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12 Sectoral systems: implications for European innovation policy

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1 Introduction

It is generally accepted that governments have an important role to play in fostering the conditions supporting innovation and competitiveness. The economic and political discourse on these issues reflects existing political debates about the capacities of firms and the market mechanisms to deliver desired outcomes.

For about forty years, academic research, in the tradition of innovation studies and the economics of technological change, has attempted to sort out what has been learned from experience throughout the world. The record of experience that they have studied includes the ambit of current political discourse as well as the more extreme examples of state socialism and autocratic regimes.

From a policy viewpoint, the results of these investigations are somewhat disappointing. No simple and obvious formula for reliably achieving success in promoting or fostering innovation has emerged. Instances can be cited of both failure and success for the prescriptions suggested by each of the poles of the current political discourse. The results of academic discourse on innovation policy have been a series of frameworks for analysis and evaluation rather than success in formulating a universally applicable policy. The value of these frameworks is that they provide a tool kit for a structured analysis of policy objectives and instruments in relation to industrial conditions and behaviors.

The results of this book promise to lead to new insights into the conduct of innovation policy by national governments and by the European Commission.

In recent years innovation policy research has followed a long progression of themes, which are identified, on the one hand, with the market failure approach and the economics of the R&D grants and, on the other, with the national and sub-national systems of innovation. The market failure approach to R&D is applicable only in certain contexts and situations, while the approach at the level of the national system has run its course.

How does the research in this book add to and modify these approaches? A useful starting point is that innovation can be considered as the result of systemic interactions among organizations and institutions, and that the SIs are assembled around sequences of innovation problems and their conjectured solutions. All systems depend on patterns of interconnections, and the connections that make an innovation system have to be articulated. The questions are: "By whom?" and "Who does the assembly?" and "What determines the organizational and institutional components that are available?" It has long been recognized that many kinds of organizations contribute to the division of labor in innovation. However, a principal role is played by for-profit firms. Firms are unique in having the requirement to combine and articulate the multiple kinds of knowledge required to innovate and build the capabilities to develop a commitment to a particular mode of solution. Each firm has its internal innovation capability, but what matters today is the ability to connect this with organizations that are external to the firm, which, collectively, comprise the innovation system that is relevant for innovative performance in a specific context.

The notion of a "*sectoral system*" is one way to pull all this together. This book has focused on the sectoral system as the appropriate unit of analysis for examining industrial conditions and the behavior shaping innovation performance. A sectoral system is the collection of economic activities organized around a common technological or knowledge base in which individual enterprises are likely to be either actual or potential competitors with one another. A sector encompasses many individual markets and enterprises that are interrelated with one another. Any system is defined in terms of boundaries, components and connections together with a set of principles that define the purpose and modus operandi of the system. In this book we focus, as specified in chapter 1 by Franco Malerba, on the three broad dimensions of sectoral systems that affect the generation and adoption of new technologies and the organization of innovation at the sectoral level: knowledge and the related boundaries; actors and networks; and institutions. Thus, sectoral systems include the supply chain and non-firm organizations such as universities as well as public and private research organizations. These organizations may be located in different national domains; and they are instituted, as a system, by virtue of the connections and interactions between the different organizations. SIs also include institutions, in the sense of the rules of the game, that influence organizations in their pursuit of innovations. Sectors can have within them several different innovation systems, focused around different problems or centered around different groups of firms. Therefore, where to draw the boundary is not always clear. Moreover,

boundaries in SIs are not static; they must be expected to evolve as the underlying problems of innovation evolve.

This sectoral system perspective, and the insight that innovation systems are not naturally given, lead us to what we consider to be a new and important insight into innovation policy. This is, namely, that the principal role of the policy maker is to facilitate the *self-organization of innovation systems* within the relevant policy domain. This approach is fully consistent with the idea that capitalism is a system that facilitates and encourages *new business experiments* as its primary process of change and development.

The structure of this chapter is as follows. Section 2 examines the reasons for public policy intervention in an innovation system perspective, while section 3 moves to a sectoral system approach and analyzes general public policy considerations. Then, in sections 4 and 5, we discuss some specific policy conclusions derived from this book in general and from the sectoral studies.

2 Reasons for public policy intervention in an innovation system perspective[1]

2.1 *The rationale*

In a modern society, the market mechanism and capitalist firms best fulfill many economic functions. The market mechanism evaluates and coordinates the behavior and resources of private and public actors – often in a smooth and flexible manner; this concerns the production of most goods, and a large proportion of service production. It is also true for many innovations, in particular incremental ones. Most of them occur through the actions of firms and in collaboration projects between firms. This is, however, less true for radical innovations, especially in the early stages of the development of new technologies.

Sometimes there are reasons to complement the market and capitalist firms through public intervention. This is true in the areas of law, education, the environment, infrastructure, social security, income distribution, research, radical innovations, etc. In some of these fields there is no market mechanism operating at all and the functions are fulfilled through other mechanisms, such as regulation. In other fields the market mechanism has, for decades, been complemented by public intervention in most industrial countries.

[1] This section is based upon Edquist, 1997, 2001a, 2001b.

What is at issue here is what should be performed by the state or public sector and what should not. This is an issue that is not only subject to ideological judgments but could – and should – be discussed in an analytical way.

What, then, are the reasons for public policy intervention in a market economy? As regards, for example, technical change and other kinds of innovations, two conditions must be fulfilled for there to be reasons for public intervention in a market economy:

(1) The market mechanism and capitalist firms must fail to achieve the objectives formulated. A *problem* of imperfect self-organization must exist (see below).

(2) The state (national, regional or local) and its public agencies must also have or be able to build the *ability* to solve or mitigate the problem.

There are no reasons for public intervention if the market and capitalist actors (including the government) fulfill the objectives.[2] Innovation policy – or other kinds of public intervention – should be a complement to the market, not intended to replace or duplicate it. In other words, there must be a "problem" – which is not automatically solved by market forces and capitalist actors – for public intervention to be "considered." Such problems can be identified through analysis.

When we talk about a "problem," we do so on an empirical basis and in a pragmatic way, not within the framework of a formal model. This is conscious and intentional. The reason is that this approach is more useful as a basis for policy design in the fields of innovation and technical change.

One difficulty in this context is, of course, that it is not possible to know for sure – *ex ante* – if public intervention can solve the problem or not.[3] The decision to intervene or not must thus be based upon whether it is likely or not that intervention will mitigate the problem. Hence, the decision must be taken in a situation of uncertainty. Then one can afterwards – *ex post* – determine through evaluations whether the problem was solved or mitigated. If this was not the case, we might be talking about a political failure. In other words, political failures can never be avoided

[2] We assume that the objectives – whatever they are – have already been determined in a political process. It should be mentioned that they do not necessarily have to be of an economic kind. They can also be of a social, environmental, ethical or military kind. They must be specific and unambiguously formulated in relation to the current situation in the country and/or in comparison to other countries. With regard to innovation policy, the most common objectives are formulated in terms of economic growth, productivity growth or employment.

[3] This is especially the case with innovation. Here, by definition, it is highly unlikely that there will be any clear-cut precedents for the problem to be solved.

completely because of the uncertainty mentioned. We must accept some mistakes in public activity – as we do in private activities. However, they should be exceptions and not the rule. Moreover, in order to determine the success or failure of a given policy intervention through an evaluation, it is necessary that the objectives of the policy were clearly formulated – *ex ante*.

There may be two reasons why public intervention cannot solve or mitigate a problem. One is that it may not be possible at all to solve the problem from a political level. Then all types of intervention will be in vain.[4] The other reason is that the state may first need to develop its ability to solve the problem. A detailed analysis of the problems and their causes may be a necessary means of acquiring this ability.[5] The creation of new organizations and institutions to carry out the intervention may also be necessary. A particular body of knowledge may not be represented in the national portfolio, requiring the establishment of a new research organization or the creation of a new policy instrument – eg. an R&D tax break. A patent office is another example of such an organization, and a patent law of such an institution.

There are two main categories of policies to solve or mitigate "problems":

(a) The state may use *non-market mechanisms*. This is mainly a matter of using regulation instead of the mechanisms of supply and demand. One example is a subsidy to poor regions. The state may also provide educational services free of charge or at a subsidized cost. Other kinds of regulation – particularly related to innovation activities – are the creation of technical standards, public subsidies for firms' R&D, or tax incentives for R&D and innovation activities.

(b) Through various public actions, the functioning of markets can be improved or the state may create markets. The *improvement* of the functioning of markets is the objective of competition law and competition (antitrust) policies. It is often a matter of increasing the degree of competition in a market. This might sometimes be achieved through "deregulation" – i.e. getting rid of old or obsolete regulations. An example is the liberalization or deregulation of the telecommunications sector in the 1980s and 1990s. One example of market *creation* is in the area of inventions. The creation of intellectual property rights through the institution of a patent law gives a temporary

[4] Hence, the problem is solvable neither by the market mechanism and private actors nor by public intervention.

[5] Hence, it may be necessary to carry out a detailed comparative empirical analysis.

monopoly to the patent owner. This makes the selling and buying of technical knowledge easier.[6] Public policy makers can also enhance the creation of markets by supporting legal security or the formation of trust. Another example is public technology procurement.[7]

In both cases, public policy is very much a matter of formulating the "rules of the game" that will facilitate the formation of operational SIs. These rules might have nothing to do with markets, or they might be intended to create markets or make the functioning of markets more efficient. In other words, policy is very much a matter of creating, changing or getting rid of institutions in the form of rules, laws, etc.

The example of market creation through the institution of patent law mentioned above indicates that a "problem" that motivates public intervention may concern the future. A "problem" may be something that has not yet emerged. A *problem-solving* policy of this kind could alternatively be called an *opportunity-creating* or anticipatory policy.[8] One of the problems to be solved could be that uncertainty prevents new technologies from emerging. One example of such a problem would be the case where public funding of basic R&D may be necessary because capitalist actors do not have the incentive to fund it. Another example could be that training people and stimulating research in public organizations in a certain field – e.g. multimedia – could create new opportunities that would not be realized without such a policy. This has been present in most of the sectors analyzed in this book. We will come back to these opportunity-creating kinds of innovation policies when discussing lock-in situations below.[9]

Another example pointing in this direction is the public creation of standards, which decreases the uncertainty for firms. For example, the creation of the NMT 450 standard by the Nordic PTTs in the 1970s and 1980s was crucial for the development of mobile telephony in the Nordic countries. This made it possible for the private firms to develop mobile systems. Ericsson and Nokia would not have assumed global leadership in this field without the NMT 450 (which later developed into

[6] Paradoxically, then, a monopoly is created by law, in order to create a market for knowledge – i.e. to make it possible to trade in knowledge. This has to do with the peculiar characteristics of knowledge as a product or commodity. It is hard to know the price of knowledge as a buyer, since you do not know what it is before the transaction. And if you know what it is you do not want to pay for it. In addition, knowledge is not worn out when used – unlike other products.

[7] Public technology procurement is addressed in detail in Edquist, Hommen and Tsipouri, 2000.

[8] There may even be reasons to treat the solving of existing problems and the creation of future opportunities as two different situations calling for public intervention.

[9] Obviously, the degree of uncertainty increases when the problems concern the future. Sometimes the problems may be very difficult to identify.

the NMT 900 and the digital GSM standard) (discussed in Edquist, 2003).[10]

A further example of a policy leading to market creation is public technology procurement – i.e. the public buying of technologies and systems that did not exist at the time. Public technology procurement was used in combination with NMT 450 in Finland and Sweden to provoke Nokia and Ericsson to enter the new field – which they were reluctant to do in the beginning (discussed by Fridlund, 2000, and Palmberg, 2000, in more detail). In this way, public innovation policy may take the role of a "midwife" in the emergence of new technology fields and whole production sectors. It could even be argued that most innovation policies should take this proactive approach – an issue that will be further discussed below.

2.2 *Selectivity in innovation policy*

When state intervention is intended to improve the functioning of markets, it is often a matter of increasing the degree of competition – rather than increasing the rate of innovation. This kind of policy can be argued to be "general" or "horizontal," in the sense that it tries to achieve the same thing everywhere. At other times policies are "specific" to certain sectors – or even products – of the economy in certain countries or regions. In these cases the degree of competition has to be estimated, and if ways to increase it are needed they must be appropriately designed and implemented.

When markets are created by public action, the policy is also "specific" to various functional areas, whether they concern inventions or the right to pollute. The creation of standards or public technology procurement is always technology-specific.

In most other kinds of public policy the state does not use the market mechanism. Instead, it complements the market or influences the consequences of its operation. Most public policy of this kind is allocative and "selective," rather than "general." It is selective in the sense that its consequences are not uniformly distributed among different activities and actors. This actually follows from the first of the two conditions that constitute reasons for public intervention: if a certain "problem" is to be solved, it has to be targeted in a selective manner. Public policy for basic research is selective. Politicians and policy makers, for example, allocate public research funds among competing fields of research. Someone must decide which fields of research are to be given priority. Should the

[10] The NMT story is told in Fridlund (2000) and Palmberg (2000).

funds be used for nuclear physics or biotechnology?[11] Regional policies are selective in a similar manner. Someone has to decide which regions to favor, why and how.

2.3 *Policy implications of the systems of innovation approach*

We can identify two main kinds of policy implications of the SI approach:

(1) The SI approach contains *general* policy implications (just like standard economic theory) that can be extracted from the characteristics of the approach. They are "general" in the sense that they are of a "signpost" character.

(2) The SI approach provides a framework of analysis for identifying *specific* policy issues. It is helpful in identifying "problems" that should be the object of policy and for specifying how innovation policies to solve or mitigate these problems can be designed. Since this cannot be based on comparisons between existing SIs and an optimal one, it will have to be based upon comparisons between different existing ones – geographically and/or historically.

2.4 *General policy issues in the systems of innovation approach*

Two general policy issues that emanate directly from the SI approach are:

(1) Organizational actors might need to be created, redesigned or abolished.

(2) Institutional rules might need to be created, redesigned or abolished.

In any SI it is important, from a policy point of view, to study whether the existing organizations and institutions are appropriate for promoting innovation. How should institutions and organizations be changed or "engineered" to induce innovation? This dynamic perspective on institutions and organizations is crucial in the SI approach, in both theory and practice. Not only organizational change but also the evolution and design of new institutions were very important in the development strategies of the successful Asian economies, as well as in the ongoing transformation of Eastern Europe. Hence, organizational and institutional changes are particularly important in situations of rapid structural change.

A general policy implication of the fact that much learning and innovation is interactive is also that this interaction should be targeted much more directly than is normally the case in innovation policy today. Thus, another general policy issue is:

(3) Innovation policy should focus not only on the elements of the systems but also – and perhaps primarily – on the relations among them.

[11] Such allocations are made every year, but are seldom discussed explicitly and publicly.

This includes the relations among various kinds of organizations and also those between organizations and institutions. For example, the long-term innovation performance of firms in science-based industries is strongly dependent upon the interactions of these firms with universities and research organizations. These interactions should be facilitated by means of policy – if they are not spontaneously functioning smoothly enough. This can partly be done by changing the laws and rules that govern the relations between universities and firms. Incubators, technology parks and public venture capital organizations may also be important in similar ways. This means that the public sector may create organizations to facilitate innovation. At the same time, however, it may create the rules and laws that govern these organizations and their relations to private ones.

From the evolutionary approach, a new indication can be derived. Because innovation processes are evolutionary and path-dependent, there is the danger of negative "lock-in" situations; that is, patterns or trajectories of innovation that lead to low growth and decreasing employment. This may apply to patterns of learning and the production specialization of firms, industries, regions and countries. The next general policy issue is, therefore:

(4) Innovation policy should ensure that negative lock-in situations are avoided.

This point is strongly emphasized by *evolutionary theory.* As Arthur (1989) and David (1987, 1985) have shown, the working of path-dependency, global or local positive feedbacks and network externalities may lead a system to be locked into an inferior technology. Potentially superior technologies may not take off and the generation of diversity may be reduced or blocked.

What are the policy options here? Three can be identified.

(4a) Keeping technological rivalry alive by supporting alternatives.

A first policy option is to keep technological rivalry open. This is not an easy task, however. David (1987) identifies a "narrow policy window paradox." Path-dependency, increasing returns and positive network feedbacks may lock an industry into a given technology or standard rather early in an industry life cycle. In order to keep options open the government has a very short period for intervention, which usually comes rather early in the competition among technologies or standards. The government may do that by using public technology procurement and R&D subsidies supporting possible alternatives to the winning technologies and by favoring experimentation. A related issue is: how can a government choose which technologies to support? This is the "blind giant quandary," discussed by David (1987). It concerns the lack of knowledge by public agencies as to the real features and potentialities of alternatives very early in the technological competition and industry life cycle. In this respect, the government may do two things. First, it may support organizations that have the specific task of exploration and experimentation, such as universities. Second, it may indirectly keep technology rivalry open by supporting "an" alternative (it may be the second most relevant at the moment of government intervention) to the winning technology. The US procurement policy on semiconductors and computers in the 1950s and 1960s did exactly that. It kept various alternatives open by supporting the competitive approaches of several firms early on in the history of the industry. High levels of exploratory activity then generated an environment in which American firms developed the winning technologies for the later stages of industry evolution (Bresnahan and Malerba, 1999).

In this respect, innovation policy may develop "anticipatory policies" or provide the domestic industry with a "vision" regarding potentially new, interesting technological alternatives, in order that domestic firms can start carrying out research in these new directions. Here, the example of the concerted "vision" of Japanese government policy with respect to new electronics technologies comes to the fore (Fransman, 1995). This "vision" by the government, however, is not easy to develop. Government policy is quite effective if it is able *ex ante* to pick the winning technology or trajectory, but it fails otherwise. In a changing, uncertain and complex world choosing the winning technologies is not an easy task to accomplish, all the more so because the government may not have the necessary competencies, the appropriate information filters or the institutional network.

(4b) Introducing diversity into the industry through the provision of support for firm entry and the survival of new firms

In addition, economic variety may be increased by the provision of support for the entry and survival of new firms. Compared to incumbents, entrants may well be characterized by different capabilities, cognitive frames and approaches. As has clearly been shown by several empirical studies, entry is not an equilibrating force. Rather, innovators bring new ideas, products and technologies with respect to incumbents. As a consequence, the government may create an environment favorable to the entry of new firms – in particular small and medium-sized enterprises – and to the growth of successful ones. As the empirical studies have demonstrated, it is the survival and growth, and not just the entry into an industry, that are the crucial processes for the long-term survival of innovative firms, because they require continuous innovation as well as major managerial and organizational changes. One of the reasons for the continuous US leadership in minicomputers and PCs and computer networks has been the high entry rates of new actors into the industrial

scene. These new actors had different products, competencies and strategies, and introduced a high rate of exploratory activities and high variety into American industry. This was not the case with European industry, which remained characterized for a long time by a few established oligopolistic actors.

(4c) Supporting the generation of variety through a common infrastructure (standards and gateway technologies).

Public policy may create the conditions for the generation of diversity by reducing the incompatibility among competing approaches and by providing a common base upon which new varieties of products may be introduced. This is the role of norms and standards. Norms and standards create a platform upon which new products and technologies may be developed, while reducing the risk of introducing incompatible innovations (Cohendet and Llerena, 1997). However, when competing approaches have progressed significantly, and have established a sufficiently large user base, the government may push for gateway technologies, which connect these previously incompatible technologies (David, 1987). In both cases, variety is reduced at the level of basic technologies, but it is potentially increased in terms of ranges of product and process innovations. Another way to support a common infrastructure upon which a variety of products and processes may be developed is the diffusion of codified information about various competing technologies, so that firms themselves may try to develop gateway technologies. This can be done through the widespread and intensive use of IT. Examples of the increasing role of standards in the innovation process are the establishment of ETSI, the creation of standards within the ESPRIT (Engineering, Science, Preparation and Introductory Training) program and the role played by the National Institute of Standards and Technology in the United States in the initial development of the semiconductor and computer industries (Mowery, 1996; and Edquist, 2003).

The final general policy issue is:

(5) Governments can facilitate changes in the production structure and the ability of firms to create new products.

There are three mechanisms through which the production structure can change through the addition of new products: existing firms may diversify into new products (examples are Japan and South Korea); new firms in new product areas may grow rapidly (the United States is an example); and foreign firms may invest in new product areas in the country (the case of Ireland is an example). In the last thirty years some countries, and regions, dominated by process innovations have experienced high and persistent unemployment rates. At the same time, product innovations have displayed the opposite tendency to generate new employment. If the objective of innovation policy is to secure job creation, governments can therefore support structural changes in the direction of production sectors, dominated by product innovations. The demand for new products often grows more rapidly than for old ones. Moreover, new products are often intermediate goods or process technologies for other sectors, and this would create productivity increases and cost reductions, as in the chemical engineering, software and machine tools sectors. The implications of these arguments are that firms, regions and countries producing new products tend to do so for markets that are growing rapidly. Growing markets mean an increase in demand and output, which reinforces the intrinsic employment creation effect of product innovations. Governments should therefore create opportunities and incentives for changes in the production structure. They should promote sectors characterized by high knowledge intensity and a high proportion of product innovations. Policy issues in this context concern how policy makers can help develop alternative patterns of learning and innovation and nurture emerging SSIs.

In sum, the general policy implications of the SI approach are different from those of standard economic theory. This has to do with the fact that the characteristics of the two frameworks are very different. The SI approach shifts the focus away from actions at the level of individual and isolated units within the economy (firms, consumers) towards that of the collective underpinnings of innovation. It addresses the overall system that creates and distributes knowledge rather than its individual components, and innovations are seen as the outcome of evolutionary processes within these systems.

These general policy issues derived from the SI approach can serve as signposts and suggest where to look for problems and possible solutions in innovation policy making. However, this is not a sufficient basis for designing specific innovation policies. The general policy issues do not tell a policy maker exactly what to do in order to improve the functioning of the system. The SI approach cannot provide this; neither can any other approach or theory. Take, again, standard economic theory as an example. The market failure analysis of this theory argues that a completely competitive, decentralized market economy would provide suboptimal investment in knowledge creation and innovation. Firms under-invest in R&D because of uncertainty and appropriation problems. This leads, for example, to a case for public subsidies for knowledge creation, or for the creation of intellectual property rights. This nicely links up with the "linear model" approaches, and economists and policy makers often consider this as a justification – or theoretical foundation – for governments to subsidize R&D.

However, the policy implications that emerge from the market failure theory are, in fact, not very helpful for policy makers from a practical

and specific point of view. They are too blunt to provide much guidance: they assume that the policy maker has at least the same information at his disposal as is available to the private decision maker – and more. They do not indicate how large the subsidies or other interventions should be or within which specific area one should intervene. They say almost nothing about how to intervene – i.e. which policy instruments should be used and the process through which they should be implemented. Standard economic theory is not of much help when it comes to formulating and implementing specific R&D and innovation policies. It provides only general policy implications – e.g. that basic research should sometimes be subsidized (Metcalfe, 1995).

3 From systems of innovation to sectoral systems: general public policy considerations

The SSI approach can be used as a framework for designing specific innovation policies. We now outline, very briefly, how this can be done. It has been mentioned that a necessary condition for public intervention in processes of innovation is that a "problem" – which is not automatically solved by markets and firms – must exist.[12] Substantial analytical and methodological capabilities are needed to identify these "problems."[13]

The important insight in the sectoral systems approach is that innovation systems are constructed and operate at multiple levels in an economy and that, to various degrees, they interact within and across national economies and technologies. The sector becomes the focusing device to identify the intersection of these different levels and scales of analysis. The idea of SIs, which can be traced back to List and Babbage in the nineteenth century, began by privileging national-level institutions and organizations that frame science, technology and innovative activities within a national political system. Here the role of universities in conducting research and training minds, and the role of public research laboratories, are often cited as examples of the components of a national system. Connections also matter in defining these systems and particular emphasis has been given to the mode of interaction between firms and public organizations in promoting innovation nationally. The idea of a national system has subsequently been generalized by recognizing that innovation processes increasingly spill across national boundaries (in the European Union this is built explicitly into the Programs of Community R&D subsequent to the Single European Act of 1987) and by

[12] This means that neutral or general policies are normally irrelevant; selectivity is necessary if specific problems are to be solved or mitigated.
[13] Such capabilities are also needed to design policies that can mitigate the problems.

recognizing that innovation processes have to be articulated at the sectoral level.

In this view, sectoral production systems and their related markets are important because it is within these systems that sequences of innovation problems are defined and "solved" by firms. The problems are specific to the sector but the solutions typically draw on a more extended division of labor that goes beyond narrowly defined production/market systems. Thus, nations and sectors support what can be called "bundles" of innovative capabilities and resources of a general kind. Firms in the pursuit of competitive advantage stimulate the application of these resources to specific innovation problems, and the context in which firms interact with the wider innovation milieu depends on the nature of the sector. Notice here the important role of the firm to act as the combinatorial locus for the many different kinds of knowledge typically required to innovate. Innovation requires more than knowledge of science and technology: it also requires knowledge of organization and market, and the latter are exclusively the province of firms, or – more precisely – business activities in sectoral contexts.

The importance of the sectoral system is that it forms the locus of intersection of numerous networks generating particular kinds of knowledge. A typical "technologist" in a firm may interact with other technologists in the community of the relevant discipline, with industry and government groups establishing standards and regulations, with technologists in rival firms and with academic researchers in supporting fields. Each of these networks has different members and different purposes, but they all contribute to innovation. Indeed, innovative ability may depend on the ability to participate in and manage these network relations. Thus, the wider significance of the sectoral perspective is to identify the complex of networks and the dynamics of their birth, growth and – even – decline in relation to innovation performance.

Of course, SSIs are quite *different* from each other, for example with regard to knowledge base, resources spent on R&D, firms' characteristics, etc. In addition, organizations and institutions constituting elements of the sectoral systems may have different roles in different countries. For example, research institutes and company-based research departments may be important organizations in one country (e.g. Japan) while research universities may perform a similar function in another (e.g. the United States). Institutions such as laws, norms, and values also vary considerably across countries.

In this book, we emphasize that sectoral systems are different and that, within each sector, there are important regional and country specificities that affect the different trajectories of industrial development. We would like to bring to the fore the importance of a sound, empirically driven comparison between sectoral systems and across countries within a sectoral system. Without such comparisons, it is difficult (as mentioned earlier) to single out "problems," missing functions, organizations and institutions. Comparisons are, therefore, the most important means for understanding the relationships within sectoral systems and their impact on the performance of firms.

Genuinely empirical and very detailed comparisons can be performed between existing systems (geographically or historically). They are similar to what is often called "benchmarking" at the firm level. Such comparisons are crucial for policy purposes. They can identify the "problems" that should be subject to policy intervention, and are necessary also to identify the causes behind the problems – at least the most important ones[14] – in order to be able to design appropriate innovation policy instruments.

Within an SI framework, an identification of the causes behind the problems is the same as identifying deficiencies in the functioning of the system. It is a question of identifying those systemic dimensions that are missing or inappropriate and that lead to the "problem" in terms of comparative performance. Let us call these deficient functions *system failures*. When we know the causes behind a certain "problem" – for example, weak technological transfer between university and industry – we have identified a "system failure."

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

3.1 A sectoral system approach provides a new methodology for the study of sectors and, therefore, for the identification of the variables that should be the policy targets

While, up to now, industrial economics and industrial organizations have focused on dimensions such as structure-conduct-performance, strategy in a game-theoretic way, transaction costs, sunk cost and the "bounds" approach, the view suggested here is that sectoral analyses should focus on systemic features in relation to knowledge and boundaries, the

[14] A causal analysis may also reveal that public intervention may be unlikely to solve the problem identified, due to a lack of ability from the government's side.

heterogeneity of actors and networks, institutions, and transformation through coevolutionary processes. As a consequence, the understanding of these dimensions becomes a prerequisite for any policy addressed to a specific sector.

In fact, one of the problems that governments may face is the inability to understand the specificity of the sector, the technology or the institutional setting in which policy has to take place. For example, in very general terms, policies that try to correct for lock-ins and variety failures (discussed in section 3.4) by promoting firms' entry should pay considerable attention to the type of sectoral system. In an entrepreneurial (Schumpeter Mark I) regime, characterized by high entry rates, policies promoting entry would be very much in tune with the organization of innovative activity in a sector characterized by high turbulence. In a routinized regime (Schumpeter Mark II), characterized by strong rivalry among a core group of innovators exploiting economies of scale and scope in R&D, policies favoring small firm entry would risk the disruption of the inner innovative dynamics of the industry. In this case, rather than entry promotion, a policy of basic research or "technology vision" addressed to the oligopolistic core of the industry could be more appropriate.

3.2 *The impact of general or horizontal policies may differ drastically across sectors*

A second point relates to the major differences that exist among sectors in the variables identifying a sectoral system. As a consequence, the impact of horizontal policies may differ greatly from sector to sector, as well as the channels and ways that policies have their effects. It is clear that, for these purposes, biotechnology and pharmaceuticals is a different sectoral system from machine tools or telecommunications, and that the differences vary with the maturity of the sector.

For example, two of the major policy statements derived from the SI approach could be further qualified by looking at the different relevance of the following phenomena across sectors.

- *Cooperation and networks (as primary policy targets in an innovation system approach) may have different relevance and characteristics among sectors.* As mentioned above, simple economic models of competition poorly represent the extent of enterprise interdependence within modern sectors. In a sector, the generation and commercialization of innovation is likely to involve extensive cooperation and division of labor, much of which is negotiated in networks rather than governed by ordinary market-clearing mechanisms. Here, the important shift in policy emphasis toward strengthening SIs, organizations and institutions (rather than seeking to influence specific innovation events) has to be supplemented by an understanding of the relevance of the role of cooperation and networks in the specific SI.
- *Non-firm organizations and institutions (as major targets of policy in an innovation system approach) may have different relevance in different sectors.* Thus, the institutional setting is very important in a sectoral system, and should be monitored and evaluated by the public authorities. For example, the legal and institutional rules governing cooperative exchange are evolving within existing legal frameworks – such as, for example, those governing intellectual property rights – that were devised for other purposes. It is very likely that there will be major unintended consequences stemming from changes in these rules. An SSI is composed of for-profit firms but its performance in any particular sectoral setting is likely to be affected by not-for-profit organizations such as public research organizations and universities. The interactions between all the organizations contribute to the sustainability and success of commercial activities within the sector. When the role of public organizations is well understood in the context of the innovation needs of a particular sector, policy can have a major impact in reshaping the missions of existing, or in creating new, public organizations.

3.3 *The analysis of the rationale and the effects of policies requires a deep and careful comparative evaluation over time, across countries and across sectoral systems*

As previously mentioned, each sector has different features, organization and dynamics, and the actual outcome is the result of the interplay of the various basic variables affecting a sectoral system and of their interaction over time. Thus, establishing a basis for the comparative analysis of the configuration of the active institutions and organizations in any particular sector is a necessary step in policy formulation. These configurations can differ across national or regional contexts, but the effectiveness of variant configurations must be analyzed rather than presumed to be sustainable. Finally, different contexts may limit the transferability across borders of sectoral policies and require different interventions.

3.4 *For fostering innovation and diffusion in a sector, not just technology and innovation policies but a wide range of other policies may be relevant*

A sectoral system approach emphasizes that innovation and technology policy are linked with and affect other types of policies, such as science policy, industrial policy and policies related to standards, intellectual property rights and competition policy. In sectors such as pharmaceuticals and biotechnology, science policies, technology policies and IPR policies all play a major and interrelated role (see McKelvey, Orsenigo and Pammolli, chapter 3 in this book). In telecommunications, standards, competition policies and IPR policies have major effects (see Edquist, chapter 5 in this book; Hommen and Manninen, 2003; and Corrocher, 2003a, 2003b).

In addition, a sectoral system approach highlights the interdependencies, links and feedbacks among all these policies, and their effects on the dynamics and transformation of sectors. In fact, the problems that shape innovation arise within the context of the sector, and neither the trajectory of the technology nor the trajectory of the market are independent of one another.

3.5 *The policy maker is an active internal part of sectoral systems at different levels*

The public actor has to be aware that it is inside a sectoral system at various levels. In the sectors examined in this book, the policy maker intervenes actively in the creation of knowledge, IPR regimes, corporate governance rules, technology transfer, financial institutions, skill formation and public procurement. As a consequence, it has to develop competencies and an institutional setting in order to be effective and consistent at the various different levels.

3.6 *Policy should consider the different geographical dimensions of sectoral systems*

The sectoral approach takes into account developments in the local, national, regional and global dimensions of markets and institutions. For example, in the chemical industry policies at the national level have been highly relevant (Cesaroni et al., chapter 4 in this book), while in telecommunications both national and transnational policies – such as the European ones – have been important (Edquist, chapter 5 in this book). On the contrary, in machine tools the local dimension has always been key (Wengel and Shapira, chapter 7 in this book).

Each of these levels influence the development and articulation of technological capabilities. While political boundaries and local proximity are influential in the generation and diffusion of innovation, modern enterprises in a liberalized global economy must take a global perspective on actual and potential competition. Policies that focus on only one level of aggregation are likely to miss constraints or opportunities that are influential in the innovative behavior of individual organizations. While

technology policies can, and sometimes should, be addressed at one level of aggregation, the rationale for these policies and their implementation must reflect a global perspective.

4 Some specific policy conclusions

This book provides a basis for making further distinctions that are relevant to policy analysis. These distinctions derive from a programme of research that was "deep" in its penetration of the workings of particular sectors while not "extensive" in its coverage of the many different sectors. The evidentiary basis for these distinctions is, therefore, provisional, and relies upon a more extensive body of research than that presented in this book. A further qualification in the generality of these distinctions is that in the sectors examined in this book innovation plays a critically important role to competitive success.

A key issue here is, therefore, the choice between supporting existing systems – with their historically accumulated knowledge bases – and supporting the development of radically new products and sectoral systems. Radical innovations and the emergence of new SSIs, especially in Europe, seem to be more of a "problem" for markets and private firms than reproduction and incremental innovation in established sectors (see Coriat, Malerba and Montobbio, chapter 11 in this book). We also know that large-scale and radical technological shifts – i.e. shifts to new trajectories – have rarely taken place without public intervention in the OECD countries. This is true for most of electronics as well as for aircraft and biotechnology – in the United States as well.

4.1 *Policies in periods of radical technological change*

In cases where technological change within a sector breaks from the past accumulation of knowledge, and current expertise and capability:

- SSIs will experience substantial stress because of the difficulties of aligning the incentives and the capabilities of the actors to the new problem sequence. For example, incumbent actors may underestimate the scope of change and focus on reactive rather than adaptive strategies. Adaptation in other parts of the sectoral system may, therefore, be delayed, increasing the long-term risks to the sector.
- Sectoral systems are neither naturally given nor static. They are constructed for a changing purpose and their boundaries, components and connections change significantly with the growth of knowledge and the evolution of problem sequences. A system can become outmoded and constrain innovation performance.

Examples of sectoral systems that constrained the innovative activity of firms can be found in the history of machine tools in the United States and pharmaceuticals in Europe. The innovation of the IOL provides an interesting example of the dynamics of the emergence of an innovation system within the broader ophthalmological sector. From its tentative origins of interaction between the innovating clinician, a lens supplier and a materials supplier, an international innovation system has been constructed by a small group of multinational medical companies. Each company articulates its own network of clinicians, suppliers and customers for IOLs, and to a degree these networks intersect within the wider, relatively autonomous networks of, for example, practitioner communities and healthcare systems (see Metcalfe and James, 2002, and Tether and Metcalfe, chapter 8 in this book).

- Radical technological change often involves an especially active role for public organizations in recognizing and promoting, or even creating, the initial conditions for market success. Governments can play important roles as lead users of radical new technologies and in supporting the early use of these technologies in public organizations. This is very clear in the case of public procurement with regard to defense capabilities and public health.

Three examples from this book can be proposed. First, the innovation of the IOL and the considerable changes over time in the related innovation systems in the United Kingdom and United States, in particular, depended greatly on the take-up of the procedure in public and private healthcare systems and on the different norms for translating clinical need into "market demand" in the two national medical systems (Metcalfe and James, 2002). Second, the US government has played a very active and decisive role in the launching of the fixed Internet (Edquist, 2003; and Corrocher, 2003a). Finally, the BioRegio program in Germany is another interesting example.

- In this respect, government capacities for monitoring the emergence of radical technological change differ substantially across countries.
- It is also particularly important to encourage transparent and open debates about the significance of emerging technologies, in order to support the formation of consensus as well as to identify possibilities for experimentation and trial.

This book has shown clearly how, in a dynamic setting, new sectoral or subsectoral systems of innovation may rapidly emerge from existing ones, such as biotechnology (McKelvey, Orsenigo and Pammolli, chapter 3 in this book) or the Internet and multimedia (Edquist, chapter 5 in this book).

- If governments do intervene, they should do so early in the development of new subsystems and new SSIs. Such intervention at an early stage in the product/industry cycle may have a tremendous impact.

In the case of the public creation of the NMT 450 mobile telecommunications technical standard in the Nordic countries about twenty years ago, this proved to be important. It was crucial for the emergence of the mobile telephone industry and for the rise of both Ericsson and Nokia to global leadership in this field.[15] On the other hand, there are many examples showing that massive government support to old and dying industries has had limited effect. Often it has only marginally delayed the death of these industries. One example is the Swedish shipyard industry in the late 1970s and early 1980s. The cost of the support to the shipyard industry was several hundred times larger than the cost of developing NMT 450.

- On a methodological level, this book indicates that existing approaches in industrial economics and standard measurement methods are not adequate for the task of identifying the changing configurations of sectoral systems and subsystems of innovation, particularly the processes of knowledge exchange between different types of organizations.
- The costs of constructing new sectoral subsystems of innovation are substantial, but this activity is not explicitly recognized in the existing literature of policy or management.
- There are major strategic opportunities available in discovering better ways to monitor, promote and reduce the costs of reconfiguration or expansion for sectoral systems and subsystems of innovation.

4.2 *Sector-specific policy conclusions*

Additional specific recommendations in relation to the various sectors examined in this book may be found in the individual chapters. These policy implications and conclusions are closely related to the problems faced by the various actors operating in the sectoral context and its specificity in terms of knowledge and boundaries, actors and networks, and institutions.

4.2.1 *Policies in services*

The application of the sectoral system concept to services creates many challenges, not least in relation to the economic importance of services

[15] In addition to the creation of standards, incubators, technology parks and the financing of new technology-based firms are examples of policy instruments relevant for the early stages of technological developments.

and the immense diversity of activities that can be grouped under this label (Tether and Metcalfe, chapter 8 in this book). Many services are premised on high degrees of interaction with manufacturing activities and many services contribute to the production of manufactures. Services can be defined in many ways but they all involve the articulation of specific transformation processes, and these are the basis for innovation.

The three cases in this book examine different aspects of the self-organization of innovation systems, the way in which they are transformed over time, the process of business experimentation and the (often complex) ways in which the relations between different actors are instituted. In relation to airport services, it is shown that the specific service features of the co-production of runway operations by airlines and airport operators have been key factors in the innovation of new operation procedures – procedures that have had a considerable impact in increasing productivity (Tether and Metcalfe, 2003). In the case of the innovation of the IOL, it is shown how the interaction between clinical practice and medical companies, and thus between clinical norms and commercial norms, has transformed this medical procedure from a craft to a virtual assembly line procedure, with great benefits to patients and the productivity of service delivery. In the process, new divisions of medical labor have emerged and the relation between need and demand has been transformed. In this case, medical companies have played a key role in assembling innovation systems at a micro-level in pursuit of competitive advantage. In the third case study (see Harvey, Nyberg and Metcalfe, 2002), the development of innovation in retailing is examined through the lens of the growth of new models of retailing business in the supermarket revolution. Even such a traditional sector as retailing has a well-defined edge of modernity, with supermarkets articulating an SI that has produced a range of important innovations in relation to the logistics of supply chains, the organization of demand and the market, and the packaging and display of foods. The different ways in which the Swedish and UK systems of retailing are organized has had a deep effect on the SIs that the two countries articulate. Thus, service activities are far from passive producers of innovations. The three sectors studied have embedded within them SIs in which the firms in question play a key role in generating their systemic properties.

Some interesting remarks can be advanced for sector-specific policies in *services*. Service innovations are often unusual in the number and type of connections that are required to assemble the components of a commercially successful innovation. This makes the problems of coordination in services particularly acute. In terms of policy, it suggests the need for identifying actual innovation requirements and for critically assessing existing approaches. In some cases, the commercialization of service innovations

relies upon the development of a relatively "standardized" package of components in which either inter-firm cooperation or a single coordinator may play a particularly important role. Such standardized packages often require changes that at least parallel (if they do not replace) existing regulatory practices and rules. For example, the issues of "interoperability" have been a central concern in European telecommunications and information services policy. In some cases, such as telecommunications interconnection, these concerns have been incorporated into regulatory practice and have reshaped the commercial environment in which firms operate. In other areas, such as standards for interfaces between software, policies have been "enabling" rather than directive, and it is important to monitor whether they are having the desired effect of increasing data transferability and mitigating the problems of "orphaned" users. Early notification of the intent to promote "standardization" is likely to lead to specific industrial proposals that can be enacted and provide an important instrument for supporting innovation, despite the inconvenience and complexity of enacting multiple rules. Correspondingly, existing rules and regulatory practices may serve as a constraint on service industry innovation, just as in manufacturing. It may be particularly important to examine these rules and practices with a view to identifying the constraints that they create for innovative behaviors.

4.2.2 Policies in software

The SSI in software is broadly distributed among private and public organizations throughout the world. In considering European interests in the software industry, the single most important issue is in developing effective means of supporting complex software systems that are specific to particular applications. These range from ERP software systems to the embedded software incorporated in consumer white goods and producer goods. The effective design of such systems requires the advantages of technical progress to be weighed against the costs of coordination. Increasingly, the design issues that underlie the construction of such application-specific software involves coordination across the boundaries of organizations, with the risk that coordination failures may occur. These failures constitute the type of "problem" for which specific sectoral policies are the solution.

The challenges of formulating such policies are, however, daunting. No directive policy is likely to be effective given both the uncertainties about the course of technical change and the difficulties of assessing the relative merits of different paths that might be followed in constructing new generations of complex software or building infrastructures for the "information society." It is possible, however, to conclude that policy has a role in bringing about industrial dialogue, particularly interactions between producers and users that are aimed at mitigating the costs of coordination. Procurement and regulatory policies that favor interoperability and that ease the costs of interconnection are a principal instrument for improving innovative performance and entry in the software industry. The publication of interface standards between software components is, arguably, as important as the establishment of reference standards for components in the manufacturing industries. While these activities are best organized and carried out by industrial associations, particularly those that include representation by user communities, they can be encouraged and promoted by policy action.

In this book, the study of the software sector has specifically illustrated that the problems of moving from intra-firm to inter-firm organization in the production of some forms of software create new demands on other actors in the SI, such as universities and public research laboratories. In embedded software, for example, the tradition of major firms assuming almost complete responsibility for the design of software tools and the implementation of systems may be replaced in the near future by specialized companies. From a European viewpoint, this appears to be a case of a larger sectoral system failure in which neither public research laboratories nor universities (with a few conspicuous exceptions) have been sufficiently active to provide the basis for European participation in emerging specialized segments. The example serves to highlight the importance of identifying potential changes in the division of labor that rely upon external research capabilities. Funding research and encouraging dialogue about such changes is likely to have positive impacts on the innovative capabilities of European software companies.

In the last few years the "open-source" or "free software" movement has grown very rapidly, creating major new challenges for policy. Some have claimed that this movement endangers the current "business model," which is responsible for generating the revenues for funding research and innovation in the industry. Others claim that this movement represents a viable alternative to the current system of using copyright to generate this revenue. It appears highly unlikely that this movement will be able to match the performance of commercial software development, either in innovation or in serving the needs of the average user. Nonetheless, free and open-source software provides two important advantages from a European perspective. First, this software provides a means of constructing components of the information society infrastructure, such as WWW servers, that support the active participation of those seeking to develop new service innovations and platforms. To the extent that such systems provide a way to support entry and innovation in the industry, it is

relevant to support their development through complementary research, education and procurement policies. Second, open-source or free software appears to provide an excellent means for supporting the acquisition of practical programming skills and knowledge. Skills shortages in software design and development have been identified as a major impediment to future European employment and growth. An assessment of the potential of open-source and free software for mitigating these problems is of considerable policy relevance.

4.2.3 Innovation policy in the Internet and mobile telecommunications

The US state was extremely important in the *very early stages* of the development of fixed data communications – i.e. in the period when the SSI of fixed data communication was fragile and not well established. Government agencies were very important as financiers of the research developing fixed data communications: they were initiating public technology procurement of elements of the system. Other agencies placed demands on organizations receiving public economic support that they had to use a certain data communications protocol. The government also injected increased dynamism into the telecommunications sector by pursuing deregulation.

State agencies were, however, not strong leaders in the creation of standards for the Internet in the United States. This was, instead, a rather spontaneous process, where private firms had a large influence. The idea of "open standards," or "compatibility of standards," appears to have been the characteristic US response.

The relations among various organizations were crucial for the development of innovations in the SSI. These included the relations between public and private organizations – as in public research funding and in public technology procurement. Relations among different private organizations were also important, both in terms of competition and in terms of collaboration.

The fact that the early development and diffusion of the Internet took place in the United States – with government support – gave a head start to US Internet equipment producers. This is an important explanatory factor behind the fact that US Internet equipment-producing firms, such as Cisco, are still very dominant globally. It is obviously very important for firm competitiveness in high-tech areas to be early, and to be close to customers in these early stages.

State-controlled organizations were very important in creating the first successful mobile telephony standard in Europe. Public telecommunications monopolies in the Nordic countries created the NMT 450 mobile telephony standard in collaboration with firms. The PTOs pushed the technical development of the standard and pulled national equipment-producing firms along their trajectory. They placed orders with firms and, up to a point, used the instrument of public technology procurement to create incentives for firms to develop equipment appropriate for NMT 450. NMT 450 provided the cradle for the development of mobile telephony in Europe. Deregulation of the telecommunications sector was also of some importance in some European countries, such as Sweden and the United Kingdom.[16] However, liberalization was not a key factor in Sweden's success with NMT and GSM. At most, it aided the diffusion process that was already under way at the time of deregulation (1993).

The relationships among organizations were obviously important in the process just described. So, were the relations between various kinds of institutions – such as NMT 450 – and the firms and other organizations involved also important? The relations between the operators – who were the main standard creators – and the equipment producers were very important for the fact that European equipment producers became leading ones, globally speaking. For firms such as Nokia and Ericsson it was also important that mobile telephony got a head start in the Nordic countries and that it grew rapidly.

Most second-generation standards were developed with the potential to become de facto world standards through international adoption. The European GSM standard – which developed out of the NMT standard – more than fulfilled the expectation of wide international diffusion. Initially conceived as a pan-European standard, it became a world standard, in practical terms. No other 2G standard achieved this. Deregulated operators (such as the Swedish Televerket/Telia) as well as firms (such as Ericsson and Nokia) were very active in the consortium that supported the development of the GSM standard. Hence, the close relations between users and producers continued. Over the longer term, however, these close relations gradually became looser. The GSM success could not be ascribed only to the strategies of a few innovative organizations but to the collaborations of a variety of different organizations: PTOs, standard-setting organizations and research organizations, plus equipment producers.

The European Commission also had a leading role in the development of GSM. The European Union was pushing one standard. This was also a standard that was technologically advanced, operated well and,

[16] Considering that state support was so important both for fixed data communications and for mobile telephony, it is tempting to think that the failure of satellite communications in the latter half of the 1990s was due to the lack of support from the state in the early stage of its development.

therefore, diffused rapidly outside Europe. In contrast, the US digital standards diffused internationally only to a limited extent, and the single Japanese standard not at all. The European Commission pushed liberalization and competition in the (mobile) telecommunications sector.[17] It did so within one single standard, and it did not care about letting standards compete, as with the US standards policy. The standard pushed by the European Union was secured to serve all member states, while the US digital standards were not completely compatible with each other. What the European Union did over – originally – thirteen European countries the United States did not manage to do over one – albeit large – country. It proved to be a major policy mistake to have several standards in the United States. This can be considered a serious policy failure for the United States as well as a great success for the European Union. The reasons for this are that it led to a slower diffusion of mobile telecommunications in the United States than in Europe, and the strongest equipment producers emerged in the GSM area.

It was of great importance for the European dominance in the production of equipment for the mobile telecommunications industry that one single standard was promoted; for example, economies of scale could be exploited. That the relations between users and producers were close also proved very important, primarily for the producers. The way GSM developed strengthened the leadership position of Nokia and Ericsson. This is all the more notable in the light of the lack of European success – and US/Asian dominance – in other ICT sectors.

Europe has emerged as a clear leader in mobile telephony due to its success in defining good standards in mobile communications. Ericsson's and Nokia's dominance among equipment producers in mobile telephony is often traced to the early success of the NMT standard, and GSM is similarly regarded as the means by which early Nordic success was generalized to other European Union countries in the second generation of mobile communications.

One reason for the relatively poor international performance of US-based 2G mobile standards was the "division" of the market between standards, none of which could match the subscriber base of GSM. These developments are considered to account for the subsequent loss of market share by US equipment manufacturers to European rivals during the second generation of mobile telephony. The slower transfer from first- to second-generation standards in the United States was due to regulatory decisions that stressed the necessity of achieving "backward

[17] In 1996 the European Commission decided that mobile services had to be competitive, with multiple GSM licenses in each member state.

compatibility" with the existing analog standards, rather than compatible digital standards. Decisions with regard to charging were another factor contributing to the low subscriber penetration rates: often the receiver has to pay for all or part of a mobile phone call.

The crisis at Ericsson during 2001–03 was mainly caused by a drastic decrease in demand because of the slowdown in the international business cycle, and thereby in telecommunications system investments. It serves to conceal the fact that Ericsson is still dominant in base stations and switches, while Nokia strongly dominates global handset production.

In the 1990s a convergence took place between traditional telecommunications, the Internet and mobile telecommunications. This was also accompanied by a wave of mergers and acquisitions (and strategic alliances), both among equipment producers and among operators. A strategic question for the equipment producers is whether they should select voice as their main business area and thus go for the growing mobile markets, or, alternatively, whether they should concentrate on the rapidly growing Internet equipment market or focus on the mobile Internet.

It is clear that Europe has had the initiative so far in mobile voice telephony. Whether this will continue during the third-generation UMTS standard is unclear. NTT DoCoMo's i-mode had 31 million subscribers in late 2001, and DoCoMo was also the first operator to enter 3G in October 2001. This means that the locus of the center of experimentation may have moved from Europe to Japan. This may spur equipment producers, since user/producer interaction proved to be important earlier. In the United States some operators have transferred to GSM, and they will be more standardized in 3G than they were in 2G. However, the United States seems to be a slow starter in third-generation mobile telephony. Although Europe will probably enter 3G earlier than the United States, it is doing so at a slower pace than Japan. This might to some extent be because of the very high prices European operators had to pay in some countries for a 3G license – i.e. it might partly be a consequence of public policy.

In 2001–03 3G was developing quite slowly. However, telecommunications operator revenue was growing by 10 percent per year in 2001 and the immediately preceding years. This indicates that telecommunications operators were not subject to a structural crisis, but that they had been hit by the business cycle downturn during 2000–03.

The most important obstacles to the diffusion of 3G are, in the short run, the availability of handsets and, in the longer run, the existence of attractive content suited for the mobile Internet. This points to the crucial role of demand in the emergence of new sectoral systems. With regard to

equipment, the policy instrument of public technology procurement was used both with regard to the Internet (the United States) and with regard to mobile telephony (Scandinavia). When it comes to content in the 3G mobile Internet, the demand has to be provided by final consumers – firms and individuals – outside the public sphere to the largest extent. The success of i-mode in Japan seems to indicate that this will happen[18] but access providers and content providers will have to be innovative, not only with regard to access and content proper but also with regard to charging systems and other innovations in the field of management and administration. It is also a matter of developing niche strategies adapted to the new medium; movies will never best be watched on a mobile phone!

With regard to the fixed Internet, diffusion is proceeding; by 2001 about 70 percent of households in the United States had access. In other countries the degree of diffusion varied considerably. The dominance of US equipment producers, which was established early in the history of the fixed Internet, seems set to remain, at least for some years. At the same time, this sector may be entering a more mature stage of development, with slower growth and smaller profits.

Here follows a summary of the three most important policy issues with regard to the fixed Internet and mobile telecommunications. They are presented in telegraphic form, and in no particular order.

- *The role of institutions has been crucial for policy*. Standards have played a major role in innovation and the success of European mobile telecommunications, both in terms of the diffusion of use and with regard to the success of equipment-producing companies. Deregulation has also played a role for the diffusion of the Internet and mobile telecommunications. Other important institutions are the structure and level of tariffs. Some institutions are national, some are sectoral and others are firm-specific. An important firm strategy objective may be to influence institutions to the firm's benefit.
- *The relations between different organizations and between institutions and organizations are crucial for the functioning and performance of the sectoral systems of innovation*. Examples are the relations between private and public organizations, in the form of research funding, standard setting or public technology procurement. Relations between different kinds of firms and other private organizations are also important – e.g. collaboration between users and producers. Organizations provoke institutional changes, and, when the new institutions come into effect, they may greatly influence the same or other organizations.

18 The slow diffusion of WAP and GPRS in Europe and the United States points in the opposite direction, however.

- *It is of crucial importance that public policy intervention occurs early in the development of the sectoral system.* This is the stage in the development of an SSI when private actors and markets function least efficiently and dynamically. Therefore, policy intervention in these very early stages often means the difference between success and failure, between life and death. Hence, limited policy resources should mainly be allocated to the early stages of the development of new SSIs or new product areas. This has proved to be very important for equipment producers in the fields of the Internet and mobile telephony.

4.2.4 Technology policy in chemicals

The study conducted using the sectoral system approach revealed that the chemical industry is characterized by the leading role played by the large firms, both for their capability to promote innovation and technology development and for their contribution to regional performance and competitiveness. At the same time, the study highlighted that, at the industry level, a division of labor can be observed between large companies and technology-based small companies, with the latter mainly engaged in licensing (process) technologies to other chemical firms. Hence, policy intervention should be focused on these two actors, and the related markets for technologies. In so doing, other elements of the chemical sectoral system will have to be considered, such as universities and other research organizations, financial organizations and IPR regimes.

4.2.4.1 Innovation policies and the large chemical firms The analysis of the process of knowledge generation and the exploration of new technologies has shown that the European chemical companies perform most of their research in their home country, and that patenting activity clusters in a few regions. This confirms that the globalization of R&D by MNEs is, at best, a quite incomplete process. Compared to the geographical cluster, the multinational company is a better mechanism for creating larger networks, for enhancing collaborations amongst delocalized inventors and for producing interdisciplinary patents. In short, this confirms that the firms, and particularly the large companies, typically promote larger research networks, and that they produce a rather general type of research, at least in the chemical business.

However, this also suggests that, as far as the large European chemical firms are concerned, there is no urgent policy intervention required for promoting the generation of R&D and related activities. The large European chemical firms do engage in these activities, they do indeed give rise to large networks of inventors and they do produce patents with wide potential applicability.

Furthermore, the analysis of the globalization process of the chemical industry has revealed that European companies have proven to be particularly active in this process, as they have typically increased their share of plants abroad. This has happened both in advanced markets, such as the United States and Japan, and in the open market of developing countries, particularly in Asia. Thus, the chemical industry has become more global, with a lower share of plants of companies from one region located in the same region, and a higher share of plants from one region in the other regions.

In sum, large (European) chemical companies have been able to invest in R&D and to compete internationally, and so they need limited policy support.

4.2.4.2 Innovation policies and the small firms In contrast to large companies, smaller firms need greater policy support, at least in terms of the creation of suitable conditions for their growth, and for enhancing the potential that their growth may have for the evolution of the industry (especially the new high-tech segments) and its effects on competitiveness and employment. The role of the smaller companies is linked to the opportunities for the development of a full-fledged market for technology in Europe, and – more generally – for the participation of the European firms in the global market for chemical technologies.

Policy interventions should be focused on removing the barriers to the creation of this market. Indeed, European markets for technology are far from being developed, and this requires policy support for their formation. However, these markets have two important features: a) they allow a significant diffusion of technology, which increases the investments of the companies operating in the final markets; and b) they enable the formation of companies that specialize in the development of the technology even if the same companies lack downstream complementary assets.

Among others, the specialized engineering firms are key in such markets. The SEFs imply efficiency gains, greater investments and greater entry by chemical producers in downstream markets, especially by producers that would not have been able to enter if they had to develop their technology in-house. Similarly, the SEFs can be quite important in diffusing new environmental technologies. This calls for policy actions to encourage the rise and growth of smaller firms specialized in the development of such technologies.

Specifically, the following policy actions could be promoted for enhancing the markets for technology in the European chemical industry, and particularly in its engineering and technological subsectors:

- *The development of proper forms of intellectual property rights to support the activities of smaller technology-based companies.* Compared to larger firms, small firms have little access to other means for appropriating the returns on their internal R&D activity, and property rights often represent the only form they can employ.
- *The development of adequate forms of financing for new technology-based companies.* These companies face a high technological risk, which can be faced only by using appropriate forms of financing (e.g. venture capital). By allowing small technology-based firms to arise and grow, markets for technology will grow as well, which implies reduced barriers to entry, greater technological diffusion and new patterns and opportunities for economic growth.
- *The development of new forms of technology diffusion by universities, and the scientific organizations more generally.* Organizations without downstream complementary assets in production and marketing have the highest incentives to license, because they have nothing to lose in the downstream markets if new competitors arise. This is the case with universities and other research organizations. As a result, by encouraging the diffusion of technology by universities (either directly through patent licensing or through spin-offs), established producers in that technological domain will also be encouraged to license, hence increasing the diffusion of these technologies.

The rise of markets for technology also has implications for the vertical structure of the chemical industry, and implies a division of innovative labor, which in turn benefits the downstream producers. The classical advantages of a division of labor are, indeed, that the downstream producers can take advantage of the input at lower costs than if such input had to be produced in-house. Apart from efficiency gains in the downstream industries, this implies greater diffusion of the technology downstream, greater entry of new competitors in final markets, etc. In turn, these advantages of vertical specialization suggest some further policy actions, focused particularly on the reduction of search costs for new technologies, the reduction of the effects of the so-called "not invented here" syndrome and, in general terms, the reduction of transaction costs emerging from technology exchange.

5 Conclusions

This chapter has presented some additions to the existing body of knowledge supporting evidence-based policy. They reflect a shift of emphasis in the formulation of innovation policies, which are, of course, much broader than policies for science and technology. Traditional innovation

policies have been formulated in providing public resources for R&D and changing the incentives for firms to innovate. Tax breaks for R&D, innovation subsidies and patents are typical examples of these policies. The sectoral system perspective does not deny the significance of this approach but recognizes that in practice it may run rapidly into diminishing returns. To offset this it is necessary that innovation opportunities be enhanced, and for this to be achieved by connecting firms within a wider division of innovative labor within and across economies. Improving the organization of an innovation system is an almost certain route to improving the complementary pay-offs from public and private R&D in any sector.

The sectoral perspective provides a tool for policy makers to comprehend the relevant innovation systems and for identifying the actors that should be influenced by policy. The quid pro quo, however, is that policy makers need to invest much more effort in understanding the idiosyncrasies of the sectors. An approach to innovation policy that is not sensitive to the important sectoral distinctions of the kind identified by this book will not yield much pay-off to the policy maker.

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