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# A framework for guiding policy makers intervening in emerging innovation systems in 'catching up' countries*

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**Abstract**

*This paper presents a framework for guiding policy makers intervening in emerging innovation systems in 'catching up' countries. The process whereby the central policy issues are identified rests on the notion that there are seven key processes, or 'functions', involved in the formation of such systems and that these processes can be empirically studied. A 'functional approach' is argued to be helpful in finding 'system weaknesses' that can act as focussing mechanisms for policy makers. An illustrative case from Germany is followed by an analysis of emerging innovation systems in catching up countries, in particular Brazil, Korea and Chile.*

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## 1. Introduction

For a long time, the rationale behind and scope for policy intervention in the industrialization process has been highly controversial. Yet, it is clear that in industrially advanced countries, policy intervention is part and parcel of larger transformation processes.[1] The intervention is, however, neither of the 'orchestrating' type, nor the conventional 'industrial policy' sort but incorporate a range of activities including those found within science and technology policies, tax policies (e.g. $CO_2$ tax), standardization measures, formation of early markets via e.g. procurement policies etc. In contrast to subsidies of dying industries, such measures are, on the whole, deemed to be legitimate. In a developing country context, it is also '… increasingly recognized that developing societies need to embed private initiative in a framework of public action that encourages restructuring, diversification, and technological dynamisms beyond what market forces on their own would generate' (Rodrik, 2004: 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 and Alam, 1994; Carlson and Jacobsson, 1997a; Rodrik, 2004), i.e. it needs to be selective, but also that it needs to change its content over time (Galli and Teubal 1997; Katz, 2004). It is also widely recognised that industrial development, and public policy associated with it, should be approached from a 'system's view' **(**e.g. Stewart and Ghani, 1991**;** Lundvall, 1992; Carlsson and Jacobsson 1997 a, b; Porter, 1998; Kemp et al., 1998; Lall and Narula, 2004**).** Such a system may have a nation in focus (national innovation system) but for our purpose it is more appropriate to think in terms of a system centred on a particular industry (e.g. solar cells or steel), henceforth labelled an innovation system (IS). How can then policy makers identify the issues that a selective and time-specific policy should aim at resolving with such a system?

The purpose of this paper is to present an analytical framework, designed to help policy makers identify the key policy issues in a specific IS and to 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 phase of the evolution of an IS.[2]

The paper is structured as follows. Section two outlines the ‘systems approach’ and point to a set of problems in identifying the key policy issues using conventional ‘market failure’ analysis. We then proceed, in section three, to present a framework that focus on ‘functions’[3], or key processes, in the evolution of an innovation system. Section four contains the illustrative example of the German IS for solar cells. In section five, we discuss the framework in a ‘catching-up’ context. Using empirical examples mainly from Brazil, Korea and Chile, we illustrate how functional requirements were handled by policy in the capital goods industry and in the salmon farming industry. We proceed to make a tentative distinction between two different patterns of sequencing in the evolution of the key processes, or functions. Some concluding remarks are given in section six.

## 2. Problems in identifying the key policy issues in an innovation system

As is argued in many strands of the literature, the innovation and diffusion process is both an individual and collective act. The determinants of this process are not only found within individual firms; firms are embedded in innovation systems that guide, aid and constrain the individual actors within them. This is a perception shared between scholars in e.g. entrepreneurship (e.g. Van de Ven, 1993), management (e.g. Porter, 1998), economics of innovation (e.g. Bergek and Jacobsson, 2004) and development studies (e.g. Narula and Lall, 2004).

Industrial development, thus, implies the formation and growth of a range of innovation systems centred on specific technologies or industries. Such a system is made up of three components: firms and other organisations, networks and institutions.[4] The *firms* are found within the whole value chain. Other organisations include universities and other parts of the educational subsystem, industry and other professional organizations, bridging organizations, other interest organizations, such as Greenpeace, and government bodies. In the course of the formation of an IS, each new firm that enters the system brings knowledge, capital and other resources into it. 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 labour is formed and further knowledge formation is stimulated by specialisation and accumulated experience (e.g. Rosenberg, 1976). Similarly, other organisations enter the system and enrich it, for instance in the form of universities providing specialised courses, bridging organisations that act as meeting places and interest organisations that promote the IS in the public arena.

The *networks* can be of various types. A first set of networks is learning networks. These can link users and suppliers, related firms (Porter 1998), competitors or university researchers and industry. Networks constitute important modes for the transfer of tacit (Metcalfe, 1992) and explicit knowledge. They also influence the perception of what is possible and desirable, i.e. expectations of the future, which guides specific investment decisions (Carlson and Jacobsson, 1993; Geels and Raven, 2006). A second type of network refers to those that seek to influence the political agenda. These are focussed on in the political science literature (see, e.g. Sabatier, 1998), which argues that policy making takes place in a context where *advocacy coalitions*, made up of a range of actors sharing a set of beliefs, compete in influencing policy in line with those beliefs. As firms and other organisations enter into the IS, these two different types of networks have to be formed, enlarging the resource base of the individual firm (in terms of information, knowledge, technology etc.) and giving the collective a voice in the political arena.

The third element is *institutions*. Institutional alignment is at the heart of the process whereby new IS gain ground (Freeman and Louca, 2002). This refers to changes in the legal and regulatory aspects as well as in norms and culture. Institutions regulate interactions between actors (Edquist and Johnson, 1997) and define the value base of various segments in society (Haveman and Rao, 1997). Institutions also refer to beliefs (cognition) that influence firms' decision in the form of frames that structure learning processes (Geels and Raven, 2006).

The formation of a new IS, thus, involves three structural processes; entry of firms and other organisations, formation of networks and institutional alignment. How can then policy makers identify the key policy issues in the formation and growth of an IS? The theoretical foundation of intervention normally rests on the notion of 'market failures', i.e. the failure of market mechanisms to reach an optimal solution to an economic problem. A number of characteristics of actors and markets are connected to such 'failures'. These include uncertainties and differences in private and social risk aversion, externalities, missing markets etc. For three reasons, this concept is, however, an inadequate guide to policy makers in an IS context.

First, policy cannot have as objective to find a (static) optimum in a dynamic and uncertain world. As Metcalfe (1992: 4) puts its: '…innovation and Pareto optimality are fundamentally incompatible'. The phenomena that the concept covers are, however, relevant in a dynamic context in that they relate to the process of industrial transformation. They need, therefore, to be analysed with respect to their influence on a range of issues related to dynamics, in particular that of processes of generation of variety, entry and selection.

Second, the phenomena labelled 'market failures' are ubiquitous and, thus, provide little guidance with respect to identifying the key policy problems. We can not, therefore, have 'market failures' as the starting point when we search for these. We need another focusing mechanism to identify the most relevant problems to tackle.

Third, the innovation and diffusion process is influenced not only by actors and market-related characteristics but also by the nature of institutions and networks, i.e. the other components of an IS. Of course, just as the nature of actors/markets may block or obstruct the formation of an IS, so can the nature of institutions and networks (Jacobsson and Johnson, 2000; Unruh, 2000; Rotmans et al., 2001). 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, which makes a system fail to develop or to do so in a stunted way (Carlsson and Jacobsson, 1997b).

In two previous papers (Carlsson and Jacobsson, 1997b; Jacobsson and Johnson, 2000), we have suggested that policy makers 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 IS.

We tried to address the policy problem by specifying a set of policy issues pertaining to possible 'generic' system weaknesses that may be particularly important to tackle in the process of emergence of a new system and which 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 an early 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 policy makers dealing with a specific IS, e.g. salmon farming in Chile or mobile data in Sweden. As Rodrik (2004: 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.' 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: 29) concludes from a study of the successful evolution of salmon farming in Chile that '…it is the diversity of roles the State has played affecting industry's behaviour what strikes as the major lesson.' *The relevant issue then is how policy makers can identify those activities/areas that are* *of critical importance to the dynamics of a specific IS.* In what follows, a framework is outlined that will allow us to identify system-specific weaknesses in emerging IS and provide guidance to policy makers who seek to identify the key policy problems.

## 3. Functional analysis as a tool for finding the key issues[8]

In order to do so, we need to develop an understanding of the key processes in the evolution of a IS. Such processes can be identified at two levels. The first level is structural and as explained above, dynamics can be analysed in terms of how actors enter into a IS, how networks are formed and how institutions are changed (or not). The second level refers to 'what is going on in the system' in terms of processes that have a more direct and immediate impact on the performance of the system. These processes are here labelled 'functions'. We propose that for an IS to evolve and perform well, seven functional requirements must be fulfilled. These functions have been identified through an extensive review of literature from various fields: economics of innovation, entrepreneurship, sociology of technology and political science, as well as through an experimental application of the framework to a number of IS.[9]

**(i) Knowledge development and diffusion**

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

**(ii) Influence on the direction of search**

For an 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 and/or pressures for them to undertake investments in the IS. The second function is the combined strength of factors influencing the search and investment behaviour.[10] Examples of these are beliefs in growth potentials (van Lente, 1993; Raven, 2005), regulations, articulation of demand by leading customers (e.g. von Hippel, 1988), technical bottlenecks (e.g. Rosenberg, 1976). 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/services are influenced in their respective search and investment processes (Franken et al., 2004).

**(iii) Entrepreneurial experimentation**

The origin of an IS can be traced back to a whole range of circumstances, such as an abundance of skilled labour (e.g. 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 that conducts 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. 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 IS without a vibrant experimentation will stagnate and, indeed, without the initial experiments, it will not be formed. Of course, in the course of this learning process, knowledge formation takes place, but of a more applied nature than that captured under the first functional heading.

**(iv) Market formation**

For an emerging IS, markets may not exist, or be greatly underdeveloped. Market places may be absent, potential customers may not have articulated their demand, or have the competence to do so, price/performance of the new technology may be poor, 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 (Kemp et al., 1998), in which the IS 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 IS in terms of number of actors (Andersson and Jacobsson, 2000). Finally, in a successful IS, mass markets may evolve, often several decades after the formation of the first market.

**(v) 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 IS 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 IS. Legitimacy is not given, however, but is formed through conscious actions in a process of legitimation, which eventually may help the new IS 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 systems and the institutional frameworks associated with them (Van de Ven and Garud, 1989). Hence, the formation of “advocacy coalitions” sharing a certain vision and the objective of shaping the institutional set-up forms a key feature of the process of structural change influencing this function.

**(vi) Resource mobilization**

As an IS 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 an IS is able to mobilize human capital, financial capital and complementary assets.

**(vii) 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. Structural change in the form of entry of firms is central to this process. New entrants may resolve at least some of the initial uncertainties with respect to technologies and markets (Lieberman and Montgomery, 1988), thereby strengthening the functions 'influence of the direction of search' and 'market formation'. New entrants may also enhance the process of legitimation the new IS (Carroll, 1997). 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. Further externalities may arise due to the co-location of firms, such as the development of pooled labour markets, emergence of specialised intermediate goods providers and information 'spill-overs' (Marshall, 1920). Hence, new entrants may contribute to a process whereby the other functions are strengthened, benefiting other members of the IS. This function is therefore not independent, but rather one which indicates the dynamics of the system.

The *functional pattern*, i.e. *what is achieved*, can be analysed empirically. This means that the seven processes are mapped empirically, and changes in these are mapped over time. This was first demonstrated in Bergek and Jacobsson (2003) and in Jacobsson et al., (2004), where analyses of functional patterns were used to understand the evolution of two systems in the energy field (wind power and solar power).

The main advantage with a functional analysis, i.e. adding this second level, is that we can separate structure from content – the focus is on 'what is actually achieved' in the IS rather than on what the components are, the 'goodness' of which is difficult to evaluate. Indeed, Mowery's (2005) analysis of the differences in paths followed by Korea and Taiwan in the semiconductor industries clearly demonstrates that industrial development does not involve following one path only but is achieved in different ways in different contexts.

'What is being achieved in the IS' is in part a result of the internal dynamics of the IS. In a rapidly developing IS, a chain reaction of positive feedback loops may materialise which involve all the constituent components and the functions of the IS. The linkages between functions may turn out to be circular, setting in motion a process of cumulative causation (Myrdal (1957). Exogenous factors, however, also come into play, influencing the internal dynamics. [11] A case in point is the transnational legislation concerning tradable emission permits which may influence investment decisions in many IS. Myrdal (1957: 18) showed a keen understanding of the interplay between internal and external sources of dynamics and even suggested that 'the main scientific task is…to analyse the causal inter-relations within the system itself as it moves under the influence of outside pushes and pulls and the momentum of its own internal processes.'

Empirical analyses of this nature not only improve our understanding of dynamics but can provide policy makers with a specification of which the weak functions are. It follows that we can also formulate policy problems in functional terms, i.e. 'what do we think should be achieved that is not' which implies that *system weaknesses can be expressed in functional terms*. For instance, a system weakness may be a 'too narrow range of entrepreneurial experiments' or 'shallow knowledge formation with respect to machinery design'. Functions, not 'market failures' can therefore become the *focussing mechanism* for policy makers in their efforts to specify the key policy issues.

## 4. The German solar cell case

The German case of solar cells (Jacobson et al., 2004; Jacobsson and Lauber, 2006) is a useful illustrative example. We will describe the emergence of that IS in functional terms; how the functions were driven by changes in structural components of the IS and by external factors; 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 programmes 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. In addition, funds were allocated to the exploration 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. The demonstration programme 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 mobilisation* 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.

An exogenous change, the nuclear accident in Chernobyl in 1986, had a deep impact in Germany. The Social Democrats committed themselves to phasing out nuclear power. 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 renewable energy (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 focussed 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 policy makers to respond to the perceived environmental threats. However, 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. The industry now expected that there would be a follow-up to the 1.000 roof programme, but no substantial programme 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 mobilise 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 and representatives from a number of interest organisations and industry formed an advocacy coalition and petitioned local governments to enforce such contracts on the utilities. After much effort, most *Länder* allowed this and several dozen cities opted for this model, including Aachen and Bonn. Due to this and other initiatives, *market formation* did not come to a halt at the end of the 1.000 roofs programme.

Again, we can see a link from early investments to market formation. In addition, at this point, the development of the IS began to characterised 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 the IS, strengthening *resource mobilisation*. 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 organisations could point to this interest when they drove the process of *legitimation* further. Lobbying by the German solar cell industry was also 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* programme was then given and two large firms decided to invest in new, and large, plants in Germany; *resource mobilisation* was dramatically strengthened.

Two sets of issues are raised with this example. First, the main system weaknesses in functional terms in this particular IS did not lie in knowledge development or in entrepreneurial experimentation but in market formation and legitimation. The key policy issues related, therefore, to these two functions. Second, although the sequence of development of functions in this particular case can not be said to be typical (simply due to an absence of case studies) it is probably not atypical for the process of emergence of a science based IS in a leading country, although the particular features of the energy sector probably made the process of legitimation so central. The most interesting aspect of the sequencing lies, however, in how the functions began to strengthen each others and when eventually positive feed-backs emerged. At this point, the diffusion process became increasingly self-sustained. The ultimate objective of policy could be argued to enable such a process to be set in motion (Jacobsson and Bergek, 2004)

## 5. Functional analysis in a 'catching-up' situation

In this section we will begin a discussion of 'functional analysis' from a developing country perspective, where industrialisation is less focussed on developing systems that are new to the world and more on catching–up. We will first illustrate how a wide range of policy instruments has handled functional requirements in three countries and in different IS, suggesting that functional analysis is of relevance also in a 'catching-up' situation. We follow with a discussion of the pattern of sequencing in terms of the evolution of a functional pattern, and the associated need for policy intervention, where we make a distinction between the case of exploitation of natural resources and that of development of an IS centred on complex machinery.

### 5.1 Functional requirements and policy in 'catching-up' cases – evidence from Korea, Brazil and Chile

Infant industry development is a matter of resource creation, including capabilities, within risk-taking firms and in supporting organisations, with the aim of realising a vision of going beyond established lines of production. For an individual firm to succeed in such a venture, and for a new IS to be formed, the seven functional requirements need to be fulfilled. We will discuss how that was achieved, referring to some successful cases (Korean machinery industry, Brazilian aerospace and steel industries and Chilean salmon farming), and note how policy addressed system weaknesses in functional terms in early phases of their evolution.

*Entrepreneurial experimentation* is vital to identify new business opportunities and to diffuse information about these to imitators, even if they are not new to the world. As Rodrik (2004: 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., (2005) argue that markets are good at signalling the profitability of already existing activities but not of uncovering 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.[12]

In the classic book on Korean industrialisation, Jones and Sakong (1980) explained how governments attempted to increase variety and experimentation through *influencing the direction of search*. The means was to manipulate the perceived opportunity set of business - 'field augmentation' - so that they would *enter into new areas for business*. As Jones and Sakong (1980: 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 Korea (Jacobsson and Alam, 1994: 175). This case, where initial advanced capabilities were 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 Korea. Similarly, Katz (2004: 29-30) argues that: 'In the case of salmon, the *perception* that large natural rents are potentially present…required the public sector to take a proactive stance in favour of inducing the erection of salmon farming production capacity…it certainly exercised a crucial catalytic role…showing that '*it could be done*' (our emphasis). This involved, inter alia, starting the first commercial salmon farming operation in Chile (Katz, 2004). [13]

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 (Jacobsson, 1993). Also salmon farming involves firm specific knowledge development. As Katz (2004: 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 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 and to the formation, in 1950, of the Centro Técnico de Aeronautica. By 1988, 800 aeronautics engineers had graduated, 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, Fundacion Chile (private/public) played a vital role in the early phase of salmon farming (Katz, 2004). Government agencies in Chile also established legal frameworks that later complied with international standards, which, of course, are of vital importance in the food processing industry. The role of Fundacion 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 Corporacion de Fomento, University of Chile and the National Institute of Agricultural Research (Rodrik and Hausmann, 2005). Indeed, it is 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' (Rodrik and Hausmann, 2005: 10).[14]

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 labour and specialisation which may generate substantial external economies. 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 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 organisation helped domestic machine tool suppliers in their (local) *legitimation process*.

*Market formation* refers to both domestic and foreign markets. In the Korean case, a protected local market was vital in the formation of various systems 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 centres 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 an early 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 liberalisation. Similarly, Embraer was supported via protection and military procurement in its early phase. 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 mobilisation* 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 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). In the case of Korean machinery industry and also in the Brazilian aerospace industry (Frischtak, 1994, Broad et al., 2005), resource mobilisation in the form of 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).[15]

Risk capital is another central resource that was amply supplied in 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 USD 44 million (a large sum in that industry at that time) when it entered into 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: 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: 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 Korea in the 1980s. Whereas the large Chaebuls 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 their development (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 being achieved’ also in such a situation – the key processes involved in the formation of a IS are the same. It has also demonstrated the sense in pursuing a multitude of policies addressing a range of distinct policy issues in connection with managing system weaknesses. 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.

### 5.2 A variety in sequencing and modes of interaction

Yet, the cases related above differ greatly. In two of these, (machinery in Korea, steel and aeroplanes in Brazil), a competitive advantage was created in areas very distant from current industrial strengths whereas the salmon farming case involves of a realisation of large ‘natural rents’, albeit by no means not automatically.[16] These differences may suggest that there are several sequences involved in developing functional patterns. Not only may the catching-up sequence be different from that revealed in the German IS for solar cells, but there may also be variation between cases in a catching-up situation. From a policy perspective, the existence of variety would, of course, have implications on the timing and sequence of policy initiatives. In what follows, we will therefore begin a discussion of different sequences.

As mentioned above, new IS 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., (2005) 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 a IS (via reducing uncertainties for followers and *influencing their 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, 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). *Knowledge formation* in the Science and Technology Infrastructure is, however, likely to be needed to be pursued in parallel with market formation, in particular as regards standard and compliance with safety regulations (*legitimation*). Setting up IS 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 mobilisation*) so that it can be responsive to later demands from a growing IS is, of course, essential.

As was underlined in the case of solar cells in Germany, these functions are not independent of each others but are interlinked where, in the best of worlds, the process becomes driven by 'autonomous dynamics' in which positive feedback loops materialize. These linkages may take a range of forms which are difficult to foresee. For instance, an initial entrepreneurial experimentation may 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 via new entrants. Formation of clusters of firms may subsequently give rise to a number of positive external economies that may strengthen other functions, including entrepreneurial experimentation. After a foundation has been laid, 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 industries 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. As Frischtak (1994: 603) explains: ‘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 specialised human capital) preceded, moreover, 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 *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 IS in steel making.[17] Similarly, Mowery (2005) 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 case, as well as in the case 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 Korea, Taiwan 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 realisation of (some of) these options. As Loasby (1998: 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 relevant. For instance, Dahlman and Fonseca (1993) point out 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 can not, however, be expected to be put to use unless other policies make it attractive to invest in the new IS. In the cases of 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* was made apparent in the form of poorly developed design capabilities (*knowledge development*) in many machinery firms in Korea. Policy aimed at improving this situation not only with an expansion of the educational system (*resource mobilisation*) and R&D programs (*knowledge development*) but with a trade liberalisation that forced the firms to develop own design capabilities.[18] In complex products, a trade liberalisation 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 Korea (Jacobsson and Alam, 1994).

The case of the machinery industry in Korea (as well as those of solar cells in Germany and Chilean salmon farming) also demonstrate the need to organize the members of the infant IS in order to create *legitimacy* (locally and internationally) for the IS, 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 contribute to the formation of platforms which provide the infant IS with a meeting place, a forum for exchange of experience and coordination of activities.

This first analysis suggests that there are many similarities between the 'catching-up' cases. Our reasoning on capabilities as options are valid across the cases as is the issue of legitimation. Yet, there are substantial differences in the sequences. In particular, we should note the long build-up time in terms of knowledge formation and resource mobilization in the cases in the machinery industry where the sequence resembles more that of solar cells in Germany than the salmon farming case.

## 6. Concluding remarks

The purpose of this paper was to present an analytical framework, designed to help policy makers identify the key policy issues in a specific innovation system and to, tentatively, discuss that framework in the context of a ‘catching-up’ process. We have focused on an early phase in the evolution of an IS in both leading countries and in ‘catching-up’ countries and provided illustrative examples from five IS; solar cells in Germany, salmon farming in Chile, machinery industry in Korea and steel as well as airplanes in Brazil.

We have suggested that a functional analysis can be a useful analytical tool for policy makers in that it helps these to systematically map ‘what is achieved’ in a specific IS in terms of seven key processes in the evolution of an IS. System-specific weaknesses in an emerging IS can then be defined in functional terms and these can be used as focusing devices for policy makers in their search for identifying the key policy issues. These policy issues are likely to be specific for each IS and for a given moment in time and the pursuit of a selective intervention requires, therefore, high level capabilities. As there are significant up-front costs involved in building such capabilities, policy bodies ought to think in terms of enabling a long-term commitment among analysts to particular innovation systems. Moreover, international comparative analyses increase these up-front costs further, which suggest that analysts should build long-term relationships with organizations abroad that pursue similar analyses.

As regards to needs for future research, two suggestions follow. First, the illustrative cases have been limited to ex post functional analysis. It would be useful to undertake a study an IS in a 'catching-up' phase where a functional analysis is used to identify the current key policy issues. Second, although we have suggested that there are no 'one size fits all' policy implications; there is no infinite variety in the evolution of different IS. It would, therefore, be of interest to study the diverse patterns of formation of innovation systems in a catching-up context; to elaborate on different sequences in terms of the evolution of functional patterns and to develop a typology. A typology of that nature would be expected to be a useful guide for policy makers in their search to find the key policy issues.

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[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] The framework has been developed in collaboration with the main Swedish technology policy actor, VINNOVA (Swedish Agency for Innovation Systems). In most of our earlier work, we have used the term ‘technological systems’ (e.g. Carlsson, 1995 and 1997, Carlsson et al., 2002, Bergek et al., 2005). We have here chosen the broader term innovation systems as the catching-up literature focuses not on individual technologies or combinations thereof but on industries or sectors.

[3] 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’. Our analogy is, instead, technical systems, with ‘hard’ system components filling different technical functions, thereby contributing to the system’s overall functionality.

[4] The following paragraphs draw heavily on Bergek et al., (2006).
[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 Franken et al., (2004).
[8] This section is based on Bergek, et al., (2005).
[9] See Bergek and Jacobsson (2003); Jacobsson and Bergek (2004); Jacobsson et al., (2004) and Bergek et al., (2005).
[10] This function also covers the mechanisms influencing the direction of search *within* the IS, in terms of different competing technologies, applications, markets, business models etc.
[11] See for instance Geels (2002) and Raven (2005) for useful discussions of how exogenous factors influence dynamics.
[12] 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).
[13] Mowery (2005) also reports that the first experimental facility for semiconductors in Taiwan was set up by the Industrial Technology Research Institute (ITRI).

[14] 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., 2005)
[15] 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).
[16] Indeed, Katz (2004) underlines that it took about two decades to catch up.
[17] 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: 20).
[18] Katz (2004) points to a similar system weakness in Chile in that the knowledge base is underdeveloped in the salmon farming IS, including the capital goods industry.