The Systems of Innovation Approach and Innovation Policy: An account of the state of the art

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Contents

1. Introduction

The Systems of Innovation (SI) approach has existed for alittle more than a decade now after the seminal work by Freeman (1987), Lundvall (1992) and Nelson (1993). The SI approach has become very established in a very short period of time. It is widely used in academic contexts and also as a framework for innovation policy-making. Does it really deserve this? .

The purpose of this article is to evaluate the state of the art with regard to the SI approach: how has it developed so far, which are the main achievements (theoretical and empirical advances) and which are the most challenging problems and puzzles still associated with the approach? It is time for a critical assessment and the emphasis in this paper will be on remaining challenges. The evaluation of the SI approach presented in this article includes a discussion of the role of the state in SIs, which, in its turn, includes a discussion of the usefulness of the SI approach as a framework for innovation policy design.

I have previously addressed the emergence and characteristics of the SI approach in (Edquist 1997). The present article is partly based on that chapter; it might be called an 'update' and development of it. In order to avoid too much repetition, I have therefore chosen to refer extensively to Edquist (1997).

In (Edquist 1997) I defined a system of innovation as "all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations." (Edquist 1997: 14) This means that the SI approach is about the determinants of innovations, not about their consequences (in terms of growth, quantity of employment, working conditions, etc).[1] Provided that the innovation concept has been specified (see section 4), the crucial issue is to identify all those important determining factors – which can also be called activities in SIs or functions of SIs (see section 5).

The main emphasis was initially on national SIs (Freeman 1987; Lundvall 1982; Nelson 1983). Since then the sectoral and regional variants have emerged and are currently used in addition to the national one. The sectoral innovation systems (SIS) approach focuses on various technology fields or product areas (e.g. Breschi and Malerba 1997; Carlson 1995; Nelson and Mowery 1999). The geographical boundaries of regional innovation systems (RIS) are regions within countries or include parts of different countries (e.g. Cooke, Gomez Uranga and Etxebarria 1997, Braczyk, Cooke and Heidenreich 1998, Asheim 1999 and Cooke 2000). These approaches can be argued to complement each other rather than exclude each other (Edquist 1997).[2] The three kinds of SIs mentioned here can be addressed as variants of a generic SI approach (Edquist 1997: 11-12).

Except for analysing he emergence of the SI approach in Edquist (1997), I also characterised it in nine dimensions. Maybe the most important one was that innovations are normally seen

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[1] New Growth Theory (NGT), on the other hand, deals with the effects of innovations and knowledge. In this sense the SI approach and NGT are supplements to each other. For a discussion of these relations, see (Gregersen and Johnson 1998). The fact that the SI approach is about determinants does not, of course, deny the fact that innovations have tremendously important socio-economic consequences.

[2] For very large countries the national SI approach is less relevant – but laws and policies are national even in the US. And some countries may not be "coherent" or "inward-oriented" enough to be called national SIs. The criteria used for identifying the geographical boundaries for regional SIs should also be applied to national SIs. I will return to these issues in section 7.

as based on learning that is interactive between organisations in the SI approach; firms do not generally innovate in isolation. (Edquist 1997: 7, 20- 22) Another important feature is that institutions are considered to be crucial elements in all versions of the SI approach (Edquist 1997: 24-26). The institutions shape (and are shaped by) the actions of the organisations and the relations between them. In addition, all versions of the SI approach consider innovation processes to be evolutionary – an issue to which we will return in section 8. (Edquist 1997: 5-7). These characteristics of the SI approach constitute major advances in the study of innovation processes. These strengths of the SI approach have made it absolutely central for the current understanding of innovation processes (Edquist 1997: 24-26).

In the 1997 chapter, I also criticised the SI approach in several respects, saying, for example, that some concepts were used, in different and inconsistent ways, by the founding fathers of the approach and sometimes this use was characterised by unclarity and fuzziness. This is true for the concept of 'institution' which is used both in the sense of organisational actors (or players) and in the sense of institutional rules (or rules of the game) by different authors. In addition, the functional boundaries of the systems were very vaguely defined. Neither were relations between variables described in a rigorous manner. Because of this, the SI approach does not deserve the status of a 'theory' of innovation, but must rather be called a conceptual framework. [3] (Edquist 1997: 28-29) I will (re-) consider these points in this article.

There is a strong need for further conceptual and theoretical development and sharpening of the SI approach. In order to make the SI approach more 'theory-like' – e.g. include more specific statements about relations between variables – it is, in my view, necessary to increase the degree of rigour and specificity of the approach. Based on this awareness, I believe that the best way of doing this is by actually using the approach in empirical (and comparative) research. This is simply because clear concepts and unambiguous statements are needed when empirical correspondences to theoretical constructs are sought. Hence theoretically based empirical work is, in my view, the best way to straighten up the SI approach conceptually and theoretically. The empirical work will function as a 'disciplining' device in an ambition to develop the conceptual and theoretical framework.

Further weaknesses of the SI approach can certainly be identified. One is that we know far too little about the determinants of innovation, although this is a weakness of innovation studies in general and not only of the SI approach. Another is that the SI approach partly neglects other kinds of learning processes than those leading to innovations in a direct and immediate way. This applies to certain kinds of organisational learning, such as the building up of firm routines and databases. In addition, the SI approach largely neglects individual learning in the form of education. Another weakness of the SI approach is that it lacks a 'theoretical' component about the role of the state. This is an important neglect, since the state and its agencies are obviously important determinants of innovation in any SI. These weaknesses will be addressed in different sections of this article.

[3] Therefore I have here consistently called it an 'approach' or a 'framework' rather than a 'theory'. One intention with this article is actually to help develop the SI approach into more of a 'theory' of innovation – or at least outline some things that should be done to achieve this.

2. Systems and Systems Analysis

In much of the literature on systems of innovation the main statements are intuitively based and relations between variables are not described in a rigorous manner. This 'inductive' mode of work and analysis based on empirical generalisations has lead to major progress with regard to our knowledge about innovation processes. As already mentioned, we have, for example, learnt that firms do normally not carry out innovations 'in isolation' and that institutions are crucial for innovation processes. This has made the SI approach central for the modern way of understanding innovations. In order to make the SI approach become more 'theory-like' it is, in my view, necessary to increase the degree of rigour and specificity of the approach. I will try to make a small contribution in this direction below, and I will do so by starting with the general notion of 'system' and 'work myself through' the SI approach with the help of this, i.e. I will use a more 'deductive' approach. Therefore, I will start with a few remarks about systems and systems analysis in general.

In everyday language, as well as in large parts of the scientific literature, the term 'system' is used generously and with limited demands of a precise definition. To the question "What is a system?" there is, however, a common answer in everyday language as well in scientific contexts:

- A system consists of two kinds of entities: There are firstly, some kinds of *components* and secondly, there are *relations* between these.
- There should be reasons why a certain array of components and relations has been chosen to constitute the system; they form a *whole*.
- It must be possible to discriminate the system in relation to the rest of the world; i.e. it must be possible to identify the *boundaries* of the system.[4] However, only in exceptional cases is the system closed in the sense that it has nothing to do with the rest of the world. That part of the rest of the world that in some sense is important for the system is called its *environment*. (Ingelstam 2000: 9)

There are considerable obscurities in these respects in a *general* sense. What can be counted as components and what can relations look like? To see the system as a whole can be problematic: a political system can conceptually be regarded as a whole, but if it is characterised by strong (internal) tensions, these will, in the analysis, be more important than the whole. A boundary between the system and its environment can in most cases be specified in many ways, largely depending on what is the purpose with the systems analysis. Finally, different analysts, partly guided by different purposes, may judge what is 'interesting' in very different ways. In *specific* works within systems analysis, these difficulties will not be problematic. On the contrary they will prove to be interesting and analytically fruitful. (Ingelstam 2000: 9)

All descriptions of systems are simplifications. The method of abstraction is used when describing; we disregard unimportant components and relations. And what is unimportant or not is partly guided by the purpose of our work and our existing knowledge in the field.

[4] We cannot neglect the question of the boundary of the system; the distinction between 'inside' and 'outside' is crucial. If we, for example, want to make empirical studies of innovation systems, we must, of course, know their extension.

3. The Main Components of Systems of Innovation (SIs)

We know intuitively and empirically that different organisations and institutions are important for innovation processes. Let us therefore, for the time being, consider organisations and institutions to be the main *components* of systems of innovation. There is also general agreement on this in the SI literature, although this is sometimes not expressed in a clear and direct manner. Let me specify what organisations and institutions here mean.

Organizations are formal structures with an explicit purpose and they are consciously created (Edquist and Johnson 1997: 47). They are players or actors.[5] Some important organisations in SIs are companies (which can be suppliers, customers or competitors in relation to other companies), universities, venture capital organisations and public innovation policy agencies.

Institutions are sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups and organisations (Edquist and Johnson 1997: 46). They are the rules of the game. Examples of important institutions in SIs are patent laws and norms influencing the relations between universities and firms.[6]

Although there is general agreement that 'organisations' and 'institutions' are the main components in SIs, there is no agreement in the literature what should be meant by these terms. For example, institutions for Nelson and Rosenberg are basically different kinds of organisations (according to the definition above), while Lundvall means the rules of the game when using the term institution. (Nelson and Rosenberg 1993: 5, 9-13; Lundvall 1992: 10) Hence, the term 'institution' is used in at least two main senses in the literature and these senses are often also confused in the literature – even by the same author. The conceptual ambiguity and fuzziness surrounding the term 'institution' has not been sorted out; it is an unresolved issue. (Edquist 1997: 24-26)

Systems of Innovation can be quite different from each other, e.g., with regard to specialisation of production, resources spent on R&D, etc. For example, industrial production in the United States is much more specialised in the production of R&D intensive ('hi-tech') products than is industrial production in the EU (Fagerberg 2001, Edquist and Texier 1996). Further, within the EU, R&D intensities vary greatly between countries. In addition, organisations and institutions constituting components of the systems may be different. For example, research institutes and company-based research departments may be important organisations in one country (e.g. Japan) while research universities may perform a similar function in another (e.g. the United States).[7] Institutions such as laws, norms, and values also differ considerably between systems.

In summary, there seems to be general agreement that the main components in SIs are organisations and institutions. However, the specification of these components certainly varies between systems.

Let me now briefly address the *relations* between the main components of SIs. We have already emphasised that *interactions between different organisations* are crucial in those

[5] Although there are other kinds of actors than organisations – e.g. individuals – the terms 'organisations' and 'actors' will, in this article, be used interchangeably.
[6] Obviously, these definitions are of a Northian character (North 1990: 5).
[7] Hence, different organisations may perform the same function in different systems.

learning processes that are normally the basis for the development of innovations. These relations may be of a market and or a non-market kind. Here it could be mentioned that markets only co-ordinate transactions, i.e. items sold and bought. They do not deal with other kinds of relations. And learning processes that are interactive between organisations concern exchange of knowledge elements and collaborations that are not easily handled through market transactions. Markets are important in systems of innovation, but other mechanisms – e.g. non-market based collaboration - which mediate the relations between components in the systems are also important.

The *relations between organisations and institutions* are important for innovations and for the operation of systems of innovation. Organisations are strongly influenced and shaped by institutions; organisations can be said to be ‘embedded’ in an institutional environment or set of rules, which include the legal system, norms, standards, etc. But institutions are also ‘embedded’ in organisations. Examples are firm specific practices with regard to bookkeeping or concerning the relations between managers and employees; a lot of institutions develop inside firms. Hence, there is a complicated two-way relationship of mutual embeddedness between institutions and organisations, and this relationship influences innovation processes and thereby also both the performance and change of systems of innovation. (Edquist and Johnson 1997: 59-60)

Another type of relation between organisations and institutions is that some organisations directly create institutions. Examples are organisations that create standards and public organisations that formulate and implement rules that we call innovation policy. (Edquist and Johnson 1997: 60) Institutions may also be the basis for the creation of organisations, e.g. when a government makes a law that leads to the establishment of an organisation.

There may also be important *interactions between different institutions*, e.g. between patent laws and informal rules concerning exchange of information between firms. Institutions of different kinds may support and reinforce each other, but they may also contradict and be in conflict with each other.

The relations between organisations and institutions are very complex and often characterised by reciprocity. This emphasis on the complex relations between components constitutes a major advantage of the SI approach. However, it also constitutes a challenge since our knowledge about these relations is very limited. The relations between two phenomena cannot be satisfactorily investigated if they are not conceptually distinguished from each other. It is therefore important to specify the concepts and to make a clear distinction between organisations and institutions in order to be able to address the relations between them. A precise scientific language is a precondition for empirical work; analytical distinctions and conceptual specificity are essential.

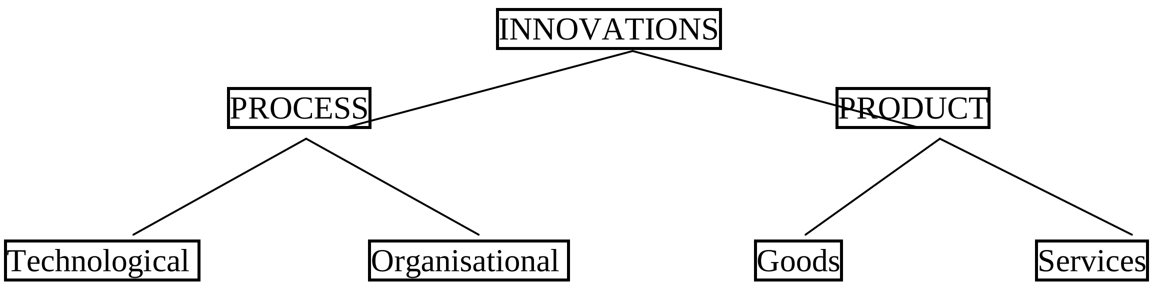
4. Taxonomies of Innovations

In spite of the name – ‘the systems of innovation approach’ – a lot of the writing within this ‘tradition’ was initially focussed on *technological* change, and not on *innovation* in a more general sense. Among the technological innovations the main focus has often implicitly been on technological *process* innovations. In order to identify the determinants and – thereby – to be able to specify the boundaries of the systems, it is necessary to be clear about what an ‘innovation’ actually is. Different kinds of innovations can be expected to have different determinants. For example, organisational process innovations have other determinants than technological ones. And product innovations have yet others. Therefore it is necessary to divide innovations into categories. We need taxonomies of innovations. Disaggregation is crucial for progress with regard to identifying the determinants of innovation. Meso and micro level analysis is important. For the reasons mentioned here, I will now specify the notion of innovation and discuss taxonomies of innovations.

Innovations are new creations of economic significance normally carried out by firms (or sometimes individuals). They may be brand new, but are more often new combinations of existing elements. It is a matter of *what* is produced by firms and *how*.[8]

The category of innovation is extremely complex and heterogeneous. It includes process as well as product innovations as indicated below.

A taxonomy of innovations



Product innovations may be goods or services. It is a matter of *what* is being produced. Process innovations may be technological or organisational. It concerns *how* goods and services are produced. Some product innovations are transformed into process innovations in a ’second incarnation’ (or ‘second appearance’). This concerns only ‘investment products’ – not products intended for immediate consumption. For example, an industrial robot is a product when it is produced and a process when it is used in the production process. Product and process innovations are closely related to each other also in many other ways. In spite of this, it is important to make distinctions between these different kinds of innovations, i.e. to disaggregate and pursue the analysis at a micro and meso level.

In this taxonomy, only goods and technological process innovations are innovations of a ‘material’ kind. Organisational process innovations and services are ‘intangibles’. It is crucial to take the intangible innovations into account also, since they are increasingly important for economic growth and employment.[9]

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[8] I addressed the concept of innovation in more detail in section 2.3.1. in (Edquist 1997).

[9] There are certainly other taxonomies of innovations that can complement the one presented above. For example, innovations take place in several forms:

(1) continuous small incremental changes,
(2) discontinuous radical innovations, and
(3) massive shifts in some pervasive ‘general purpose technology’ (GPT), sometimes called ‘techno-economic paradigms’. (Edquist and Riddell 2000)

Product innovations are the main mechanism behind changes in the production structure. It is therefore inappropriate to ignore product innovation as is often done by mainstream economics. Technological process innovations are certainly not the only ones that are important for economic growth and employment. Although product innovations are crucial for changes in the production structure, this must not, however, be interpreted to downgrade the importance of process innovations; the latter are necessary for the competitiveness of all firms in all countries, sectors and regions.

The SI approach can handle all of these categories of innovations, although the main emphasis in some of the SI literature is on technological innovations. This capability of the SI approach should be exploited and all the four kinds of innovations mentioned above should be addressed.

Now when we know what can be meant by 'innovations', we are one step closer to identifying the boundaries of the systems. But given the definition presented initially, we also need to know more about the determinants of innovation processes

5. The Main Functions of SIs

When the innovation concept has been specified, a crucial issue becomes to identify all the important factors influencing the development, diffusion and use of these innovations. It is not sufficient to identify the main components of SIs and the relations between them. We must also explicitly address what 'happens' in the systems. What do the organisations do in relation to innovation processes? How do institutions constrain/prevent or stimulate the organisations to do certain things related to innovation processes? What role does the relations between the components in the systems play for innovation processes? What is the overall function of the system as a whole – constituted by the components and the relations between them?

Hence, it is important to move beyond descriptions of components of the systems and the relations between them. An obvious way to do so is to deal with what could be called the 'activities' in the systems or the 'functions' of the systems. In Edquist (1997: 19) I mentioned the function of R&D in SIs and that this function may be performed by different organisations or actors – such as research institutes, company R&D units or universities - in different SIs.[10] I also hinted at a discussion of activities within SIs in (Edquist 1997: 15). And 'systems' were referred to as complex wholes with some "clearly defined overall function" (Edquist 1997: 13). These references to 'activities' and 'functions' were, however, only hints and they were not discussed in a systematic manner in Edquist (1997). The same is true for the early contributions to the development of the SI approach, e.g. Lundvall (1992) and Nelson (1993). Hence, we have neglected what actually happens in the systems. As we will see below this neglect has been supplemented with some later contributions to the literature.

A third taxonomy is between development, diffusion and use/production of new processes and products. A fourth is the distinction between innovations in low, medium and high technology sectors of production (Edquist 2001).

[10] The relations between organisations and functions will be further addressed in section 6.

At one level the most important function - i.e. the 'overall function' - in an SI is, of course, to produce, diffuse and use innovations. At a more specific level it is a question of focussing upon things that influence the development, diffusion and use of innovations. These are what we have above called the 'determinants' of innovations. Examples may be the production of economically relevant knowledge through R&D or the financing of the development of innovations. Hence the 'activities' in the systems or the 'specific functions' of the systems are more or less the same thing as determinants of innovation processes or factors influencing them.[11]

This focus is in line with recent work by Xielin Liu and Steven White (2000), which addresses what they call a fundamental weakness of national innovation system research, namely "the lack of system-level explanatory factors" (Liu and White 2000: 4). They focus upon the 'activities' in the systems. These 'activities' are related to "the creation, diffusion and exploitation of technological innovation within a system" (Liu and White 2000: 6). They focus upon how fundamental activities of the innovation process are organized, distributed and co-ordinated.

Liu and White identify five fundamental activities. These are:

1. research (basic, developmental, engineering),
2. implementation (manufacturing),
3. end-use (customers of the product or process outputs),
4. linkage (bringing together complementary knowledge), and
5. education. (Liu and White 2000: 6-7,)

"These activities extend beyond the R&D system, including important inputs to research activity as well as the use of research outputs." (Liu and White 2000: 7)

Johnson and Jacobsson (2000) emphasise that "a set of functions, e.g. supply of resources, have to be fulfilled in order for the growth of an industry to be supported. We suggest that we can evaluate the performance of an innovation system by assessing its 'functionality', i.e. how well these functions are served." (Johnson and Jacobsson 2000: 2)

Johnson and Jacobsson have suggested that "a technology or product specific innovation system /i.e. a sectoral system of innovation or a technological system/ may be described and analysed in terms of its 'functional pattern', i.e. in terms of how these functions are served. The pattern stems from the character of, and interaction between, the components of an innovation system, i.e. actors (e.g. firms and other organisations), networks and institutions (Carlsson and Stankiewicz, 1995), which may be specific to one innovation system or 'shared' between a number of different systems." (Johnson and Jacobsson 2000: 3)

Johnson and Jacobsson mention five functions:[12]
1. to create 'new' knowledge,
2. to guide the direction of the search process,
3. to supply resources, i.e. capital, competence and other resources,

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[11] The term 'determinants' was used in the definition of a system of innovation presented in the introduction to this article.

[12] Anna Johnson previously discussed these issues in Johnson (1998). There she identified functions mentioned or implicitly addressed in various previous contributions to the development of the SI approach. She also listed and stressed various benefits of using the concept of 'function' in SI studies.

4. to facilitate the creation of positive external economies (in the form of an exchange of information, knowledge and visions), and
5. to facilitate the formation of markets. (Johnson and Jacobsson 2000: 3-4)

Rickne (2000) discusses what ‘functionality’ each type of actor can provide to new technology based firms (NTBFs). The extent to which these functions are filled may be seen as an indicator of performance for how well any specific innovation system supports the establishment and growth of NTBFs.[13] (Rickne 2000: 175)

She provides a long list of functions:
1. to create human capital,
2. to create and diffuse technological opportunities,
3. to create and diffuse products,
4. to incubate in order to provide facilities, equipment and administrative support,
5. to facilitate regulation for technologies, materials and products that may enlarge the market and enhance market access,
6. to legitimise technology and firms,
7. to create markets and diffuse market knowledge,
8. to enhance networking,
9. to direct technology, market and partner research,
10. to facilitate financing, and
11. to create a labour market that the NTBF can utilise.

There are important similarities between the list of ‘activities’ and the two lists of ‘functions’, but there are also differences. This may simply be seen as a reflection of the fact that this field of research work, in a systematic form, is at an early stage of development. The lists seem to have been compiled on an intuitive basis. There is simply no established knowledge with regard to which the most important functions in a system of innovation are; a lot remains to be done here.[14]

For now, we will have to leave this issue as an unresolved one. Surprisingly little systematic and detailed research seems to have been done on determinants of innovation. At the same time it is a crucial issue, which motivates that a major effort should be made to increase our knowledge in the field of explaining innovation. The determinants of innovation, activities in SIs and functions of SIs is an area of ‘basic research’ in the field of innovation studies that should be given more emphasis.[15] That these activities, functions or determinants of innovation should be given increased emphasis is a major point in this article.[16] Such work might also be very important in an attempt to raise the theoretical status of the SI approach,

[13] Hence she does not discuss the overall performance of a system, but how well the system supports NTBF establishment and growth.
[14] Another important issue is which of the relevant functions that are or should be served by firms and markets and which ones that are or should be served by governments and their agencies. This policy issue will be discussed in section 10.1.
[15] Given our limited existing knowledge of determinants of innovations, case studies of the determinants of specific innovations or specific (and narrow) categories of innovations would most probably be very rewarding. Relevant questions to ask would include the following. Which activities of which organisations were important for the development, diffusion or use of the innovations? Which institutional rules influenced the organisations in carrying these activities?
[16] This would lead to an improved ability to specify the boundaries of innovation systems – as discussed in section 7 below.

i.e. move it along the way from being a 'conceptual framework' into some kind of (appreciative) 'theory'.[17]

Innovations can be expected to be multi-causally explained. Therefore the explanatory work would include a specification of the relative importance of determinants. We might have to make a distinction between central determinants and less important ones. In addition, the different determinants cannot be expected to be independent of each other; they probably support and reinforce each other.[18] We might therefore need to establish 'a hierarchy' of causes á la E.H. Carr.[19]

The array of determinants and the relations between them can also be expected to vary between different kinds or categories of innovation, e.g. the determinants will probably vary between process and product innovations as well as between incremental and radical innovations. It is therefore important to pursue this explanatory work at a meso or micro level of aggregation. Taxonomies of different categories of innovations can therefore be expected to be important in this work.

There are strong reasons to integrate conceptual and theoretical work with empirical studies in an effort to identify determinants; it can be expected to lead to cross-fertilisation. The SI approach should be used as a conceptual framework in specific empirical analyses of concrete conditions. Testable statements or hypotheses should be formulated on the basis of the approach and these should be investigated empirically. As stated in the introduction, theoretically based empirical work is the best way to straighten up the SI approach conceptually and theoretically; the empirical work will function as a 'disciplining' device in an ambition to develop the conceptual and theoretical framework.

In addition, such work would increase our empirical knowledge about determinants, functions and activities in the systems, and this knowledge could then be a basis for further empirical generalisations to develop the framework – maybe into a theory. To illustrate, it might be mentioned that this procedure has been efficient in research on the relations between organisations as a source of knowledge generation. Intuitive and case study based knowledge about the relations between users and producers in the Danish dairy industry as a source of innovations was a basis for the formulation of the (Danish variant of) the national systems of innovation approach in a systematic form. This approach was later used as a point of departure in detailed questionnaire based empirical work on co-operative relations between

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[17] The interest in work on determinants of innovation seems to be increasing. One example is the conference held last week in Paris with the title "What do we know about the sources of Technical Change?"

[18] This can be compared to the attempts to explain economic growth by means of 'growth accounting': "The growth sources feed from each other" (Abramovitz 1989: 23). Gregersen and Johnson address this in the following way: "There are, for example, obvious interdependencies between technological change and capital investments as well as between technological change and investment in human capital. This makes it impossible to isolate the contributions to growth from specific factors and it is not easy to discuss causality within this model. To understand growth it is necessary to understand the interdependencies between different sources of growth." (Gregerson and Johnson 1998: 8) To explain innovation is even more complicated since the category of 'innovation' is less homogeneous than the category of 'economic growth'.

[19] Carr argued that the study of history is a study of causes and that the historian continuously asks the question, Why?. Further, the historian commonly assigns several causes to the same event. (Carr 1986: 81, 83) He continues: "The true historian, confronted with this list of causes of his own compiling, would feel a professional compulsion to reduce it to order, to establish some hierarchy of causes which would fix their relation to one another, perhaps to decide which cause, or which category of causes, should be regarded 'in the last resort' or ' in the final analysis….. as the ultimate cause, the cause of all causes." (Carr 1986: 84)

organisations as a source of product innovation.[20] The empirical results revealed that most innovations were developed in collaboration between firms and other organisations. And this constituted systematic empirical support to the element of interactive learning in the SI approach. This is a very good example of how conceptual and theoretical work can be integrated with systematic empirical work – and lead to cross-fertilisation. It is an illustration of how knowledge can fruitfully be accumulated in innovation studies.

6. Relations between Components and Functions in SIs

The increased emphasis on 'functions' and 'activities' in this article and other recent work – as compared to early work on SIs – certainly does not mean that we can disregard or neglect the 'components' in SIs and the relations between them. Organisations perform the activities and institutions provide incentive frameworks for these activities. Thereby we are back to the realm of components. Hence, we need to focus both on activities and components if we shall be able to understand and explain innovation processes. And we need to address the relations between components and functions.

Which are then the relations between the components of SIs – i.e. organisational actors and institutional rules - and the functions performed within them? In section 3, I argued that there seems to be general agreement that the main components of SIs are organisations and institutions, but that the specifications between these categories vary between systems. A similar correspondence seems to be true with regard to functions. The main functions or activities of the systems are similar in all systems, but they may be performed by different organisations – and they perform them in contexts of different specific institutions.

Hence, there is not a one-to-one relation between functions and organisations. Several different organisations can fulfil each function. For example, research or the creation of new knowledge can be carried out by research institutes, universities, or research-oriented firms. The same is true for most other functions listed above. Further, most actors can perform more than one function. For example, universities provide both new knowledge and educated people (human capital).

The relations between functions and institutions are less direct. I briefly discussed the relations between institutions and organisations in section 3. The role of institutions in relation to functions seems to be that they influence how the organisations perform the functions.[21]

7. Boundaries of SIs: spatial, sectoral and functional

The main components in and the main functions of SIs have been dealt with above. These are the nuclei of SIs. As indicated in section 2, the issue of the boundaries of systems of innovation cannot be neglected. The distinction between what is inside and outside the system

[20] Examples of such empirical work are Edquist, Ericsson and Sjögren (2000), Christensen, Rogaczewska and Vinding (1999) and Orstavik and Nås (1998).
[21] There are also important relations between functions, i.e. relations between determinants which we discussed in section 5.

is crucial. It is, for example necessary if empirical studies of specific SIs – of a national, regional or sectoral kind – shall be carried out. One way to identify the boundaries of SIs is to identify the causes or determinants of innovations.

The discussion of boundaries is somewhat different between different kinds of innovation systems. Therefore, I will first briefly address national, regional and sectoral SIs.

We saw in the Introduction that the specification 'national systems of innovation' is only one among several possibilities. However, there are strong reasons to talk about innovations in terms of national systems. One reason is the fact that the various case studies in Nelson (1993) show that there are sharp differences between various national systems in such attributes as institutional set-up, investment in R&D, and performance. For example, the differences in these respects between Denmark and Sweden are remarkable – in spite of the fact that these two small countries in Northern Europe are very similar in other respects such as language, culture, standard of living, lifestyle, consumption patterns, size of the public sector, and strength of trade unions (Edquist and Lundvall 1993: 5-6). Another very important reason is that most public policies influencing innovation processes or the economy as a whole are still designed and implemented at the national level.[22] In other words, the importance of national systems of innovation has to do with the fact that they capture the importance of the political and policy aspects of processes of innovation. It is not only a matter of geographical delimitation; the state, and the power attached to it, is also important.[23]

Systems of innovation may be supranational, national or subnational (regional, local) – and at the same time they may be sectoral within any of these geographical demarcations. There are many potential permutations. National, regional and sectoral systems of innovation can be regarded as three variants of a generic SI approach. This means a generalisation from the initial national approach. Whether a system of innovation should be spatially or sectorally delimited – or both - depends of the object of study.[24] All the approaches mentioned above may be fruitful – but for different purposes or objects of study. Generally, the approaches complement each other rather than exclude each other. This is because it is a limitation to talk about globalisation and regionalisation without addressing the national level. Therefore, it is useful to consider sectoral and regional systems of innovation as parts of national ones.

There are three senses in which we can identify boundaries of SIs:

1. Spatially/geographically,
2. Sectorally, and
3. Functionally.

(1) To define the spatial boundaries is the easier task, although it also has its problems. These boundaries have to be defined for regional and national SIs, and sometimes also for sectoral ones.[25] The problem of *geographical* boundaries is somewhat more complicated for a regional than for a national SI. One question is which criteria that should be used.

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[22] For very large countries the national SI approach is less relevant than for smaller countries – but institutions such as laws and policies are still mainly national, even in a country like the USA.
[23] We will return to the political and innovation policy aspects further in section 10.
[24] An 'industrial complex' or 'cluster' as used by Porter (1990) can be seen as a combination of a sectoral and a regional SI.
[25] However, in the latter case it is actually in practice normally a question of a combination of a sectoral and a national/regional delimitation.

For a regional SI the specification of the boundaries should not be a question of choosing or using administrative boundaries between regions in a mechanical manner (although this might be useful from the point of view of availability of data). Rather it should be a matter of choosing geographical areas for which the degree of 'coherence' or 'inward orientation' is large with regard to innovation processes.[26] One possible operationalisation of this criterion could be a minimum level of localised learning spill-overs (between organisations), which is often associated with the importance of transfer of tacit knowledge between (individuals and) organisations. A second one could be localised mobility of skilled workers as carriers of knowledge, i.e. that the local labour market is important. A third possible one could be that a minimum proportion of the collaborations between organisations leading to innovations should be with partners within the region. This is a matter of localised networks, i.e. the extent to which learning processes between organisations are interactive within regions.

For a national SI the country borders often provide the boundaries. However, it could be argued that the criteria for regional SIs are as valid for national ones. In other words, if the degree of coherence or inward orientation is very low, it is not meaningful to consider the country to have a national SI.

On what it means to be 'national', Nelson and Rosenberg write: "On the one hand, the concept may be too broad. The system of institutions supporting technical innovation in one field, say pharmaceuticals, may have very little overlap with the system of institutions supporting innovations in another field, say aircraft." (Nelson and Rosenberg 1993: 5)[27] They actually here argue for a sectoral approach.[28]

(2) Hence, leaving the geographical dimension, we can also talk about '*sectorally*' delimited systems of innovation (i.e. systems that include only a part of a regional, a national, or an international system). They are delimited to specific technology fields (generic technologies) or product areas.[29] The 'technological systems' approach belongs to this category. Carlsson and Stankiewicz state that the "nation-state constitutes a natural boundary of many technological systems. Sometimes, however, it may make sense to talk about a regional or local technological system… In yet other cases the technological systems are international, even global. Where the boundaries are drawn depends on the circumstances, e.g., the technological and market requirements, the capabilities of various agents, the degree of interdependence among agents, etc. (Carlsson and Stankiewicz 1995: 49)

Hence, specific technologies or product areas define the boundaries of sectoral systems, but they must also normally be geographically delimited.

(3) However, within a delimited geographical area (and perhaps also limited to a technology field or product area), the whole socio-economic system can, of course, not be considered to be included in the SI. The question is then which parts that should be included? This is a matter of defining the *functional* boundaries of SIs. These have to be defined for all kinds of

[26] This is also important with regard to policy, since it is difficult to influence a very outward-oriented system from a political level within the region.
[27] It may be noted that they here use the term 'institution' in the sense in which we have defined 'organisation' in section 3 and that they deal only with 'technical' innovations.
[28] Richard Nelson also takes up this perspective in an edited book which appeared in 1999 (Mowery and Nelson 1999)
[29] They can be, but are not necessarily, restricted to one sector of production.

SIs: national, regional and sectoral. And this is more complicated than in the cases of the spatial and sectoral boundaries.

Actually, the founding fathers of the SI approach did not address this problem in a systematic manner (and they did not use the term 'functional'). They did not provide a sharp guide to what exactly should be included in a '(national) system of innovation' (Edquist 1997: 13-15, 27).[30] Neither have the functional boundaries of the systems been defined in an operational way since then.

In the beginning of this article, I defined system of innovation as "all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations." If the concept of innovation is specified and if we know the determinants of their development, diffusion and use, we would be able to define the functional boundaries of the SIs. This is a reason why I have discussed taxonomies of innovation in section 4 and strongly stressed the importance of research on identifying functions in SIs and determinants of innovation processes in section 5. Given the satisfactory solutions of these tasks we would be able to identify the functional boundaries of SIs, whether they are national, regional or sectoral. Admittedly this is not as easy in practise as in principle and for the time being it is an unresolved problem of a 'catch 22' character. Still it is very important.

To conclude: All SIs must be functionally delimited, they must be geographically delimited if they are not global, and sometimes the boundaries of the SIs are also sectorally delimited.

8. The Evolutionary Heritage of the SI Approach

In the SI approach, a long-term historical perspective is natural and important. This is because innovation processes take time, sometimes decades. They also have evolutionary characteristics, as I mentioned in the introduction, i.e., the innovation processes are often path dependent over time.[31] They develop along certain trajectories. It is not clear—even to the actors involved—what the end-result will be, i.e., which path will be taken. Hence, there is a close affinity between evolutionary theories of innovation and the SI approach. The implications of such an evolutionary perspective are very important for the understanding of innovation processes as well as for the design and implementation of innovation policy.

Since innovations occur everywhere in a system - to a greater or lesser extent - and because of the evolutionary character of innovation processes, an innovation system never achieves equilibrium. We do not even know whether the potentially 'best' or 'optimal' trajectory is being exploited at all, since we do not know which one it would be. This means that the notion of optimality is irrelevant in a system of innovation context. We can not specify an

[30] Nelson and Rosenberg provided "no sharp guide to just what should be included in the innovation system, and what can be left out" (Nelson and Rosenberg 1993: 5-6). Lundvall claimed that "a definition of the system of innovation must be kept open and flexible" (Lundvall 1992: 13).
[31] I have previously shown that all the founding fathers of the SI approach were committed to the idea that innovation processes have evolutionary characteristics (Edquist 1997: 7). There is a close relationship between all variants of the SI approach and evolutionary theories of innovation. There is also an intimate relation between (interactive) learning theories and evolutionary theories in the sense that learning is one mechanism through which diversity is created. Learning might even be an element in the process of selection (Edquist 1997: 7)

optimal or ideal system of innovation. Therefore we cannot compare an existing SI with an ideal or optimal one - which is done in the market failure approach in traditional economics. This means that the market failure approach loses its meaning and applicability in a SI context.[32] Instead, the SI approach relies on comparisons of existing systems.

As argued in section 3, SIs can be quite different from each other in terms of patterns of production specialisation, R&D intensities, and with regard to the set-up of organisations and institutions. The SI approaches make the differences between systems of innovation a main focus, rather than something to be abstracted from. This makes it not only natural but also vital to *compare* different existing systems. Without such comparisons it is impossible to argue that one system is specialised in one or the other way, or that a system performs well—or badly.[33]

9. Other Kinds of Learning than Innovation Processes - in Systems of Learning?

One weakness of the SI approach is that it partly neglects other kinds of learning than innovation processes. Product and process innovations are the results of learning processes such as R&D, learning-by-doing, learning-by-using and learning-by-interacting. Since firms normally control the results of these learning processes, we could label them ‘organisational learning’. To study such organisational learning processes is a natural element in empirical innovation studies. However, there are other kinds of organisational learning which are often not addressed in innovation studies. Examples are the building up of firm routines, creation of manuals, building databases, etc. It is important to expand the focus by addressing also such kinds of organisational learning processes.[34]

In addition, the SI approach to a large extent neglects learning in the form of education. A major exception to this is the writing of Bengt-Åke Lundvall. When designing Lundvall (1992), the Aalborg group planned to have a chapter on the education system, but at the end they did not succeed (Lundvall and Christensen: 3). This ambition of Lundvall’s is also reflected in other work, including a major OECD study on knowledge management in the learning Society managed by the Centre for Educational Research and Innovation (CERI) (Lundvall 2000; OECD 2000). Another recent CERI study included a conceptual framework which tried to integrate ‘innovation’ and ‘education’ in the same generic ‘learning’ conceptual framework as well as empirical studies of the role of education and innovation for economic growth at a regional level (OECD 2001). Hence, the crucial importance of education for innovation is pointed out in some writing on systems of innovation. However, no really profound analyses of education have, to my knowledge, been carried out in the context of analyses of innovation systems.

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[32] The market failure approach is an important mechanism for policy formulation in neo-classical economics.
[33] There are important implications of this discussion for policy design. For example, comparisons between existing systems is the only way to identify problems that should be the object of policy – since the market failure approach is irrelevant in an SI context (Edquist 2001). See also section 10 below.
[34] Organisational learning is sometimes said to lead to the generation of ‘structural capital’, i.e. knowledge capital controlled by organisations (e.g. firms) rather than individuals. Structural capital does not go home in the evening – like human capital (which might not return the next day).

Education may be labelled 'individual learning', since human capital, which is controlled by individuals, is created in this process. Individual learning and human capital are certainly necessary pre-requisites for innovation processes and other kinds of organisational learning of the kind mentioned above. It is therefore important to relate innovations, as perceived by the systems of innovation approach, to individual learning (education). In doing this, it is possible and important to build upon analyses of economic aspects of education carried out outside the SI approach and innovation studies in general, e.g. in educational studies and in economics of education.

In conclusion, it might be important to widen the perspective of systems of innovation. We should not only address those learning processes that lead to process and product innovations in a direct sense and an immediate way. We should focus on the knowledge infrastructure in a more generic way. This would mean to transcend the SI approach and move into thinking along lines of 'Systems of Learning' rather than 'Systems of Innovation'. Systems of Learning would include individual learning (leading to creation of human capital) as well as organisational learning (leading to creation of structural capital, e.g. innovations).[35] It would also make it natural to study the relation between education and innovation, e.g. to find out which kinds of education that is most important for process innovations and product innovations respectively.

It is increasingly often argued that knowledge is the most fundamental resource in the modern economy and, accordingly, that the most important process is learning (Lundvall 1992: 1). If this is true, knowledge in the form of human capital and structural capital become more important than physical capital (machinery and buildings). This would then imply that the economy *operates* in a completely different way. This should be reflected in our approaches.

10. SIs and the State

As mentioned in the introduction, another weakness of the SI approach is that it lacks a component ('theory') about the role of the state. This is an important neglect, since the state and its agencies are important determinants of innovation in any SI. For example, many laws and rules, which influence innovation processes, are created by the state.

A component about the role of the state in the SI approach should include the mechanisms through which the state influences the innovation system (e.g. through innovation policy), but also how the rest of the system – and of the society at large – influences the state. I will address these topics in two subsections. Section 10.1 deals with innovation policy in general and some policy implications of the SI approach. Section 10.2 focuses upon how innovation policy is actually designed and implemented in practice.

[35] Maybe it would be useful to talk about the subsystem of organisational learning (including systems of innovation) and the subsystem of individual learning when analysing generic Systems of Learning?

10.1. Innovation Policy and Policy Implications of the SI Approach[36]

Innovation policy is public action that influences technical change and other kinds of innovations. It includes elements of research and development (R&D) policy, technology policy, infrastructure policy, regional policy and education policy. This means that innovation policy goes beyond science and technology (S&T) policy, which mainly focuses on stimulating basic science as a public good from the supply side. Innovation policy also includes public action influencing innovations from the demand side.[37]

One fundamental question for the design of public innovation policy is what should be performed by the state or public sector and what should not. In other words, what should the division of labour be between the state, on one hand, and markets and companies, on the other? As I see it, two conditions must be fulfilled for public intervention to be justified in a market economy.

(1) Firstly, the market mechanism and firms must fail to achieve the objectives formulated; i.e. a '*problem'* must exist.

A 'problem' exists when firms and markets do not automatically realise the objectives that have been politically determined. There are no reasons for public intervention if the firms and the markets fulfil the objectives, i.e. if there are no 'problems'. This is in line with the principle that innovation policy should complement firms and markets, not replace or duplicate them.

(2) Secondly, the state and its public agencies must also have the *ability* to solve or mitigate the problem.

If the public sector does not have this ability, there should, of course, be no intervention, since the result would be a failure. In other words, this condition is an attempt to make sure that political failures are avoided to the largest possible extent.[38]

We have, in section 8, pointed out that innovation processes are, in the SI approach, seen as having evolutionary characteristics and that the notion of optimality is therefore irrelevant in a SI context. Therefore, a 'problem' can not be identified through comparisons between an existing system and an optimal one. The remaining methodology to identify 'problems' that should be subject to policy is to compare existing systems with each other – something which is currently in fashion and called 'benchmarking'.

However, to know that there is reason to consider public intervention is not enough. It is only a first step. It only indicates where and when intervention is called for. It says nothing about how it should be pursued. In order to be able to design appropriate innovation policy

[36] This section is partly based upon Edquist (2001 b) and Edquist (forthcoming, 2001 c). These articles discuss the innovation policy implications of the SI approach in much more detail than has been possible here.
[37] One important demand side innovation policy instrument is public technology procurement, i.e. when public agencies place orders on products that are not yet developed, i.e. for the delivery of which innovations are necessary (Edquist, Hommen and Tsipouri 2000). Demand side oriented innovation policy is also addressed in Edquist and Hommen (1999).
[38] However, political mistakes and failures cannot be completely avoided; public actors may fail, just like markets and private actors.

instruments, it is also necessary to know the causes behind the problems identified – at least the most important ones.[39]

Within a systems of innovation framework an identification of the causes behind the problems is the same as identifying deficiencies in the functioning of the system. It is a matter of identifying functions that are missing or inappropriate and which lead to the 'problem' in terms of comparative performance.[40] Let us call these deficient functions 'system failures'. When we know the causes behind a certain 'problem' we have identified a 'system failure'.

There are at least four main categories of system failures (which are partly overlapping):

- Functions in the SI may be inappropriate or missing.
- Organisations may be inappropriate or missing,
- Institutions may be inappropriate or missing, or
- Interactions or links between these elements in the system of innovation may be inappropriate or missing.

Not until they know the character of the system failure do policy-makers know whether to influence or change functions, organisations, institutions, interactions between them – or something else? Therefore, an identification of a problem should be supplemented with an analysis of its causes as a part of the analytical basis for the design of an innovation policy. Benchmarking is not enough!

In summary, concrete empirical and comparative analyses are absolutely necessary for the design of specific innovation policies. National, regional, local and sectoral systems of innovation must be systematically compared with each other in a very detailed manner. Only in this way can specific innovation policies be designed. There is no substitute for concrete analyses of concrete conditions in an effort to design innovation policy. The SI approach is an analytical framework suited for such analyses. It is appropriate for this purpose because it places innovation at the very centre of focus and because it is able to capture differences between systems.

10.2. The Design and Implementation of Innovation Policy

In the previous subsection I discussed how innovation policy could be designed in a process of 'social engineering', based on the knowledge about innovation processes that we have accumulated and that has been 'summarised' in the form of the SI approach. However nothing guarantees that innovation policy is designed in this way. On the contrary, there are many other factors than knowledge and rationality that may influence the state in its role of pursuing innovation policy.

It can be argued that imitation is a very common mechanism of policy-making. In many countries, policy-makers are simply doing similar things to what has been done previously in other countries (or in the same country). There is a visible copycat effect. Examples are the many national technology programmes in the fields of information technologies, new

[39] A causal analysis might also reveal that public intervention might be unlikely to solve the problem identified, due to lack of ability from the point of view of government.
[40] See section 5 above for a discussion of the main functions (activities, determinants of innovation) in SIs.

materials and biotechnology. A consequence is that variations in national characteristics between countries are often not taken into account. In addition, you are bound to be a lagger when imitating. (Edquist 1994: 71)

Another important mechanism behind the formulation and implementation of innovation policies is lobbying. Private firms, state agencies and other organisations often act with the objective to influence innovation policies in order to get them designed and implemented in their own interest. This mechanism is often combined with imitation. (Edquist 1994: 75) Lobbyism is often a conserving mechanism, since it requires that the lobbyists have an economic power position – and he works to permanent status quo, for example with regard to the structure of production. Emerging products and sectors of production can, of course, not (yet) be represented by economically powerful interest groups. (Edquist 1993)

We need more knowledge about how innovation policy has actually been designed and implemented and which societal forces that have governed these activities. On that basis it would be possible to make empirical generalisations or create (appreciative) theories about what determines innovation policy. These attempts should also build upon and be related to the knowledge about policy processes accumulated within political science. This could then be the beginning of formulation of a 'component' about the role of the state in the SI approach and in the field of innovation. Maybe such knowledge could contribute to make innovation policies analytically based to a larger extent and more long term?

12. Conclusions

(To be written.)

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