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Industrial Development Report 2005
Background Paper Series

Formation and Growth of Sectoral Innovation Systems—"Functional Analysis" as a Tool for Policy Makers in Identifying Policy Issues

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Industrial Development Report 2005 Background Paper Series

Formation and growth of sectoral innovation systems – 'functional analysis' as a tool for policymakers in identifying policy issues

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April 2005

Office of the Director-General

This series includes the background papers commissioned to cover specific aspects addressed in the Industrial Development Report 2005 "Capability building for catching-up – Historical, empirical and policy dimensions". The digital versions are available, together with the full report, on the IDR 2005's website at www.unido.org/idr.

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1. Introduction

For a very long time, the rationale behind, and scope for policy intervention in the industrialization process has been highly controversial. Yet, it is abundantly clear that in industrially advanced countries, policy intervention is very frequent, and part and parcel of larger transformation processes.[1] The policy intervention is, however, neither of the 'orchestrating' type, nor the conventional 'industrial policy' sort but incorporates a range of activities including those found within science and technology policies, tax policies (e.g. CO2 tax), standardization measures, formation of early markets via, e.g., procurement policies, measures to broaden the search space of firms, etc. In contrast to subsidies of dying industries (e.g. the Swedish textile and clothing policy in the 1970s and 1980s, see Alänge and Jacobsson, 1994), such measures are, on the whole, deemed to be legitimate. In a developing country context, it is also '... increasingly recognized that developing societies need to embed private initiative in a framework of public action that encourages restructuring, diversification, and technological dynamisms beyond what market forces on their own would generate" (Rodrik, 2004, page 1).

In such a framework, it has not only been argued that the appropriate public action needs to differ across industrial fields (Katz, 1983; Jacobsson, 1986; Jacobsson and Alam, 1994; Carlson and Jacobsson, 1996 and 1997a; Rodrik, 2004), i.e. they need to be selective,[2] but also that it needs to change its content over time (Teubal 19XX; Carlson and Jacobsson 1997b; Katz, 2004). Policymaking is, furthermore, conducted under very considerable uncertainty, or even ignorance (Stirling, 1994; Rosenberg, 1996) over what the key policy issues are and how the policy goals should be formulated (Carlsson et al., 2005). This uncertainty is compounded by the length of the learning period, which is often counted in decades rather than in years (Porter, 1990; Jacobsson, 1993; Katz, 2004; Carlsson et al., 2005). How then can policymakers identify the issues that a selective and time-specific policy should aim at resolving?

The purpose of this paper is to present an analytical framework, designed to help policymakers identify the key policy issues in a specific sectoral system of innovation at a given moment in time. The framework has been developed in collaboration with the main Swedish technology policy actor, VINNOVA (Swedish Agency for Innovation Systems). We will also discuss, in a tentative way, the application of this framework to a developing country context, involving catching-up processes and the formation of capabilities in an early and 'formative' phase of the evolution of sectoral innovation systems.[3]

The paper is structured as follows. Section 2 contains a brief discussion of the rationale for policy intervention and the associated problem of identifying the key policy issues. We then proceed, in section 3, to present the new framework that focus on 'functions'[4] in a sectoral innovation system (SIS), i.e. 'what is happening in the system' rather than on the structure of the system. Section 4 applies that framework to a 'formative' phase. An illustrative example (ex post analysis) is given in the form of the German SIS for solar cells. We end the section with a second case ('IT in home care' in Sweden) where the framework is used to find the key policy issues facing policymakers today. In section 5, we move to discussing the framework in a 'catching-up' context. We begin by outlining a set of uncertainties stemming the evolution of the global SIS, which the 'catching-up' country attempts to enter. Using empirical examples mainly from Brazil, the Republic of Korea and Chile, we will then illustrate how functional requirements were handled by policy in the evolution of SIS in the capital goods industry and in the salmon farming industry. Finally, we discuss two central policy-related themes in a formative phase. Some concluding remarks are given in section 6.

2. Rationale for policy and how to find the key policy issues?

The theoretical foundation of industrial, trade and technology policy normally rests on the notion of 'market failures', i.e. the failure of market mechanisms to reach an optimal solution to an economic problem. For three reasons, this is an inadequate guide to policymakers in an innovation system context. First, policy cannot have as objective to find a (static) optimum in a dynamic and uncertain world. In such a world, optimality has no role to play. As Metcalfe (1992, p.4) puts it: "...innovation and Pareto optimality are fundamentally incompatible". The phenomena that the concept covers are, however, relevant in such a world. The problems associated with 'market failures' in a dynamic context relate to their role in, and impact on, the process of industrial transformation. They need, therefore, to be analyzed with respect to their influence on a range of issues related to dynamics, in particular that of processes of discovery and generation of variety; entry and selection.

Second, the phenomena labeled 'market failures' which may be caused by the presence of increasing returns to scale and scope, externalities, missing markets, coordination problems, uncertainty etc., are ubiquitous in any SIS and, thus, provide little guidance on how to identify the key policy problems. We cannot, therefore, have 'market failures' as the starting point when we search for the key policy issues. We need another 'filter' to identify the most relevant problems to tackle.

Third, the innovation and diffusion process is influenced not only by market-related phenomena but also by the nature of institutions and networks, i.e. the other components of an SIS. Of course, just as the nature of markets may block or obstruct the formation of an SIS, so can the nature of institutions and networks (Jacobsson and Johnson, 2000). By combining market, institutional, and network 'failures' (or, rather, weaknesses), we also open up for the possibility of 'failures' (weaknesses) at the level of the entire system, i.e. where a system fails to develop or does so but in a stunted way (Carlsson and Jacobsson, 1997b).

In two previous papers (Carlsson and Jacobsson, 1997b; Jacobsson and Johnson, 2000), we have suggested that policymakers should abandon the 'market failure' approach and instead search for *system weaknesses*. These may be features of actors, markets, institutions and networks that may block or obstruct the evolution of an SIS.

We tried to address the policy problem by specifying a set of policy issues pertaining to possible 'generic' system weaknesses. These may be particularly important to tackle in the process of emergence of a new system (Carlsson and Jacobsson, 1997; Jacobsson and Johnson, 2000; Jacobsson and Bergek, 2004), and require the application of *systemic instruments*, as distinct from those which primarily focus on individual organizations or bilateral relations (Smits and Kuhlmann, 2002).[5] Safeguarding of variety is such a key policy issue in the face of uncertainty; formation of 'prime movers' is vital in the formative phase; the formation of new networks may be required to enable an alignment of actors' expectations and coordination of their investment;[6] articulation of demand[7] is required to form markets and induce firms to enter etc.

Potentially 'generic' policy issues are, however, of little guidance for policymakers dealing with a specific sectoral innovation system, e.g. salmon farming in Chile or mobile phone data in Sweden. As Rodrik (2004, p. 14) argues, policy has to focus on specific activities, (e.g. a new technology, a particular kind of training, a new good or service) rather than on a sector per se and should be thought of as "...a process designed to elicit areas where policy actions are most likely to make a difference" (Rodrik, 2004, p. 25). As mentioned above, these areas differ between industries and change over time and, therefore, require the application of non-uniform and often a wide range of policies. Indeed, Katz' (2004, p. 29) concludes from a study of the successful evolution of salmon farming in Chile that "...it is the diversity of roles the State has played affecting industry's behavior what strikes as the major lesson". The relevant issue then is how policymakers can, ex ante, identify those activities or areas that are of critical importance to the dynamics of a specific SIS. In what follows, a framework is outlined that will allow us to systematically identify system-specific weaknesses in emerging innovation systems and provide guidance to policymakers who seek to identify the key policy problems.

3. Functional analysis as a tool for finding the key issues and policy goals[8]

An SIS is made up of components (actors, networks and institutions) that in some way 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).[9] We propose that if an SIS is to evolve and perform well, seven functional requirements must be fulfilled. These functions have been identified through reviewing the literature on innovation systems and through an experimental application of the framework to a number of SIS.[10]

The main advantage with a functional analysis is that we can separate structure from content – the focus is on 'what is actually happening' in the SIS rather than on what the components are (the 'goodness' of which is difficult to evaluate). Indeed, industrial development, for advanced or for catching-up countries, does not involve following one path only but is achieved in different ways in different contexts.[11] A further advantage is that we can formulate policy problems in functional terms, i.e. 'what do we think should be happening that is not?' In what follows, we will outline the content of these seven functions.[12]

1. Knowledge development and diffusion

This is the function that is normally placed at the heart of an SIS in that it is concerned with the knowledge base of the SIS (globally) and how 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 that knowledge is diffused and combined in the system.

2. Influence on the direction of search

If an SIS is to develop, a whole range of firms and other organizations have to enter into it. These do not only have to have the ability to identify new opportunities but there must also be sufficient incentives or pressures for them to undertake investments in the SIS. The second function is the combined strength of factors influencing the search and investment behavior.[13] 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, beliefs in growth potentials, regulations, articulation of demand by leading customers, technical bottlenecks etc. Frequently, there is a need to coordinate investments between firms. For instance, a shift to fuel-cell-powered automobiles requires a simultaneous investment in development and production of fuel cells, fuel-cell-driven cars, production of energy carriers for fuels cells, 'petrol stations' for fuel cells, etc. Coordination then requires that a range of firms supplying complementary products or services are influenced in their respective search and investment processes.

3. Entrepreneurial experimentation

The origin of an innovation system can be traced back to a whole range of factors and circumstances, such as an abundance of skilled labor (Breschi and Malerba, 2001; De Fontenay and Carmell, 2001), unique university research expertise (Porter, 1998), competence in related industries (Porter, 1998), advantageous geographic location (Feldman and Schreuder, 1996) or abundance of natural resources (Katz, 2004). These 'triggering factors' operate, however, only if there are entrepreneurs who conduct experiments, delving into uncertain markets and technologies and challenging institutions. These uncertainties are a fundamental feature of technological and industrial development. From a social perspective, the way to handle these is to ensure that many entrepreneurial experiments take place.[14] These experiments imply a continuous 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. An SIS without a vibrant experimentation will stagnate and, indeed, without the initial experiments, it will not be formed.

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 as are the availability of complementary products and services.

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.

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 organizations 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 SIS and the institutional frameworks associated with them.

6. Resource mobilization

As an SIS evolves, a range of different resources needs to be mobilized. These resources are of different types: technical, scientific, financial, etc. Hence, we need to understand the extent to which the SIS is able to mobilize human capital, financial capital and complementary assets.

7. Development of positive externalities

As markets go beyond the first niches, there is an enlarged space in which the emerging system can evolve and the functions be strengthened. Entry of firms is central to this process.

First, each new entrant brings knowledge and other resources into the SIS, strengthening the 'resource mobilization' function. 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 'influence of the direction of search' and 'market formation' functions. Third, new entrants may, by their very entry, legitimize 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 positive externalities on other firms, established as well as new entrants. Further externalities may arise due to the co-location of firms. Marshall (1920) discussed economies that were external to firms but internal to a location. Developing his ideas, Audretsch and Feldman (1994) and Krugman (1991) outlined three sources of such economies:[15]

- Emergence of pooled labor markets, which strengthens the 'knowledge development and diffusion' function 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 labor unfolds, costs are reduced and further 'knowledge development and diffusion' is stimulated by specialization and accumulated experience.[16]

- Information flows and knowledge 'spill-overs', contributing to the 'knowledge development and diffusion' function.

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 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 positive externalities. This function is therefore not independent, but rather one which indicates the dynamics of the system.[17]

The functional pattern,[18] i.e. how (the extent to which) they are filled, can be analyzed empirically. This was first demonstrated in Bergek and Jacobsson (2003) and in Jacobsson et al., (2004), where analyzes of functional patterns were used to understand the evolution of two SIS in the energy field (wind power and solar power).

An empirical analysis of a current functional pattern provides policymakers with an understanding of which are the weak functions, which implies that system weaknesses can be expressed in functional terms. Functions, not 'market failures' can therefore become a first 'filter' for policymakers in specifying the key policy issues. We suggest, moreover, that the concept of a functional pattern may also be helpful for specifying the goals of policy and the key obstacles for reaching those goals.

We suggest that it is possible, and useful, to discuss in terms of a 'process goal' for policy which could be formulated in terms of a desirable functional pattern, rather than in the final outcome, i.e. a particular rate of diffusion or growth. Hence, instead of thinking in terms of moving from point A to point B, where B is specified in terms of a given competing design, application or volume of economic activity, policy goals that are subjected to fundamental sources of uncertainty,[19] policymakers could think in terms of intervening to strengthen weak functions, e.g. broaden the knowledge base or promote entrepreneurial experiments. 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 in the long term, and what is desirable to achieve, is very high.[20]

With a functional analysis, it is also possible to identify factors (and actors), which influence the ways in which functions are currently fulfilled; these factors either induce or block the strength of the functions. Blocking mechanisms, or key obstacles for reaching policy goals, may be found in the actors, institutions and networks as well as markets (Carlsson and Jacobsson, 1997; Bergek and Jacobsson, 2003; Johnson and Jacobsson, 2000; Kemp et al., 1998; Unruh, 2000 and Walker, 2000). It is these concrete bottlenecks or critical points, i.e. system weaknesses in structural terms, which then may be subject to scrutiny by policymakers, and these constitute the second 'filter' for policymakers. Some of these may be in the form of 'market failures', including large elements of uncertainty, but others may lie in features of institutions and networks. Hence, the relevant system-specific weaknesses come out of the functional analysis – with such an analysis we make explicit the reasons for choosing the key policy issues to focus on.

4. Functional analysis in a formative stage

In a dynamic world, we would expect that 'what is actually happening in an SIS', and the precise character of possible system weaknesses, alter as the system evolves. In order to identify the sources of system weaknesses, we therefore need to understand how SIS emerge and evolve, i.e. we need to describe the overall pattern of the 'dynamics of innovation systems'. It is common to think of such an evolution in terms of a movement between different phases. *Drawing on a wider set of studies in economics of innovation, political science, population* ecology and management of technology, we will briefly explore the nature of an early, and formative, phase. We will then present an ex post analysis of the functional pattern in this phase in the German case of the SIS centered on solar cells. We conclude the section with an analysis of the Swedish SIS centered on 'IT in home care' where we make an ex ante link between functional patterns and specific policy issues.

4.1 A formative phase[21]

Some characteristics of a formative phase may be found in the literature on industrial life cycles (e.g. Afuah and Utterback, 1997; Utterback and Abernathy, 1975; Van de Ven and Garud, 1989; Utterback, 1994; Klepper, 1997; Bonaccorsi and Giuri 2000). It emphasizes the existence of a range of competing designs, small markets, many entrants and high uncertainty in terms of technologies, markets and regulation. We need, however, to understand the conditions under which this formative stage, with all its uncertainties, emerges in a specific country or region. We will outline four key features of such processes. These are institutional changes, market formation, the formation of SIS-specific advocacy coalitions, and the entry of firms and other organizations.

First, as emphasized in the literature on 'economics of innovation' institutional change is at the heart of the process (Freeman and Louca, 2002). It includes alterations in science, technology and educational policies. For instance, in order to generate a range of competing designs, a prior investment in knowledge formation must take place and this usually involves a redirection of science and technology policy well in advance of the emergence of markets. Institutional alignment is also about the value base (as it influences demand patterns), market regulations, standards, tax policies as well as much more detailed practices which are of a more immediate concern to specific firms, as discussed, for instance, by Maskell (2001).

The specific nature of the institutional framework influences access to resources, availability of markets as well as the legitimacy of a new technology and its associated actors. As argued in the literature of both 'innovation systems' (e.g. Carlsson and Jacobsson, 1997) and 'transition management' (Rotmans et al., 2001), the nature of the institutional framework may therefore act as one of many mechanisms that either opens up for or obstruct the emergence of a formative phase. Firms, therefore, compete (and collaborate) not only in the market for goods and services but also to gain influence over the institutional framework (Van de Ven and Garud, 1989; Davies, 1996).

Second, institutional change is often required to generate markets for the new technology. The change may, for instance, involve the formation of standards, such as the Nordic telecommunication operators' decision to share a common standard (NMT) for mobile telecommunications. In the formative phase, this normally involves exploring niche markets, markets where the new technology is superior in some dimension. These markets may be commercial and involve unusual selection criteria (Levinthal, 1998) or involve a government subsidy. A 'protected space' for the new technology may serve as a 'nursing market' (Ericsson and Maitland, 1989) where learning processes can take place and the price/performance of the technology improve (see also Porter, 1998). Nursing markets may, through a demonstration effect, also influence preferences among potential customers. Additionally, they may induce firms to enter, provide opportunities for the development of user-supplier relations and other networks, and, in general, generate a 'space' for a new SIS to evolve in.

The importance of early markets for learning processes is not only emphasized in management literature but also in the policy oriented literature on 'Strategic Niche Management'. A particularly clear statement of this is found in Kemp et al. (1998, p.184):

> Without the presence of a niche, system builders would get nowhere... Apart from demonstrating the viability of a new technology and providing financial means for further development, niches help building a constituency behind a new technology, and set in motion interactive learning processes and institutional adaptation... that are all-important for the wider diffusion and development of the new technology.

Third, whereas individual firms, and related industry associations, may play a role in competition over institutions (Feldman and Schreuder, 1996; Porter, 1998), such actors may be but one part of a broader constituency behind a specific technology. The build-up of a constituency involves the 'entry' of other organizations than firms. It may involve universities but also non-commercial organizations (e.g. Greenpeace). Unruh (2000, 823) underlines the existence of a range of such organizations and the multitude of roles they play.

> ...users and professionals operating within a growing technological system can, over time, come to recognize collective interests and needs that can be fulfilled through establishment of technical... and professional organizations... These institutions create non-market forces... through coalition-building, voluntary associations and the emergence of societal norms and customs. Beyond their influence on expectations and confidence, they can further create powerful political forces to lobby on behalf of a given technological system.

The centrality of the formation of constituencies is well recognized in the political science literature, in particular in the literature on networks (Marsh and Smith, 2000; Rhodes, 2001). Sabatier (1998) and Smith (2000) argue that advocacy coalitions, made up of a range of actors sharing a set of beliefs, compete in influencing policy. For a new technology to gain ground, SIS-specific coalitions need to be formed and to engage in wider political debates in order to gain influence over institutions and secure institutional alignment. As part of this process, advocates of a specific technology need to build support among broader advocacy coalitions to advance the perception that a particular technology, e.g. solar cells or gas turbines, answers wider policy concerns. Development of joint visions of the role of that particular technology is therefore a key feature of that process. Hence, the formation of "political networks" sharing a certain vision and the objective of shaping the institutional set-up is an inherent part of this formative phase.[22]

Fourth, the entry of new firms is central to the transformation process. Each new entrant brings knowledge, capital and other resources into the industry. New entrants experiment with new combinations, fill 'gaps' (e.g. become a specialist supplier) or meet novel demands (e.g. develop new applications). A division of labor is formed and further knowledge formation is stimulated by specialization and accumulated experience (e.g. Smith, 1776; Young, 1928; Rosenberg, 1976). Finally, early entrants raise the returns for subsequent entrants, and for incumbents, in a number of additional ways, as was elaborated on above.

4.2 An ex post functional analysis of an SIS in a formative phase-the German solar cell case

We will illustrate what may 'actually be going on' in a formative phase with the German case of solar cells (see Jacobsson et al., 2004 and Jacobsson and Lauber, forthcoming). We will describe the emergence of that SIS in functional terms; how the functions were driven by changes in structural components of the SIS and how the functions interlocked and began to drive the system forward in a (partly) self-reinforcing way.

Beginning in the end of the 1970s, institutional changes occurred which began to open up a space for solar power. Knowledge development was fostered by Federal RDD programs that provided opportunities for universities, institutes and firms to search in many directions, which was sensible given the underlying uncertainties with respect to technologies and markets. In the period 1977-89, as many as 18 universities, 39 firms and 12 research institutes received federal funding. Although the major part of the research funding was directed towards cell and module development and the prime focus was on one particular design, that of crystalline silicon cells, funds were also given to research on competing designs; i.e. to several thin-film technologies. In addition, funds were allocated to the exploration of a whole range of issues connected to the application of solar cells, such as the development of inverters.

The first demonstration project took place in 1983. In 1986, it was followed by a demonstration program which by the mid-1990s had contributed to building more than 70 larger installations for different applications. The demonstration program had only a minor effect in terms of market formation. However, it 'influenced the direction of search' among smaller firms and led to a degree of entrepreneurial experimentation which meant that it was effective as a means of enhancing knowledge development in terms of application knowledge 'downstream'. Resource mobilization took place not only in the form of Federal funding but also in terms of investments by these smaller firms as well as in four larger firms which had entered into solar cell production proper. These larger firms were particularly important as they accepted large losses over a sustained period of time.

The nuclear accident in Chernobyl in 1986 had a deep impact in Germany. The Social Democrats committed themselves to phasing out nuclear power; the Greens demanded an immediate shutdown of all plants. Also in 1986, a report by the German Physical Society warning of an impending climate catastrophe received much attention, and in March 1987 Chancellor Kohl declared that the climate issue represented the most important environmental problem. As a consequence, there was a consensus among political parties to foster renewables (institutional change in terms of value base) which simplified a subsequent process of legitimation of solar power. A second program, the 1.000 roof program (institutional change), for market formation and knowledge development (applied) was initiated in 1990, this time focused on small solar cell installations.

Here we can discern a first link from the initial investments in a knowledge and actor base to (further) market formation in that this base generated an opportunity for policymakers to respond to the perceived environmental threats.

Whereas the 1,000 roof program was successful, the *market formation* that it induced was not large enough to justify investments in new production facilities for the solar cell industry, in particular as the industry was running with large losses. The industry now expected that there would be a follow-up to the 1,000 roof program, but no substantial program emerged. If the industry was to survive, market formation had to come from other quarters than the Federal level. This led to intensified efforts to mobilize other resources, a process which demonstrated the politics of legitimation.

The most important help came from municipal utilities. In 1989 the federal framework regulation on electricity tariffs – the tariffs themselves are set at the *Länder* level – was modified in such a way as to permit utilities to conclude cost-covering contracts with suppliers of electricity using renewable energy technologies. On this basis, local activists together with representatives from a number of interest organizations formed, with industry, an SIS specific advocacy coalition and petitioned local governments to enforce such contracts on the utilities. After much effort, most *Länder* allowed such contracts, and several dozen cities opted for this model, including Aachen and Bonn. Due to this and other[23] initiatives, market formation did not come to a halt at the end of the 1,000 roofs program.

Again, we can see a link from early investments to market formation. In addition, at this point, the development of the SIS began to characterized by cumulative causation, i.e. a strengthened market formation began to impact on the other functions, which through a subsequent feed-back loop, strengthened market formation even further. In particular, we want to point to two sequences.

First, a number of new, often small, firms entered and enlarged the SIS, strengthening resource mobilization. Among these, we find both module manufacturers and integrators of solar cells into facades and roofs, the latter moving the market for solar cells into new applications. Individual firms were 'first movers' into new applications and provided positive external economies to follower firms in that they made visible new business opportunities; they reduced uncertainties and 'influenced the direction of search' of other firms. As a consequence, the range of entrepreneurial experiments was broadened; knowledge development (applied) was strengthened, as was market formation.

Second, the large number of cities with local feed-in laws revealed a wide public interest in increasing the rate of diffusion – the legitimacy of solar power was made apparent. Various environmental organizations could point to this interest when they drove the process of legitimation further. Lobbying by the German solar cell industry was also at this point intensified and industry representatives argued that to continue production in Germany without any prospects of a large home market would clearly be questionable from a firm's point of view. A promise of a forthcoming market formation program was then given and two large firms decided to invest in new, and large, plants in Germany; resource mobilization was dramatically strengthened.

Two sets of issues are raised with this example. First, it is possible and useful to analyze the dynamics of an SIS in functional terms, in addition to in structural terms. Although the sequence of development of functions in this particular case cannot be said to be typical (simply due to an absence of case studies), it is probably not atypical for the process of emergence of an

SIS in a leading country. The most interesting aspect of the sequencing lies in how the functions begin to strengthen each other, i.e. when positive feed-backs emerge and begin to develop through cumulative causation (Myrdal, 1957). The ultimate objective of policy could be argued to enable such a process to be set in motion (Jacobsson and Bergek, 2004)

Second, in retrospect, the main system weaknesses in functional terms in this particular SIS in its formative phase did not lie in knowledge development or in entrepreneurial experimentation but in market formation and legitimation. In a 'bottom-up' process, activists, firms, interest organizations and politicians at the *Ländern* level drove a process of legitimation with the aim of changing the institutional framework (institutional weaknesses) to open up a larger market space. Eventually, the 'bottom-up' process was successful and with the forthcoming programs, the SIS shifted into a growth phase (as from 1998).

4.3 Functional patterns and policy issues – the case of 'IT in home care' in Sweden

- We will now proceed with a brief illustrative example of how functional analysis has been applied to the formative phase of an SIS in Sweden for the purpose of identifying the current key SIS-specific policy issues.[24] Less emphasis is given to the descriptive part and more to the identification of key policy issues. The SIS is 'IT in home care' and is defined by the application of a generic technology (IT) to a particular application: care of elderly and ill people in their homes instead of in a hospital.[25] For a number of reasons (demographic, public sector funding restrictions, technological opportunities etc), this is an SIS which is thought of as having a large growth potential. However, the SIS is still in a formative phase, as judged by, e.g., the following structural features:
- There are many competing experiments that are linked to specific IT platforms (no standards and high technical uncertainty).
- The number of firms supplying IT solutions is small.
- Markets are small, with high uncertainties, e.g. with respect to applications and choice of software
- The 'advocacy coalition' for the SIS is weak
- The demand is poorly articulated by customers with poorly developed competence

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

- Knowledge development: pilot projects in some of the 290 counties and 21 country councils
- Market formation: local pilot projects give 'nursing markets', albeit fragmented.
- Influence the direction of search: government R&D funding, opportunities to find new markets, awards
- Entrepreneurial experimentation: a few IT firms have developed solutions
- Resource mobilization: EU and government R&D funding, some co-funding by firms, poor adjustment by the higher educational sector
- Legitimation: partly underdeveloped legitimacy, especially among care providers
- Positive externalities: early stage of cluster formation in three cities

The current functional pattern is shaped by both inducement and 'blocking' mechanisms, where the latter are particularly important to understand from a policy perspective. Figure 1 outlines five of the functions and links a set of 'blocking mechanisms' to these. 'Market formation' is blocked by as many as four factors: absence of standards and three factors that reflect poor awareness and competence among potential customers and an associated lack of knowledge among suppliers of IT solutions of customer needs. The main 'system weakness' lies in this function. Additionally, 'entrepreneurial experimentation' and 'influence the direction of search', are both blocked by two factors. [26, 27]

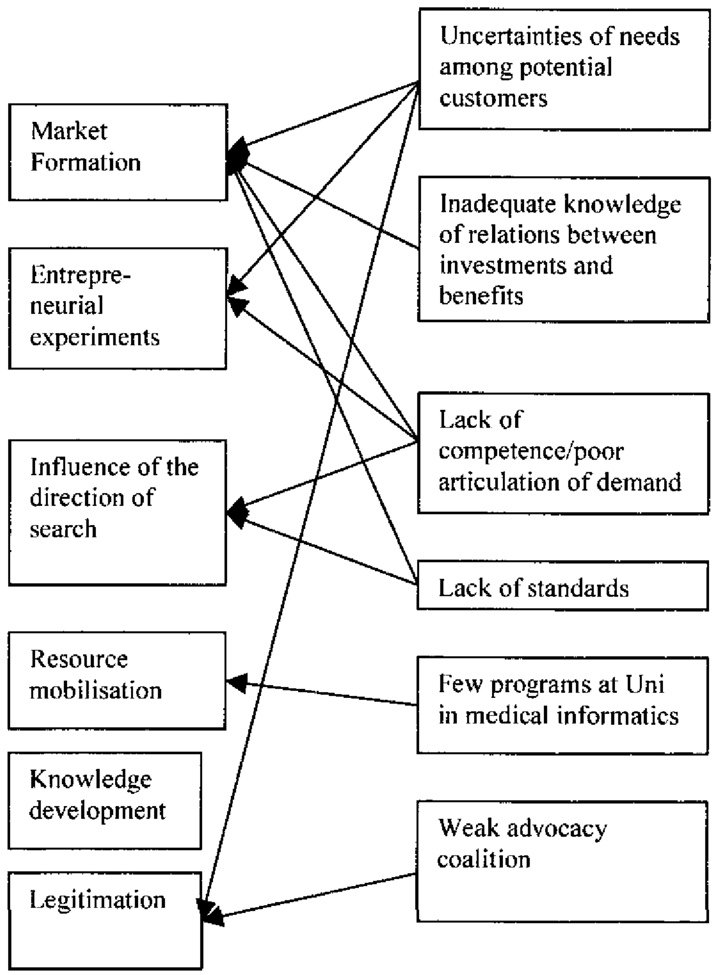
In this case, the blocking mechanisms are manifold and powerful and each of these refers to 'system weaknesses' in structural terms (as indicated in bold below). Our identification of these blocking mechanisms and system weaknesses lead us to formulate six policy issues. First, an obvious policy issue is how to develop standards (**institutional weakness**) so as to move from a fragmented market of 290 local councils and 21 county councils.

A second policy issue is how to raise user competence (**market weakness**) so that demand is articulated and uncertainties reduced for potential suppliers. 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 organizational boundaries **(market weakness)** -'market formation' is enhanced and b) diffuse knowledge of the outcome of early experiments (**network weakness**) - which reduces uncertainties further with above mentioned potential consequences.

A fourth may be how to support experimentation with new applications so as to reduce the level of uncertainty of needs (**market weakness**) – which strengthens 'market formation', broadens 'entrepreneurial experimentation' and enhances 'legitimation' of "IT in home care". A fifth lies in altering research and education at Universities (**institutional weakness**)[28] so as to allow for a 'resource mobilization' in terms of staff with relevant background. A sixth may be to support a weak 'advocacy coalition' (**network weakness**) so that it can improve the process of 'legitimation'.

Hence, by analyzing the functional pattern of the SIS ('what is actually going on'), we can identify the key blocking mechanisms and the associated system weaknesses in structural terms that, in turn, can be the focus of policy.

Figure 1
Functions and blocking mechanisms in the case of "IT in home care".



5. A 'catching-up' perspective on functional analysis and capabilities in the 'formative stage'

In this section we will discuss 'functional analysis' from a developing-country perspective where industrialization is less focused on developing SIS that are new to the world and more on catching–up in an SIS that is already established elsewhere. We will begin by supplementing the discussion above of features in a 'formative stage' with one focused on the shift over to a growth phase simply since 'catching-up' countries often enter into a (local) formative phase when the leading countries are moving into such a growth phase. The conditions of the (global) SIS into which they enter are, therefore, highly relevant and we will emphasize that uncertainties remain large in this phase and that advanced capabilities are required to pursue a useful policy.

We will then initiate a discussion on how the proposed framework might be applied to a catching-up situation. We will start by using the literature to illustrate how policy has handled functional requirements in three countries and in different industries/SIS. The brief illustrative examples come from heavy machinery industry in the Republic of Korea, aerospace and steel in Brazil and from salmon farming in Chile. In the two former cases, a competitive advantage was created with heavy investments over a long period of time (Jacobsson, 1986; Jacobsson and Alam, 1994; Frischtak, 1994; Dahlman and Fonseca 1993; Lim, 1997; Broad et al., 2005) whereas the latter represents a case of a realization, albeit not 'automatic', of large 'natural rents' (Katz, 2004). We follow with an analysis of two themes that are particularly relevant for discussing policy in a formative phase. The first theme is the pattern of sequencing in terms of the evolution of a functional pattern and the associated need for policy intervention. The second theme is the length of the learning period.

5.1 Uncertainties in the growth phase

A shift from a formative into a growth phase may occur when investments have generated a large enough, and complete enough system for it to be able to 'change gear' and begin to develop more fully in a self-sustaining way (Carlsson and Jacobsson, 1997; Porter, 1998). As it does so, a chain reaction of powerful positive feedback loops may materialize, strengthening a process of cumulative causation.[29] Indeed, as pointed out long ago by Myrdal (1957), these virtuous circles are central to a development process – as these circles are formed, the diffusion process becomes increasingly self-sustained and characterized by autonomous dynamics (Rotmans et al., 2001).[30]

Whereas some literature emphasizes a reduction of uncertainties as an industry, or SIS, moves into a growth phase, we would like to underline that not only are the conditions for 'take-off' extremely difficult to predict (which is really important for those who contemplate an attempt to 'catch-up') but so is the direction that the SIS takes in its evolution; the outcome of the 'autonomous dynamics' is unpredictable (i.e. how will the SIS evolve into which a catching-up country attempts to enter?)

A 'change in gears' has often been associated with, or even driven by, a technological discontinuity, such as in the case of the machine tool industry in the wake of the incorporation of microprocessor-controlled CNC units (Jacobsson, 1986). Sometimes, such discontinuities are enabled by changes in the regulatory framework - the Nordic innovation systems in mobile telephony moved into a growth phase with the European GSM standard. Also in other cases, alterations in the regulatory frameworks have triggered a set of actions and reactions and propelled the system forward. In the case of wind turbines in Germany, for example, it was a combination of a vast demonstration-cum-market-formation program (the 250 MW program in 1990) with a new pricing policy for electricity which led to a rapidly growing market (Bergek and Jacobsson, 2003). A change in gears is also often associated with the exploitation of new segments/applications. Indeed, the diffusion of a new technology can be seen as an exploration of a whole series of niches/segments, including that which opens up mass markets. In between the very early niches, and the 'killer application', we may find markets that provide 'bridges' to the mass markets (Andersson and Jacobsson, 2000; Geels, 2002).[31]

Whereas we know the importance of these factors, we can not predict, in the individual SIS case, the effects on that SIS of discontinuities, regulatory changes and the exploitation of new segments. What we know, though, is that we can not expect initial conditions to be stable, all evidence instead pointing to continuing fluidity and uncertainty[32] in the evolution of an SIS. We will point to two brief illustrative examples.

The first is the Korean case of machine tools (Jacobsson, 1993). One particular firm, Daewoo Heavy Industries not only entered at a time when computer-numerically-controlled (CNC) machine tools began to substitute for conventional machine tools, but at a time when the global CNC machine tool industry shifted from a formative to a growth phase, with a dramatic rise in volumes of sales, associated scale economies and rising entry barriers. Consequently, the resources required for catching up and the length of the learning period to foster the required capabilities rose substantially from those estimated at the initiation of the venture. Catching-up is, thus, complicated since the international industry forms a 'moving target'.[33]

The second case, which illustrates another type of uncertainty (choice of technology) is found in Mazzoleni's (2005) analysis of the Brazilian steel industry where there was a choice to follow the developed countries in a technological discontinuity to technologies based on coke, mineral oil or electric energy in the 1930s, or to stay with the 'dated' charcoal technology and pursue an own technical development aiming at up-scaling that technology.

Hence, whereas the emphasis of the life-cycle literature is on uncertainties in terms of a range of competing designs, markets and regulation in the formative phase, other uncertainties matter more in a catching-up situation.[34] The nature of these, however, are such that the properties of an SIS still emerge in an open-ended process, the results of which are difficult to foresee – as are the long-term outcomes of any particular policy intervention. Myrdal's process of 'cumulative causation' is hard to predict, but possible to follow in real time, if adequate capabilities are in place (Jacobsson and Bergek, 2004).

As emphasized in the contingency theory of management of product development, uncertainty implies a shift from planning to experience-based processes, where the latter are more exploratory and guided by real-time experience (Eisenhardt and Tabrizi, 1995).[35] These uncertainties and the need for SIS-specific policies suggest that advanced policy capabilities are required.[36] Indeed, a major contribution of early formation of advanced capabilities in the Escola de Minas in Brazil lay in making available technically competent personnel for local and federal bureaucracies (Mazzoleni, 2005). Yet, such capabilities are normally in short supply and constitute a binding constraint to pursuing SIS-specific policies. Such policies should, therefore, be preceded by efforts to build advanced policy capabilities and to a choice of which sectors to focus on (Hausmann et al., nd).

5.2 Functional requirements and policy in 'catching-up' cases – evidence from the Republic of Korea, Brazil and Chile

Infant industry development is a matter of resource creation, including capabilities, within risk-taking firms and in supporting organizations, to realize a vision of going beyond established lines of production. For an individual firm to succeed in such a venture, and for a new SIS to be formed, the seven functional requirements need to be fulfilled. We will discuss these in a formative phase, referring to some successful cases (Korean machinery industry, Brazilian aerospace and steel industries and Chilean salmon farming), and note how policy has addressed system weaknesses in functional terms.

Entrepreneurial experimentation is vital to identify new business opportunities and to diffuse information[37] about these to imitators (possibly leading to cluster formation), even if they are not new to the world. As Rodrik (2004, p. 9) puts it, "What is involved is not coming up with a new product or process, but 'discovering' that a certain good, already well established in world markets, can be produced at home at low cost".

Such experimentation does not, however, necessarily come about automatically. Hausmann et al., (nd) argue that markets are good at signaling the profitability of already existing activities but not of uncovering the profitability of those that might exist. They also point to the abundance of informational externalities where possible losses by local 'first movers' are private but gains are socialized. Under these conditions, investments in new activities are likely to be smaller than desirable.[38]

In the classic book on Korean industrialization, Jones and Sakong (1980) explained how government attempted to increase variety and experimentation through influencing the direction of search. The means was to manipulate the perceived opportunity set of business - 'field augmentation' - so that they would enter new areas for business. As Jones and Sakong (1980, p. 83) explain: "Field augmentation... operates through expanding information about existing opportunities. The controlee/the firm considers his perceived opportunity set that includes only a finite number of feasible alternatives, due to limited information. The controller/the government can expand the decision-maker's perceived opportunity set by filling this information gap."

This was achieved in a number of ways. An illustrative case in point was the Government R&D Institute ETRI which not only supplied the integrated circuit industry with its early designs but played a catalytic role in demonstrating that advanced integrated circuits could be made in the Republic of Korea (Jacobsson and Alam, 1994, p. 175). This case, where initial advanced capabilities are formed in the Institute sector, is not unique. Lim (1997), for example, provides us with more evidence from the case of numerically controlled machine tools in the Republic of Korea.

Similarly, Katz (2004, pp 29-30) argues that: "In the case of salmon, the *perception* that large natural rents are potentially present... required the public sector to take a proactive stance in favor of inducing the erection of salmon farming production capacity...it certainly exercised a crucial catalytic role...showing that '*it could be done*'." (our emphasis). This involved, inter alia, starting the first commercial salmon farming operation in Chile (Katz, 2004, p. 6). Finally, Mowery (2005) reports that the first experimental facility for semiconductors in Taiwan Province of China was set up by ERSO, which was part of the Industrial Technology Research Institute (ITRI).

While catching-up countries have access to imported technology, knowledge development involving firms and 'infrastructure' is still vital. Indeed, catching-up involves substantial technological activities. Daewoo Heavy Industries, for instance, had to design six CNC lathes before they received an initial acceptance from domestic customers. Also farming salmon involves firm specific knowledge development. As Katz (2004, p. 19) explains: ...the ecological and environmental parameters strongly vary across locations. Water quality, temperature, salinity and a vast list of ecological variables related to the micro organisms that populate each particular lake and marine location vary..."

Some of the knowledge development occurs at institutes and in universities. In Brazil, the origin of the international success case of the aeroplane manufacturer Embraer (now the world's fourth-largest airline manufacturer, see Broad et al. (2005)) dates back to (at least) the establishment of the School of Aeronautics Engineering, transformed to the Instituto Tecnológico da Aeronáutica in 1946 and to the formation, in 1950, of the Centro Técnico de Aeronáutica (CTA). By 1988, the former had graduated 800 aeronautics engineers, many of which worked with aircraft design in the latter (Frischtak, 1994). Similarly, the origin of the Brazilian steel industry dates back to the foundation of the Escola de Minas in 1876 (Mazzoleni, 2005).

In Chile, public sector agencies and, especially, Fundación Chile (private/public) played a vital role in the formative phase of salmon farming (Katz, 2004). Government agencies in Chile also established legal frameworks that later complied with international standards (Katz, 2004, p. 10), which, of course, are of vital importance in the food-processing industry. The role of Fundación Chile remains important as knowledge diffuser and as providers of technological assistance to firms who desire to upgrade to a technological more demanding export mix, involving a reclassification of the products into more advanced (and higher priced) classes (Katz, 2004).

The case of salmon farming is not unique in Chile. The foundations of the fruit industry were laid through efforts of the Corporación de Fomento, University of Chile and the National Institute of Agricultural Research (Text on El Salvador, p. 9). Indeed, it even suggested that: "The Chilean fruit industry is almost a textbook example of how public investments in technological expertise combined with private sector dynamism can generate a sustained economic boom" (text on El Salvador p 10). Similarly, INIA (Instituto Nacional de Investigación Agropecuaria) - an agricultural research unit in Uruguay – has played a key role in raising productivity in the agricultural sector (Hausmann et al . nd).

These examples, thus, highlight the importance of knowledge formation not only in manufacturing firms but also in the 'Science and Technology Infrastructure' (Wagner and Reed, 2005). This infrastructure has both private and public components and arises in a process of division of labor and specialization which may generate substantial external economies. As indicated above, a key aspect of this infrastructure is its ability to generate and diffuse knowledge about standards. Whereas standards may be seen as trade costs, it is equally relevant to underline the efficiency enhancing aspects of complying with standards and, most importantly, their potential to reduce reputational barriers to entry. Hence, standard-setting and regulatory frameworks are prime examples of how firms are supported not only in knowledge development but also in their legitimation process in the (world) market.

Again, this is not limited to the obvious case of food processing. In the Republic of Korea, Lim (1997) suggests that a government institute (KIMM) '...contributed to user-producer interaction by testing and evaluation of newly developed machines, which is important if the new machine is to gain credibility in the domestic market.' Hence, a 'neutral' testing organization helped domestic machine tool suppliers in their (local) legitimation process.[39]

Market formation refers to both domestic and foreign markets. In the Korean case, a protected local market was vital in the formation of various SIS in the machinery industry. In particular, quantitative import restrictions were used to limit imports. For instance, in 1983, all of the 63 items classified as machine tools at the CCCN 8-digit level were restricted. For machining centers and CNC lathes, these restrictions lasted until 1988, when these products were put on the import diversification list (Jacobsson and Alam, 1994). The experimental niche markets in the formative phase in leading countries is here replaced by a local market 'space' in which firms are given the opportunity to build up an adequate size and enough capabilities to be able to respond to a subsequent trade liberalization.[40] Similarly, Embraer was supported via protection and military procurement in its early phase. In fact, the first aircraft was designed by members of the CTA. These were then transferred to Embraer when it was set up to supply the military with 80 planes. Not only a local knowledge formation but also a local market formation preceded an international expansion (by many years). It was not until 1997 that civilian aircraft production overtook military aircraft production for Embraer (Broad et al., 2005).

Resource mobilization refers in particular to human and financial capital. Whereas catching-up countries would, by definition, have a shortage of experienced engineers and scientists, they can compensate with a larger volume of 'output' of highly educated people. This refers to both the Bachelor and the PhD level. In the Republic of Korea, the number of graduates with a Bachelor degree in engineering rose from 7,787 in 1977 to 28,726 in 1986 and the number of master's and doctor's degrees awarded in Science and Technology rose from 1,282 in 1975 to 11,376 in 1991 (Jacobsson and Alam, 1994, p. 778).

In the case of Korean machinery industry and also in the Brazilian aerospace industry (Frischtak, 1994, Broad et al., 2005), resource mobilization, in particular, training of engineers has been central to their success, as was the case historically with Germany in the chemical industry (Mowery, 2005) and currently in the case of Ireland (Crafts, 2005). This training was combined with early design developments in firms and a gradual and longer term development of design capabilities. This was also a key element in the development of the Brazilian steel industry (Dahlman and Fonseca, 1993).[41]

Risk capital is another central resource that was amply supplied in the Republic of Korea in the 1970s and early 1980s. A huge financial and risk-absorption scheme was created for the machinery industry in the 1970s. For instance, Daewoo Heavy Industries received US$ 44 million (a large sum in that industry at that time) when it entered the machine tool industry, all at low or negative interest rates. Moreover, the government absorbed the risks of the venture. This funding allowed this new firm, and others, to accumulate capabilities rapidly (Jacobsson, 1986; Jacobsson and Alam, 1994). Similarly, in the case of Embraer, Frischtak (1994, p. 606) underlines the role of the military in providing risk capital: "None of the Embraer's initial projects were financed by the company (they were generally underwritten by the Brazilian Air Force)..."

Finally, as regards positive externalities, we have already pointed to the key role of early experiments in reducing uncertainties (or in generating informational externalities about new opportunities, Rodrik, 2004). In addition, it is useful to underline that the process of legitimation is often obstructed by 'political' factors that need to be handled by organized advocacy coalitions. In the Chilean case of salmon farming, this refers to allegations of dumping in the US where (Katz, 2004, p. 11) "...the efforts to put into fighting the charges and the money spent for that for lobbying in Washington had a positive effect as it made the industry more cohesive". In other words, the firms organized themselves to gain legitimacy in the US market. In the Korean case, there was a fierce battle over the (domestic) legitimacy of the entire machinery and transport industry in the Republic of Korea in the 1980s. Whereas the large Chaebols received strong support (legitimacy) and direction from parts of the government, many argued that it was wasteful to foster these industries and questioned the whole institutional set-up promoting the development of these industries (see Jacobsson, 1993; Jacobsson and Alam, 1994). Eventually, there was a policy shift, but not prematurely.

This brief review of some cases of 'catching-up' illustrates how functional analysis can capture 'what is going on' also in such a situation. It has also demonstrated the multitude of policies that were used to address a range of policy issues in connection with these functions. It clearly suggests that it may be useful to systematically search for and define policy issues in functional terms also in a catching-up situation.

5.3 A note on two policy-related themes in the formative phase

Whereas functional thinking clearly is relevant, several issues need to be explored further if we are to apply functional analysis to a formative phase in a catching up situation. We will introduce and discuss two such issues. The first is that we expect a variety in sequencing and modes of interactions between different SIS. Here we will make a first and very preliminary distinction between the case of exploitation of natural resources and that of development of an SIS centered on complex machinery. The second issue is the length of the learning period, i.e. the length of the period under which a new SIS needs to be fostered.

5.3.1 A variety in sequencing and modes of interaction

As mentioned above, new sectoral innovation systems may have a many different types of origins. These origins give rise to potential advantages which need some kind of 'triggering' to be realized. Drawing on the experiences of economies with abundant natural resources (Chile, Uruguay and El Salvador, Rodrik (2004) and Hausmann et al., (nd) emphasize the importance of a process of 'self-discovery' which essentially involves encouraging experimentation that discovers potential advantages and their associated business opportunities. Hence, entrepreneurial experimentation is likely to be a first step, or one of the first steps, in discovering new opportunities and begin the formation of clusters (via reducing uncertainties for followers and influencing the direction of search). As the Chilean case of salmon farming demonstrates, the initial experimentation may be undertaken by others than members of the business community.

This first step in a sequence needs, however, to be closely followed by other steps. Market formation is, of course, vital. For products such as salmon, that come out of a process in which competitiveness draws on 'natural' advantages, market formation is likely to involve linking up to international markets very early on. In the Chilean salmon case, government played a key role in creating contracts with the Japanese market (Katz, 2004, p. 21). It is likely that knowledge formation in the Science and Technology Infrastructure will have to be pursued in parallel with, or even to an extent, prior to market formation, in particular as regards standards and compliance with safety regulations (legitimation). Setting up SIS-specific research units, such as the INIA in Uruguay, may be part of a policy for knowledge formation. Strengthening the higher educational system in selective areas (resource mobilization) so that is responsive to demands from a growing SIS is, of course, essential.

As was underlined in the case of solar cells in Germany (see section 4.2), these functions are not independent of each others but are so interlinked that, in the best of worlds, the process becomes driven by 'autonomous dynamics' in which the functions are interlocked and in which positive feedback loops materialize. These linkages may take a range of forms. For instance, an initial entrepreneurial experimentation may, as was suggested above, influence the direction of search of other firms; knowledge formation in the Science and Technology Infrastructure and an associated improved legitimation may reduce reputational barriers to entry and further strengthen that function. Cluster formation may subsequently give rise to a number of positive external economies that may strengthen other functions, including entrepreneurial experimentation. It is this dynamics that policy has to focus on, stimulate and adjust to.

The triggering factors and the sequence of interaction would be quite different in complex products such as machine tools, steel, earth-moving machinery and airplanes. Here, the triggering lies in a vision and associated policies to build competitive advantages in SIS that are not linked to the exploitation of natural resources and which are 'distant' from present industrial structure. These policies involve knowledge formation over a sustained period of time (see more below). As Frischtak (1994, p. 603) explains in the case of Embraer: "Embraer's technological development efforts can be characterized as part of a long-term strategy to accumulate knowledge progressively and become proficient in aircraft design and manufacture". Similarly, the case of the Brazilian steel manufacturer USIMAS (Dahlman and Fonseca, 1993) reveals a long term process of knowledge formation which goes from learning to operate foreign made equipment to a development of basic engineering capabilities.

The knowledge formation and resource mobilization (in terms of specialized human capital) preceded the establishment of Embraer by more than two decades and learning at the USIMAS plant by many decades. Mazzoleni's (2005) analysis of the impact of the establishment of the Escola de Minas in Brazil in the 19th century illustrates the wide range of ways in which students and staff contributed to the formation of a Brazilian SIS in steel making.[42] Similarly, Mowery (2005, p. 26) reveals the role of ITRI (Industrial Technology Research Institute), founded in 1974, as a source of new technology, trained manpower and new firms in the Taiwanese semiconductor industry. Hence, in these cases, as well as in that of Germany in the chemical industry in the 19th century (Mowery, 2005), knowledge formation and resource mobilization preceded, rather than followed, a demand from industry, often by many years.

The examples from the Republic of Korea, Taiwan Province of China and Chile of the catalytic role of non-industrial actors in opening up new business opportunities (as given in the prior section) reveals one value of such an early formation of capabilities. More generally, knowledge formation may be seen as having an optional value and the associated capabilities embody the ability to generate, and eventually, to contribute to the realization of (some of) these options. As Loasby (1998, p. 144) argues:

> "Capabilities are the least definable kinds of productive resources. They are in large measure a by-product *of past activities, but what matters at any point in time is the range of future activities which they make possible. What gives this question its salience is the possibility of shaping capabilities, and especially of* configuring clusters of capabilities, in an attempt to make some preparation for future events, which, though not predictable, may... be imagined" (our italics).

In a catching-up situation, it may be easier to imagine the future use of capabilities than for leading countries. Yet, thinking of capabilities in terms of their optional value may still be pertinent. For instance, Dahlman and Fonseca (1993) make the interesting point that an early learning to 'stretch' capacity evolved into learning of basic engineering capabilities, an option that was perhaps less imaginable in the early phase of the life of the USIMAS steel plant. Even more clearly, when the initial investments in formation of capabilities in Brazil in charcoal-based steel manufacturing were made (Mazzoleni (2005), these could hardly have been imagined to be the basis for the pursuit of Brazilian path towards large-scale production of pig iron that was different from the one that emerged as dominant in the developed countries and for eventual export of such technology to developing countries

Capabilities and lessons from early experiments cannot, however, be expected to be put to use unless other policies make it attractive to invest in the new SIS. In the case of solar cells in Germany, this meant implementing cost-covering regulation, initially in some cities and later nationally. In the case of 'IT in home care' in Sweden, market formation would involve standardization and development of capable customers. In the cases of the Brazilian steel and airplane industries, import restrictions were part and parcel of the policy package. Similarly, in the Korean machinery industry, the main market formation measure was in the form of quantitative import restrictions that opened up a local 'space' for Korean firms in a vibrant economy.

Yet such protective measures have to be temporary. By the mid-1980s, a system weakness became apparent in the form of poorly developed design capabilities (knowledge development) in many machinery firms in the Republic of Korea. Policy aimed at improving this situation not only with an expansion of the educational system (resource mobilization) and R&D programs (knowledge formation) but with a trade liberalization that forced the firms to supplement licenses with own design development.[43] In complex products, a trade liberalization is, however, clearly only one phase in a long process of fostering firms, the success of which depends on how previous policy regimes have succeeded in creating a powerful response capacity among firms, such as the kind seen in the case of hydraulic excavators and machine tools in the Republic of Korea (Jacobsson and Alam, 1994).

The case of the machinery industry in the Republic of Korea (as well as those of solar cells in Germany, 'IT in home care' in Sweden and Chilean salmon farming) also demonstrate the need to organize the members of the infant SIS in order to create legitimacy (locally and internationally) for the SIS, with consequences for market formation, resource mobilization, etc. Building a strong advocacy coalition, and associated legitimacy, is normally a 'bottom-up' process but policy could aid that process in a range of ways, in addition to providing a market 'space'. These may be of technical nature that aims at improving legitimacy, such as employing international standards in the food processing industry or providing 'neutral' testing facilities for machine tools. They may also be of organizational kind, where government may organize the formation of platforms which provide the infant SIS with a meeting place, a forum for exchange of experience and coordination of activities.

This first analysis suggests that it may be useful to think in terms of a typology of patterns of emergence of SIS in catching-up countries, of associated functional evolution and policy options. Yet there are also many similarities between these two cases. A similar reasoning on capabilities as options can well be applied to the case of exploitation of natural resources; the issue of legitimacy is central to both cases and resource mobilization figures prominently in both cases.

5.3.2 The length of the learning period

In the formation of an SIS that is new to the world, the formative phase often lasts several decades or more (e.g. mobile telephony, numerically controlled machine tools, solar cells, steam ships, integrated circuits and video recorders). [44] We would expect 'catching up' to involve a shorter 'learning period', as many of the technical and market uncertainties are solved and as technology can be imported. Yet, as was evident in the above discussion, catching up is complex and involves institutional change, market formation, entry of a range of firms and other organizations and the formation of these into networks of various types. The time scale for this process varies, of course, between different SIS.

In the early to mid-1980s, a common view in the Republic of Korea was that the learning period, even for complex products like construction machinery, ought to be less than ten years. A view that was often expressed in the Republic of Korea was that:

> "Many of the once infant industries that were given blanket protection have grown into uncompetitive adults... the automobile industry... still is not producing cars that meet basic U.S. quality and safety requirements... another example of where protection has not guaranteed success is construction equipment...The Korean products have not been able to compete in price and quality with Japanese equipment (Business Korea, 1984, p. 31).

Today, we can note that in the two industries mentioned, automobiles and construction machinery, the Republic of Korea has successfully carved out a share of the world market. Indeed, in construction machinery, one of two Korean firms (Daewoo Heavy Industries) was acquired by Volvo and was turned into a Center of Excellence for excavators. Clearly, the appropriate time scales involved go much beyond what has been commonly thought.

The case of Embraer in Brazil confirms that the length of the learning period may be counted in decades rather than years (Dahlman and Fonseca, 1993). Perhaps more surprising is Katz's (2004, p. 31) conclusion about salmon farming in Chile: "From inception to 'maturity' and globalization, the process absorbed the best part of two decades at the end of which Chile found itself with a highly efficient salmon farming industry, successfully competing in international markets".

Hence, it is clear that the length of the learning period can be substantial. This implies that policymakers have to be persistent. Yet, they also need to be able to develop the capabilities and tools for monitoring progress and change the direction of experiments as well as the independency and integrity required to terminate some experiments.

6. Concluding remarks

The purpose of this paper was to present an analytic framework, designed to help policymakers identify the key policy issues in a specific SIS and, tentatively, to discuss that framework in the context of a catching-up process. We have focused on the nature of a 'formative' phase in both leading countries and in catching-up countries and provided illustrative examples from six SIS; solar cells in Germany, 'IT in home care' in Sweden, salmon farming in Chile, machinery industry in the Republic of Korea and steel as well as airplanes in Brazil.

We have suggested that a functional analysis can be a useful analytical tool for policymakers in that it helps these to systematically map 'what is going on' in a specific SIS and to explain 'what is going on' in terms of both inducement and blocking mechanisms. Functions are then the first filter, or focusing device, for policymakers. These can then apply policies to strengthen the relevant inducement mechanisms or weaken blocking mechanisms, which then constitute the second filter, or focusing device. With a functional analysis, we make explicit the reasons for choosing the key policy issues to focus on.

As regards needs for future research, we would like to make two suggestions. First, in all but one of the cases, we have provided an ex post functional analysis, whereas in one case we identified the key policy issues today in the Swedish context. It would be useful to undertake, on an experimental basis, a study of that kind in a catching-up case. Second, although we have tried to find commonalities in the process of formation and growth of SIS, we want to emphasize that this does not imply that all innovation systems follow the same development pattern. Indeed, the whole point of the functional analysis is that sectoral innovation systems differ so much in terms of determining factors, time frames, etc., that there are no 'one size fits all' policy implications. Nor is there, however, an infinite variety. It would, therefore, be of interest to study the diverse patterns of formation of SIS in a catching-up context; to elaborate on different sequences in terms of functional development and interaction and to develop a typology.

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Notes

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

[2] Of course, many policies have an impact of a whole range of SIS, e.g. tax policies or exchange rate policies.

[3] The framework can also aid policymakers in assessing the appropriateness of various policy instruments but for reasons of space, we will exclude that aspect.

[4] 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.

[5] This means that we have left the old and sterile debate over the ability of the state to 'pick winners' in the form of individual firms (Carlsson and Jacobsson, 1996). As Stewart and Ghani (1991) rightly pointed out many years ago, the systems view on the innovation process makes us instead focus on the conditions and processes whereby winners are created.

[6] In Carlsson and Jacobsson (1993), we spoke in terms of the role of networks in 'blending visions' or technological expectations.

[7] This point is emphasized in Hekkert et al. (2004).

[8] This section is based on Bergek, et al., (2005).

[9] 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.

[10] See Bergek and Jacobsson (2003); Jacobsson and Bergek (2004); Jacobsson et al., (2004) and Bergek et al., (2005).

[11] See for instance Mowery's (2005) analysis of the differences in paths followed by Korea and Taiwan Province of China in the semiconductor industries.

[12] The description of the seven functions is taken from Bergek et al., (2005). We refer to the source for references to the literature on which this section is built.

[13] This function also covers the mechanisms influencing the direction of search *within* the SIS, in terms of different competing technologies, applications, markets, business models etc.

[14] See also Rodrik (2004) on this point.

[15] In addition to these, they also mention provision of non-tradable inputs specific to an industry.

[16] See Smith (1776); Young (1928); Stigler (1947); Rosenberg (1976); Maskell (2001). For a case study of mobile data in Western Sweden, see Holmén (2001).

[17] We have benefited from discussions with Professor Ruud Smits and Dr. Marko Hekkert on this point.

[18] This concept has no normative connotations but is purely descriptive.

[19] See also Rodrik (2004) on uncertainty and on policy as a process of social learning about problems and goals for policy making.

[20] Process goals have the additional the advantage for policymakers 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.

[21] The following paragraphs are based on Jacobsson and Bergek (2004) and Jacobsson and Lauber (forthcoming).

[22] This is not identical to the cruder 'rent-seeking' behaviour often pointed out in the development literature but an inherent process of alignment of technology and institutions.

[23] Additional help came from some of the Länder, which had their own market introduction programs, the most active being North Rhine-Westphalia. Some states acted through their utilities, which would subsidise solar cells for special purposes, e.g. schools (Bayernwerk in Bavaria, or BEWAG in Berlin).

Some offered "cost-oriented rates" which however remained below the level of full cost rates (thus HEW in Hamburg). Finally, in a major effort, Greenpeace gathered several thousand orders for solar cell rooftop "Cyrus installations".

[24] This case was developed together with Cecilia Sjöberg at the Swedish Agency for Innovation Systems (VINNOVA).

[25] For discussions of how to delineate and focus an SIS, see Carlsson et al., (2003) and Bergek et al., (2005).

[26] We can also see that 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'.

[27] A poor 'market formation' negatively affects both 'entrepreneurial experimentation' and 'influence of the direction of search', that in turn influences 'knowledge development'. This means that the impact of blocking mechanisms is magnified by interdependencies.

[28] Universities are largely in the domain of the government in Sweden and, therefore, weaknesses in the supply of skilled people should be classified as failure in policy.

[29] Above, we saw that a process of cumulative causation may begin already in the formative phase.

[30] All the four features of the formative phase are involved in such dynamics. For instance, the emergence of a new segment may induce entry by new firms, which strengthen the political power of the advocacy coalition and enables further alignment of the institutional framework (which, in turn, may open up more markets and induce further entry etc.).

[31] Such 'bridging markets' allow for larger volumes of production and a series of 'secondary innovations,' in Schmookler's (1966) terminology, both of which may be required before the new technology can become a commodity.

[32] For instance, there is abundant evidence of the extreme difficulties to determine what the initial niches/applications will eventually turn out to be and, even more, what the 'killer application' will be. The steam engine, for instance, was initially seen as a pump and not as a technology to power machinery (Rosenberg, 1996). Uncertainties of this nature often remain long into the life of a new product. In the case of the transition from mini- to microcomputer-controlled machine tools (which took place about two decades after the sale of the first numerically controlled machine tool in the mid 1950's), a few Japanese firms all but out-competed the hitherto leading U.S. firms by exploiting a new segment; the small machine shops. Indeed, the president of the world's largest machine tool firm at that time, Cincinnati Milacron, admitted that 'The segment wasn't as apparent to all of us as it was to them.' (Financial Times, 7 April 1983, cited in Jacobsson, 1986, p. 80).

[33] A similar development took place for the semiconductor and the hydraulic excavator industries (Jacobsson, 1993, Jacobsson and Alam, 2004).

[34] These uncertainties suggest that it may be useful also in a catching-up situation to use functional analysis as a tool to specify policy goals.

[35] See also Hausmann et al., (nd) page 25 for an interesting note on uncertainties and policy.

[36] This applies, of course, also to leading countries; see Jacobsson and Bergek (2004) for a discussion of policy in the field of renewable energy technologies.

[37] The situation is similar to that portrayed in the literature on first mover advantages and imitators, where a first mover opens up new fields for business (see e.g. Lieberman and Montgomery, 1988).

[38] El Salvador gives a set of examples of policies that may enhance experimentation, e.g. subsidising part of the cost of self-discovery.

[39] This was, of course, only a minor element in a fierce battle over the legitimacy of the entire machinery and transport industry in Korea in the 1980s. Whereas the large Chaebols received strong support (legitimacy) and direction, from the Government, many argued that it was wasteful to foster these industries (see Jacobsson, 1993; Jacobsson and Alam, 1994).

[40] This does not preclude a participation in the international market prior to the trade liberalization.

[41] Such knowledge formation was intertwined with the use of foreign technology in Brazil (Frischtak, 1994; Dahlman and Fonseca, 1993) as well as in Korea (Jacobsson and Alam, 1994; Lim, 1997).

[42] These included: investing partners in new firms, technical consultants, technically trained staff in steel making firms, inducement mechanism for foreign firms' investment, provision of staff for local and federal bureaucracies, links to international technical development (Mazzoleni (2005, p. 20).

[43] Katz (2004) points to a similar system weakness in Chile in that the knowledge base is underdeveloped in the salmon farming SIS, including the capital goods industry.

[44] This length of the learning period is also emphasized in a recent study of Israel's 'Silicon Wadis,' which began a rapid period of growth in the 1990s after a history starting in the 1970s (de Fontenay and Carmel, 2001). See also Geels (2002).

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Printed in Austria
V.05-89007—November 2005—100

About the cover illustration:
The graph on the cover, generated by means of fractal geometry model, simulates a pattern formed by three ring vortices playing catch up with one another (also called 'chaotic leapfrogging').

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