparative analysis with other national SISs, e.g. the ones in Japan, Korea, and Norway. Although data availability did not allow for systematic comparisons with respect to all functions and structural features, some functions were clearly identified as weaker in Sweden, e.g. market formation.

Based on the phase analysis and/or one or more comparative analyse(s), it is possible to come to a conclusion regarding functionality of the SIS, that is, in relation to what is reasonable to expect taking the phase of development and/or the comparison with other systems into consideration. It is, then, also possible to specify policy goals in terms of how the functional pattern should develop in order to reach higher functionality, i.e. towards a targeted functional pattern. Such goals (e.g. broaden the knowledge base or widen the range of experiments) can be seen as ‘*process goals*’ in contrast to final goals (such as growth). Process goals have the advantage for policy makers in that they are ‘closer’ to the various instruments that can be used and it is easier to evaluate how well a particular policy works. In particular, in early phases of development final goals may be close to impossible to define, since the uncertainty regarding what the SIS may be able to achieve, and what is desirable to achieve, in the long term is very high.

For example, in the Swedish wood manufacturing case (see Carlsson and Jacobsson, 2004) we defined process goals in terms of an *ex ante* desired functional pattern for a growth phase (in broad terms):

- ‘Market formation’: size of demand, new segments (e.g. municipalities)
- ‘Resource mobilization’: number of new entrants and investment resources put into the SIS
- ‘Knowledge development’: size of academic R&D supporting the SIS; the development of dedicated educational programs and the formulation of handbooks and standards.
- ‘Entrepreneurial experimentation’: number of applications for which wood is used as construction material

In the case of “Mobile data”, one of the process goals was formulated in terms of stronger knowledge development concerning markets, services, and business models for the purpose of accelerating a transition into a self-sustaining growth phase.

However, functional patterns may be very complex. Functional patterns that seem different may produce similar outcomes, whereas patterns that seem similar at a glance may eventually lead to very different outcomes (Jacobsson and Bergek, 2004). Thus, we need to be careful not to specify the ‘desired’ functional pattern too rigidly and, again, be open for reformulation and iteration in the process of analysis.

## **5. IDENTIFY MECHANISMS INDUCING AND BLOCKING FUNCTIONALITY**

There are many reasons for expecting that the environment is biased, and will remain biased, in favour of established SISs.<sup>14</sup> A new SIS may consequently exhibit weak functions and develop very slowly, or in a stunted way. The functions may be weak for a number of reasons. These may be found in features of the structural components of the emerging SIS or in the larger context surrounding it. This larger context includes the sector in which the new SIS operates, e.g. the electric power sector for the emerging SIS centered on solar cells, but also factors that go beyond that sector. For instance, the reaction, or lack of it, to global warming

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<sup>14</sup> Jacobsson and Johnson (2000) and Johnson and Jacobsson (2001) elaborate on various types of ‘blocking mechanisms’. See also Unruh (2000) for an extensive review of mechanisms locking us into a carbon economy and Walker (2000) for a case study on entrapment in a large technological system.

acts as either as an inducement or blocking mechanisms in many sectors and influences many emerging SIS.<sup>15</sup>

What 'is being achieved' in the SIS is therefore only in part a result of the internal dynamics of the SIS. Exogenous factors also come into play, influencing the internal 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".

From a policy perspective, it is particularly important to understand the nature of 'blocking mechanisms' that shape the nature of the dynamics. These could for instance be of the following types:

- The proponents of the new technology may be organisationally too weak to influence the function 'legitimation'; they may, for example, lose in the 'battle over institutions' if they attempt to achieve institutional alignment to the new technology with regard to the regulatory framework or the functioning of the educational and capital markets. Unaligned institutions may then lead to poor 'market formation' that, in turn, limits the strength of the functions 'influence on the direction of search' and 'entrepreneurial experimentation'.
- Underdeveloped competence among potential customers may lead to an absence, or poor articulation, of demand which leads to a poor development of the functions 'market formation', 'influence on the direction of search' and 'entrepreneurial experimentation'.
- Networks may fail to aid new technology simply because of poor connectivity between actors. Networks may also 'influence the direction of search' among suppliers or customers away from the new SIS.

As is evident from these examples, there may be structural features that 'block' the development of several functions. The path to achieving a higher functionality may, therefore, be littered by a range of such 'blocking mechanisms'. These may operate in a formative stage, but they may also obstruct a transition towards a more self-sustained SIS i.e. one which is to an increasing extent driven by its own momentum rather than by outside 'pushes or pulls' in the form of policy.

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<sup>15</sup> Geels (2002) makes a distinction between 'regime' and 'landscape levels where 'regime' is broadly equivalent to sector.

It is empirically possible, and very useful, to map the relationship between inducement and blocking mechanisms and functions. In the following, we will illustrate this with examples from three cases. First, we will illustrate the complexity of a complete mapping of inducement and blocking mechanisms influencing the functions in the case of “Mobile data”. Second, the case of “IT in home care” will be used to show a picture of the most important functions, in order to guide policy makers to those areas in which they can do most to improve the functionality of the SIS. Third, the different mechanisms influencing one single function, ‘Knowledge development and diffusion’, will be described in the case of “Biocomposites”.

The case of “Mobile data” (see Figure 2) displays a complex set of inducement and blocking mechanisms. Four mechanisms block more than one function, indicating that they strongly inhibit the Swedish mobile data SIS in attaining a leading position in the transition from mobile telephony to mobile data. There is uncertainty regarding applications, markets, business models and customer utility, which is closely linked to fact that Swedish ‘market formation’ is weak, at least compared with leading national SISs. This uncertainty also stalls ‘knowledge development’, does not provide any strong positive ‘influence on the search process’, and reduces incentives for ‘entrepreneurial experimentation’. Several functions are further weakened by three additional mechanisms: a) lack of standards for appropriating value from new applications (payment mechanisms, digital rights management) and for developing new applications (APIs); b) operators (not innovative, revenue sharing schemes etc.), and c) lack of a large and homogeneous home market.<sup>16</sup>

Still, there are a number of strong inducement mechanisms, which could assist in a catching-up process with leading SISs, given that the blocking mechanisms are removed or weakened. These are, in particular, a well built-out network infrastructure, a high ICT penetration, a strong engineering education in relevant fields, an actor presence in all important parts of the value chain, and Ericsson’s position as the dominant infrastructure supplier.

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<sup>16</sup> Some of these blocking mechanisms may in turn be signs of a coordination failure.

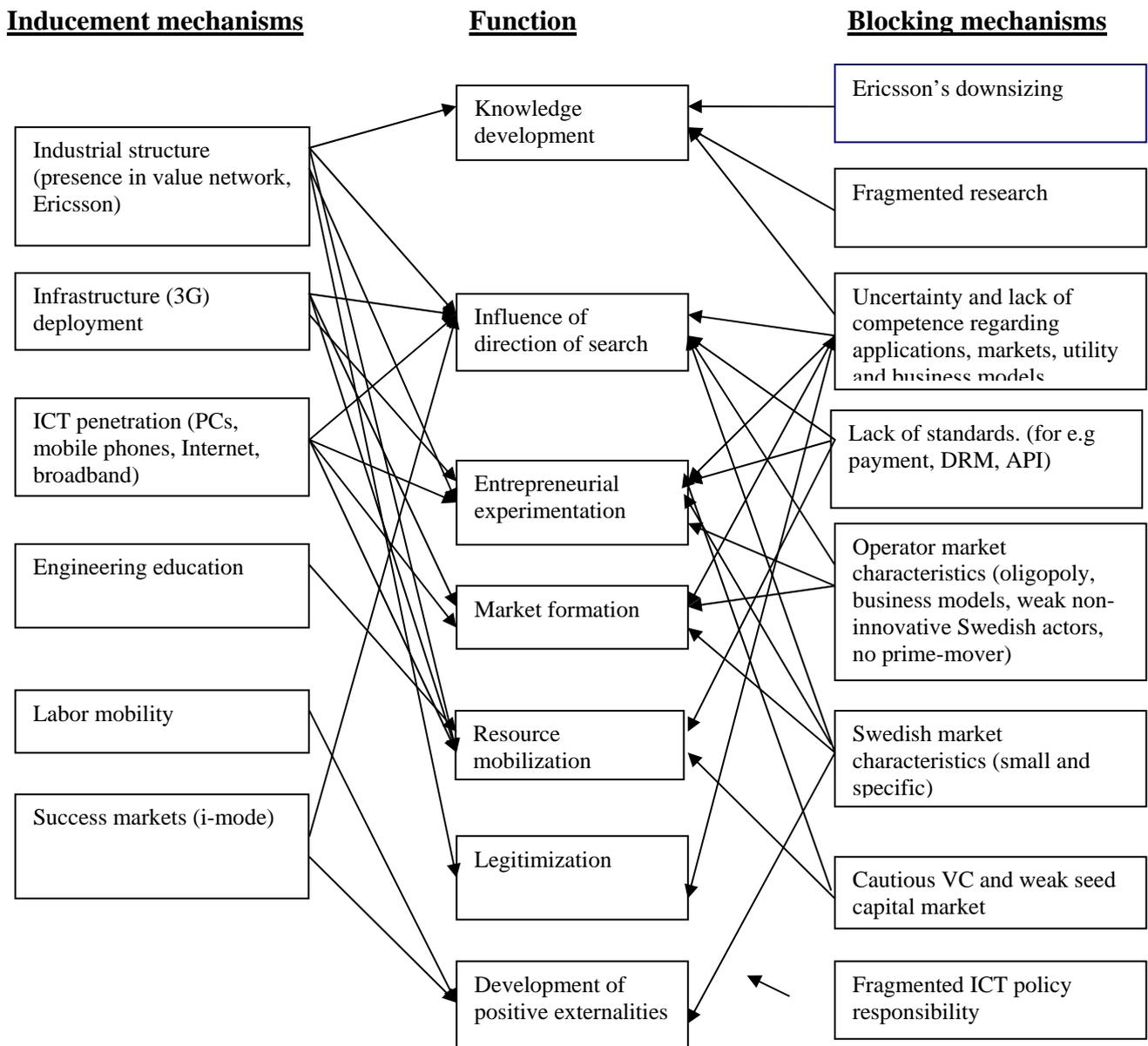


Figure 2: Inducement and blocking mechanisms in the case of "Mobile data".

In Figure 3, the most important mechanisms and functions in the case of 'IT in home care' are described. Two main observations can be made from this. First, there are two significant inducement mechanisms; belief in growth potential and government R&D policy. The former is driven by a range of factors, technological opportunities, demographic trends, deregulation of the public sector, public sector budget restrictions etc. This inducement mechanism has a bearing on the function 'influence of 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

strengthens the function ‘influence on the direction of search’ and acts upon ‘resource mobilization’, ‘knowledge development and diffusion’, ‘entrepreneurial experimentation’ and ‘legitimation’.

Second, there is no one-to-one relationship between functions and blocking mechanisms. ‘Market formation’ is blocked by as many as four factors and some factors block several functions. For example, a poor articulation of demand (due to lack of competence) blocks ‘market formation’, ‘entrepreneurial experimentation’ and ‘influence of the direction of search’. Moreover, functions are not independent, but rather tend to reinforce each others. A poor ‘market formation affects negatively both ‘entrepreneurial experimentation’ and ‘influence of 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.

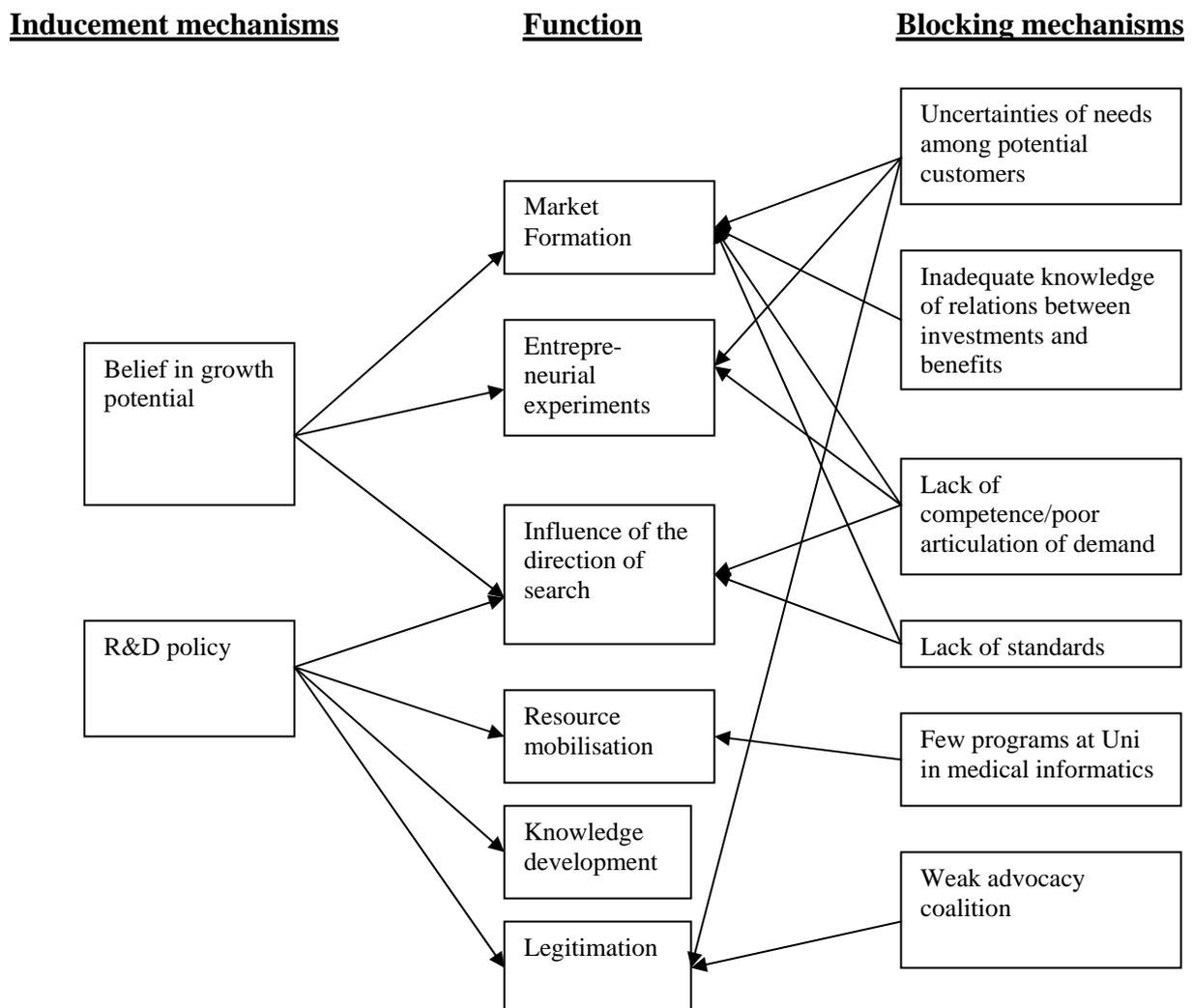


Figure 3: Inducement and blocking mechanisms in the case of “IT in home care”.

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 case of “Biocomposites” (Figure 4), we can see how *one particular function*, i.e. ‘knowledge development and diffusion’ is blocked by a number of different blocking mechanisms: (1) Lack of actors and resources “in the middle” of the value chain, resulting in a too small basis for learning and experimentation, (2) poorly articulated demand and uncertainty regarding applications, which creates uncertainties regarding what characteristics to develop further, (3) lack of vision, definition and focus, which implies a risk that development activities become too general and do not address bottleneck problems, (4)-(5) lack of integration between subsystems and lack of platforms and meeting places, which both imply that the development activities of different actors are separated from each other and, thus, block knowledge diffusion and learning, and (6) the secrecy of some of the large firms that are involved in the development of biocomposites, which may perhaps be understandable but nevertheless blocks the diffusion of knowledge within the system.

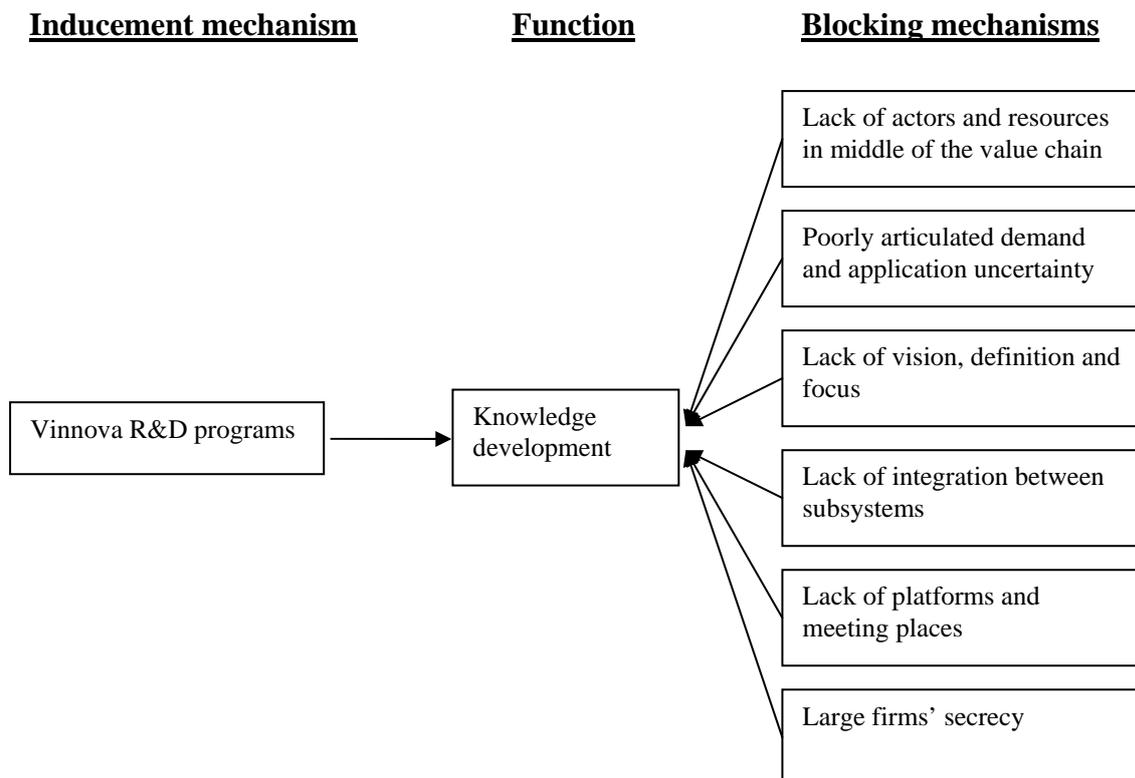


Figure 4: Inducement and blocking mechanisms in the case of “Biocomposites”.

## 6. SPECIFY THE KEY POLICY ISSUES

Process goals were defined in step number 4 above. Having made explicit the reasons for setting these specific process goals and how to measure whether the goals are reached, we can now specify the policy issues in terms of *features of the structural components that hinder, or promote a development of a desirable functional pattern* (towards greater functionality).

Here, we thus take a step away from the traditional ‘market failure’ rationale for policy interventions into innovation processes, and argue that policy should instead aim at remedying poor functionality in relevant innovation systems by strengthening/adding inducement mechanisms and weakening/removing blocking mechanisms. We will illustrate this with all our cases.

In the case of “IT in home care”, it is easy to come up with quite a long list of issues as the blocking mechanisms are manifold and powerful (see appendix). Yet, many of these refer to various aspects of potential customers. An obvious issue is how to develop standards and terminology so as to move from a fragmented market of 290 local councils and 21 county councils. Another one is how to raise user competence so that uncertainties can be reduced and demand articulated. Eventually, this may positively affect ‘market formation’, ‘entrepreneurial experimentation’ and ‘influencing the direction of search’. A third is how to support users in order to a) increase their knowledge of the benefits of IT in home care and how to distribute the costs and benefits over organisational boundaries (‘market formation’ is enhanced) and b) diffuse knowledge across organisational boundaries of the outcome of early experiments (which reduces uncertainties further with above mentioned potential consequences). In addition to focusing on potential customers, a key policy issue may be how to support experimentation with new applications so as to reduce the level of uncertainty of needs, ‘form markets’, broaden ‘entrepreneurial experimentation’ and enhance ‘legitimation’ of “IT in home care”.<sup>17</sup>

Key policy issues in the case of “Mobile data” partly overlap those of the “IT in home care” case. In particular, for applications, markets, utility and business models: uncertainty has to be

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<sup>17</sup> In addition, policy may change LOU so as to open up for smaller firms and to alter science and educational policy.

reduced; knowledge developed and demand articulated. This could be e.g. through targeted research programs concerning market aspects, public procurement, creation of user networks etc. Clearly standardization and platform development also need to be encouraged. It should be emphasized, however, that several of the blocking mechanisms (such as lack of standards, operator market characteristics) are difficult to address by national policy actors. Policy could still take a role to help coordination among market participants, which in turn could stimulate standard and platform development and in the end stimulate market formation. Also, there seems to be room for policy action at higher (e.g. European) levels.

In the case of “Biocomposites”, the key policy issue with regard to the function ‘knowledge development and diffusion’ seems to be to broaden the actor base and, thus, the base for learning. This could include identifying actors “in the middle” of the value chain and provide them with incentives to enter and resources for product development etc. Moreover, the different subsystems need to be integrated so that experiences and knowledge may be shared, e.g. in networks. One way of achieving this is to aid actors in the creation of meeting places and platforms, and to help them see themselves as part of the same SIS.

## **7. ANALYSE VARIOUS POLICY INSTRUMENTS AND THEIR LIKELY EFFECT ON FUNCTIONAL PATTERN**

When we have come this far in the analysis, we have come to understand the functional pattern of the focal SIS and have made an assessment of its functionality in relation to its phase of development and/or comparable innovation systems. We have identified process goals, inducement and blocking mechanisms influencing the functions and the key policy issues. The next step involves choosing instruments that deal with the policy issues and help us to achieve the goals.

Before we discuss how to choose among policy instruments we need to highlight three problems that policy makers will encounter when trying to influence the functionality of an innovation system.<sup>18</sup> First, there is no general ‘success model’ for stimulating the emergence and growth of new sectoral innovation systems; each case has to be understood in its details. Second, the complexity of a functional pattern may be very high: As shown by the three cases above and in Appendix B, many different mechanisms may influence the innovation process, each mechanism may influence several functions and functions may influence each other. It

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<sup>18</sup> This section is based on Jacobsson and Bergek (2004).

may, thus, be very difficult to assess the relative strength of inducement and blocking mechanisms for each function and for the system as a whole and, consequently, to understand what to do to stimulate, e.g., market formation (see Jacobsson and Bergek, 2004).

This means that an analysis of this kind cannot be done without the analysts having a thorough understanding of the technology/products/applications in question. It is only through being updated on the industries and technological areas, reading sector specific literature, conducting interviews and sending out questionnaires that we can undertake such an analysis. This is an extremely time consuming task, and there are evidently significant up-front costs that clearly suggest that VINNOVA ought to think in terms of enabling a long-term commitment among analysts to particular sectoral innovation systems. Moreover, international comparative analyses increase these up-front costs further, which suggest that analysts should build long-term relationships with organizations abroad that pursue similar analyses.

Third, the results of any intervention (policy or other) are very uncertain; any policy or strategy can have secondary effects in the form of feedback loops that are difficult to foresee and that be more far-reaching than originally intended. Again, we may refer to Lindblom (1959): “A wise policy-maker consequently expects that his policies will achieve only part of what he hopes and at the same time will produce unanticipated consequences he would have preferred to avoid. If he proceeds through a succession of incremental changes, he avoids serious lasting mistakes in several ways.” (p. 86). Thus, we need to be reminded that policy-making is an iterative process and that policy learning is indeed crucial.

Keeping this in mind, what can we do to analyze the potential effect of various policy instruments on the functionality of a SIS? As mentioned above, policy should aim at remedying poor functionality in relevant innovation systems by strengthening inducement mechanisms and weakening, or even removing, blocking mechanisms. Policy instruments should, consequently, be assessed with respect to how they manage to achieve this task. Two paths seem, then, to be possible to take:

- (1) Assess the extent to which a particular policy instrument may be expected to weaken/remove (or strengthen/add) previously identified blocking (or inducement) mechanisms in a particular SIS by addressing the key policy issues identified above.

- (2) Assess the influence a particular policy instrument may be expected to have on each of the seven functions, the interactions between them and, thus, the functionality of innovation systems in general.

We have tried the first path in several cases, the ones appended to this manual included. Here, we will illustrate with the case of 'IT in home care'. As mentioned above, a long list of policy issues could be identified. The analysts need here to select those that can be tackled with the policy instruments that are available to VINNOVA. Other issues need to be dealt with by others, although VINNOVA could, of course, play a mediating role rather than an intervening role. For 'IT in home care', four possible policy instruments can be mentioned (the list is neither exhaustive nor conclusive).

First, '*integrating projects*' and *demonstrators* can be funded, both of which address three key policy issues (and associated blocking mechanisms):

- Raise user competence among care providers; leads to reduction in uncertainties and improved articulation of demand and affects positively the functions 'market formation', 'entrepreneurial experimentation' and 'influencing the direction of search'.
- Experiment with new applications; leads to reduction in uncertainties and improves knowledge of relations between investment and benefits. Affects positively the functions 'market formation', 'breadth in 'entrepreneurial experimentation', 'free utilities' in the form of reduced uncertainties for suppliers and customers.
- Diffuse knowledge of early experiments; reduces uncertainties with the same effects as above.

Second, policy may support the work of the '*bridging organisation*' Carelink. This may strengthen a meeting place in which activities may take place to form standards. In addition, a stronger advocacy coalition that drives legitimation may be formed in that meeting place.<sup>19</sup> This is expected to improve 'market formation' and 'influence the direction of search'. Moreover, 'free utilities' in the form of information diffusion may be enhanced.

Third, *research* may be directed towards improving our knowledge of the relationship between investments and benefits in complex organizational structures. 'Market formation' is

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<sup>19</sup> In addition, policy may help small supplier firms to build networks for the dual purposes of enhancing diffusion of knowledge and to drive a legitimation process.

expected to be positively affected. Fourth, *provision of seed capital* may strengthen the inducement mechanisms and foster a greater ‘entrepreneurial experimentation’.

This approach provides guidance on which instruments are likely to suit a particular case. The drawbacks are that we risk having a too narrow perspective of the SIS if we only concentrate on the current inducement and blocking mechanisms and that the assessment will be valid for one innovation system only.

The second path, which is somewhat broader, has only been attempted twice: In the report of the latest Swedish Energy Commission (see SOU 2003) and in an assessment of the Swedish Tradable Electricity Certificate System (see Bergek (2004)). In the former, the expected influence of a number of different economic, administrative and informational policy instruments on the functionality of different renewable energy technologies was assessed on an overview level. In the latter, a particular support scheme was analyzed in detail with respect to its influence on the functions. We will use the latter case to illustrate this approach.<sup>20</sup>

In 2003, an “electricity certificate system” was implemented in Sweden with the purpose of increasing the amount of electricity produced from renewable energy sources. In 2004, the Swedish Energy Agency asked one of us to analyze the influence of the certificate system on the functionality of relevant SISs, i.e. innovation systems related to different renewable energy technologies. In addition to a number of detailed pros and cons of the new support scheme in comparison to earlier ones, the analysis revealed the following:

- The electricity certificate system is unlikely to have any substantial influence on the ‘market formation’ function for immature technologies. There are no protected niches in which immature technologies may improve through learning and gradual improvements. Instead, all renewable electricity technologies are made to compete with each other in spite of their very different characteristics and phases of development.
- As a consequence, the system will provide little ‘influence on the direction of search’ towards immature technologies, since no market can be expected to develop for these in the foreseeable future. This implies limited ‘knowledge development’ and ‘entrepreneurial experimentation’ within immature technology fields, possibly resulting in a lack of variety.

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<sup>20</sup> This example is based on Bergek (2004).

- 'Resource mobilization' is limited within the electricity certificate system as it is designed to minimize costs for electricity users. The consequences of this will be largest for immature technologies, both because they have larger needs for development resources and because they cannot expect any large income from market transactions due to the limited market development.
- The 'legitimation' process for immature technologies will be blocked as they are forced to compete on the same market as more mature technologies and, thus, are compared with them.
- In summary, there is a serious risk of "negative feedback" to occur so that the gap between mature and immature technologies widens as mature technologies are being diffused, used and improved, whereas the immature technologies fail to enter a formative phase.

By using one or both of these methods, the possible influence of different policy instruments on functionality may be analyzed so that their suitability for supporting a particular SIS may be assessed. However, in addition to the difficulties mentioned above, we need to recognize that the assessment even with the latter method is SIS and time specific. An instrument that in one case may solve a number of the key policy issues may fail to do so in another case, or may even make the situation worse. Moreover, sometimes a 'bottleneck' function needs attending to before instruments aiming at other functions is of any use. We, therefore, need a dynamic policy process in which goals, key issues and instruments are reformulated and reassessed over time. The timing of application of instruments is, thus, important.

## **8. EVALUATE, LEARN AND DOCUMENT**

In the course of this manual, we have emphasised the many sources of uncertainties that are not only inherent in the process of industrial development but also those additional ones facing the analyst in search of useful methods and tools. We are still in an early stage in our understanding of how innovation systems emerge and develop and we still need to learn a lot about methods such as indicators and how to assess functionality.

A manual of this kind builds on this incomplete knowledge and it is, therefore by no means a finished product. This incompleteness provides an opportunity for VINNOVA to organize a learning process in which the experiences of each and every analyst can be used to improve the manual. We suggest, therefore, that VINNOVA build a process of reflection, learning and

feed-back to the manual, drawing on the vast and varied experiences of its analysts. Only by a systematic learning process can we improve our understanding of the opportunities and limitations of policy making.

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## **APPENDIX A: MATCHING FUNCTIONS IN THE LITERATURE**

In the table below, we have matched the functions suggested by different authors. Most of these original functions are formulated as verbs, in contrast to the functions in the manual, which are formulated as nouns. This reflects a conscious choice on our part; we want to emphasise the process nature of the functions and remove any notion of a particular actor filling them. From the table, we can make the following observations.

First, three of the functions are more or less identical in all lists: ‘stimulate/create market’, ‘supply resources’ and ‘create knowledge (base)’ (although the authors differ in the degree of detail provided for each function; for example, in Rickne (2000) the function ‘supply resources’ corresponds to four different functions). In the manual, these functions are labeled ‘market formation’, ‘resource mobilization’ and ‘knowledge development and diffusion’.

Second, Bergek and Jacobsson’s (various) function ‘guide the direction of search’ is an aggregate of four of Bergek’s (2002) functions (by design) and corresponds, at least in part, to Hekkert et al.’s (2004) ‘articulation of demand’ (which is much broader than the demand articulation that others include in ‘market formation’), to Carlsson and Jacobsson’s (2004) ‘incentives’ and to Rickne’s (2000) ‘direct technology, market and partner search’. Edquist’s (2004) function ‘creating or changing institutions that provide incentives or obstacles to innovation’ is broader and applies also to another function in the manual (see below). In the manual, all these functions are gathered under the label ‘influence on the direction of search’.

Third, Bergek and Jacobsson’s (various) as well as Carlsson and Jacobsson’s (2004) function ‘promoting positive externalities’ is much broader than Bergek’s (2002), Hekkert et al.’s (2004) and Rickne’s (2000), which focus on one source of external economies – diffusion of information/knowledge. Indeed, this function was developed a great deal in Bergek and Jacobsson (2004) and built yet further on in Carlsson and Jacobsson (2004). In the manual, we use the label ‘development of external economies’ for the broader concept.

Fourth, Bergek’s (2002) ‘counteract resistance to change’, which refers primarily to the extremely important process of legitimation, may be linked to Hekkert et al.’s (2004)

‘development of advocacy coalitions’, to Rickne’s (2000) ‘legitimize technology and firms’ and to Edquist’s (2004) ‘creating or changing institutions that provide incentives or obstacles to innovation’. Carlsson and Jacobsson (2004) discuss this aspect under the heading of ‘incentives’, and Bergek and Jacobsson (various) included it into ‘guide the direction of search’ We are, however, hesitant to include advocacy coalitions in a function, since they are a kind of network, i.e. a structural component. In the manual, this function is labelled ‘legitimation’.

Finally, the function ‘promoting entrepreneurial experiments’ mentioned by Carlsson and Jacobsson (2004) is not explicitly mentioned by any of the other authors, with the exception of Edquist (2004) who includes “enhancing entrepreneurship” in his function ‘creating and changing organizations needed’. In the manual, we use the label ‘entrepreneurial experimentation’ in order to emphasise that it is the creation of new combinations and variety that is in focus and that many different types of actors – not only new ones – may contribute to this function.

BERGEK (2002)	BERGEK AND JACOBSSON (VARIOUS)	CARLSSON AND JACOBSSON (2004)	HEKKERT ET AL (2004)	RICKNE (2000)	EDQUIST (2004)
Create knowledge	Create new knowledge	Creating a knowledge base	Creation of technological knowledge	Create human capital	Provision of R&D Competence building
Identify problems Guide the direction of search Provide incentives for entry Recognise the potential for growth	Guide the direction of the search process	Creating incentives	Articulation of demand Prioritizing of public and private sources (the process of selection)	Direct technology, market and partner search Create and diffuse technological opportunities	Articulation of quality requirements (demand side) Creating/changing institutions that provide incentives or obstacles to innovation
Stimulate market formation	Facilitate the formation of markets	Creating markets or appropriate market conditions	Regulation and formation of markets Articulation of demand	Create market/diffuse market knowledge Facilitate regulation (may enlarge market and enhance market access)	Formation of new product markets Articulation of quality requirements (demand side)
Facilitate information and knowledge exchange	Facilitate the creation of positive external economies	Promoting positive externalities, or 'free utilities'	Exchange of information through networks	Enhance networking	Networking
Counteract resistance to change			Development of advocacy coalitions for processes of change	Legitimize technology and firms	Creating/changing institutions that provide incentives or obstacles to innovation
Supply resources	Supply resources	Creating resources (financial and human capital)	Supply of resources for innovation	Facilitate financing Create a labour market Incubate to provide facilities etc Create and diffuse products (materials, parts, compl. products)	Financing of innovation processes etc Provision of consultancy services Incubation activities
		Promoting entrepreneurial experiments			Creating and changing organizations needed (e.g. enhancing entrepreneurship)

Sources: Bergek (2002), Bergek and Jacobsson (various), Edquist (2004); Hekkert et al., (2004); Carlsson and Jacobsson (2004), Rickne (2000).

**APPENDIX B: THREE CASE STUDIES (TO BE ADDED)**