63
Technology Policy and Economic Growth

25. Figures from American Association for the Advancement of Science, *Congressional Action on Research and Development in the FY 1997 Budget*, special table, "Trends in R&D, FY's 1994–97"; and National Science Foundation, *Science and Engineering Indicators, 1996*, Text Table 4–5.

26. For additional discussion of the political dynamics underlying TRP and the Pentagon's other dual-use technology initiatives, see Jay Stowsky, "The Dual-Use Dilemma," *Issues in Science and Technology*, Vol. 13, No. 2 (Winter 1996–97), pp. 56–64.

27. For a discussion of the history and fate of CRADAs at the Department of Energy (DOE) labs, see "DOE to Industry: So Long, Partner," *Science* (Vol. 274), October 4, 1996. For more on the National Flat Panel Display Initiative, see Kenneth Flamm, "Flat-Panel Displays: Catalyzing a U.S. Industry," *Issues in Science and Technology*, Vol. 11, No. 1 (Fall 1994). For more on the Clean Car Initiative, see Daniel Sperling, "Rethinking the Car of the Future," *Issues in Science and Technology* Vol. 13, No. 2 (Winter 1996–97), pp. 29–34.

28. For evidence, see e.g., Daniele Archibugi and Jonathan Michie, "The Globalization of Technology: Myths and Realities," *Cambridge Journal of Economics*, No. 19 (1995); and Keith Pavitt and Parimal Patel, "The International Distribution and Determinants of Technological Activities," *Oxford Review of Economic Policy*, No. 4 (1988), pp. 35–55.

[21]

The Systems of Innovation Approach and its General Policy Implications

3.1 *The Systems of Innovation Approach—Characteristics and Core Concepts*

3.1.1 Introduction

Systems of Innovation (SI) is a new approach for understanding innovations occurring in an economy. This approach has emerged during the last decade. It points to the fact that innovation processes are evolutionary, and does not therefore make use of the notion of optimality. It also stresses that firms do not normally innovate in isolation but in interaction with other organisations within the framework of specific institutional rules. This approach is still evolving; indeed the ISE project is itself part of this development process, opening new ground and contributing to the consistency and coherence of the approach. In particular, the ISE project has applied the SI approach to several new areas of empirical research, including corporate governance, financing of innovation, and public technology procurement.

3.1.2 Institutions and Organisations

Innovation is a complex phenomenon, embracing both new processes (technological and organisational) and new products (goods and services). Similarly, the processes through which innovations emerge are extremely complex. These processes concern not only the emergence, diffusion, and combination of knowledge elements, but also the *translation* of these into new products and production processes. This translation from basic research to applied research and to the development and implementation of new processes and new products by no means follows a *linear* path. Instead, it is characterised by complicated feedback mechanisms and interactive relations involving science, technology, learning, production, institutions, organisations, policy, and demand.

Most innovations occur in firms. However, innovation is a collective effort whereby innovating firms normally interact with other organisations in the context of existing institutional rules. Innovations emerge, therefore, in systems where organisational actors and institutional rules are important elements. The importance of institutions and organisations is stressed—albeit to varying degrees—in all versions of the SI approach. *Systems* approaches to innovation are essentially an attempt to think through and analyse the nature and implications of the collective character of innovation.

The *organisations* with which innovating firms interact—to gain, develop, and exchange various kinds of knowledge, information and other resources—may be other firms (suppliers, customers, competitors). Of particular importance are inter-firm relations involving sustained interaction between users and producers of technology. Here the argument is that inter-firm linkages are far more than arm's-length market relationships. Rather they often constitute ongoing co-operative relationships which shape learning and technology creation. Firms also interact with non-firm organisations such as universities, research institutes, private foundations, financing organisations, schools, government agencies, etc.

Organisations are formal structures with an explicit purpose and have been consciously created. They are the players or actors (in processes of innovation). It is important to study how firms and non-firm organisations perform in relation to innovations. Is the support that public organisations give to innovation appropriate? Are the technological support organisations doing the right things and doing them reasonably well? In periods of structural change, a country might have to redesign many of its organisations; this has been the case recently in Eastern Europe. The design of new organisations was very important also in the development strategies of Japan, South Korea, and other Asian economies.

The *institutional context* within which organisations interact is constituted by laws, social rules, cultural norms, routines, habits, technical standards, etc. *Institutions are not organisations.* Rather, institutions are the rules of the game; they shape the behaviour of firms and other organisations by constituting constraints and/or incentives for innovation. Some institutions are created by design, for example patent laws or (some) technical standards. Others have evolved spontaneously over extended periods of time, such as various kinds of social rules or habits. Those designed by public agencies may serve as innovation policy instruments. Through institutions the behaviour of firms is also influenced by the social and cultural context in a wide sense. These environmental conditions are often seen as specific to local, regional or national contexts, but they are also dynamic: their forms of operation change with political conditions, changing technological opportunities, economic integration processes and so on. A basic argument of systems approaches is that

system conditions have a decisive impact on the extent to which firms can make innovation decisions, and on the modes of innovation which are undertaken.

In any system of innovation it is important to study whether the institutions are appropriate for promoting innovation. How should institutions be changed or 'engineered' to induce innovation? How can organisations be influenced by changing the institutional structure around them? Are the incentives for innovation appropriate and strong enough? This dynamic perspective of institutional change is crucial in the SI approach. The evolution and design of new institutions was also very important in the development strategies of the successful Asian economies mentioned above. Change in institutional rules and organisational forms are important engines in the changes of whole systems of innovation. However, many of these changes occur spontaneously and can therefore not be directly influenced by policy-makers.

3.1.3 Interaction

As pointed out above, firms almost never innovate in isolation. They interact with other organisations and they do so within a context of institutional rules. *Interaction and interdependence* is one of the most important characteristics of the SI approach, where innovations are thought to be determined not only by the elements of the system but also by the *relations* between them. For example, the long-term innovative performance of firms in science-based industries is strongly dependent upon the interactions of these firms with universities and research institutes. Therefore, a description of a system of innovation must be more than simply an enumeration of its elements. The relations between them must also be addressed.

Both the organisations within a system of innovation and the interdependencies among them are often shaped by—or embedded in—institutions. The relations between different organisations and between organisations and institutions are extremely complex and often characterised by reciprocity, interactivity, and feedback mechanisms in several loops. This makes their measurement and evaluation extremely difficult.

In contrast to the linear view of innovation, the SI approach emphasises systemic learning processes. Another consequence of the interdependent and non-linear view that characterises the SI approach, is that demand is often pointed to as a determinant of innovation. Demand conditions have also been singled out in another complementary approach as one of the four factors determining the creation of a competitive advantage in an industry. Early contributions to the SI approach concentrated on combining the themes of learning and demand. This has been done, for example by focusing on interactive learning as a relation between users and producers of new technology.

A corollary of treating demand as an important determinant of innovation is a widening of the traditional view of innovation policy to include not only supply side instruments, but also demand-oriented instruments. Examples of demand-oriented instruments are government designed institutions such as laws and regulations in the fields of consumer safety and environmental concerns. Another example is technology diffusion policy, including instruments affecting choices between alternatives and their use. A focus on demand also naturally leads to an emphasis on public technology procurement as an innovation policy instrument. Such procurement occurs when a public agency places an order for a product or system that does not (yet) exist, i.e. it can trigger innovation.

3.1.4 Levels

Initially the SI approach was dominated by the national level. However, other systems of innovation than those defined by a country criterion, should be, and are being, identified and studied. An innovation system can be 'supranational' in several senses; it can be truly global, or it can include only part of the world (e.g. an integrated Europe). It can also be 'regional' within a country, an example being the Silicon Valley in California, or Route 128 in Massachusetts. Leaving the geographical dimension, we can also talk about 'sectoral' systems of innovation (i.e. 'technological' systems that include only a part of a regional, national, or international system). In the ISE project we have concentrated on the national and European levels, i.e. on those levels where policy-making is concentrated.

3.1.5 Methodology

The SI approach is holistic and interdisciplinary. Potentially, it encompasses all or most determinants of innovation. This contrasts with 'the traditional OECD approach' which focuses on R&D in a narrow sense (mainly by studying inputs to R&D activities). One important reason to go beyond R&D is that many—or even most—innovations emerge outside the formal R&D system, through the learning processes immanent

in ordinary economic activities. In addition, innovations are not only developed but also produced, diffused, and used. They also change during these processes. All the factors and processes mentioned here are included in a system of innovation—but not in an R&D system! Further, the SI approach allows for the inclusion not only of economic factors influencing innovation but also of institutional, organisational, social, and political factors. As mentioned, its scope is not fixed and these factors may be studied in a national, regional, or sectoral context.

In the SI approach, a long-term perspective is natural and important. This is because innovation processes take time, sometimes decades. They also have evolutionary characteristics, i.e. the processes are often path dependent over time and—still—open ended; it is not clear—even to the actors involved—what the end-result will be, i.e. which path will be taken. The system never achieves an equilibrium. We do not even know whether the potentially 'best' trajectory is being exploited at all, since we do not know which one it would be. History matters!

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

These differences are stressed, rather than abstracted from, in the SI approach. This makes it not only natural but also vital to compare different systems. Without such comparisons it is impossible to argue that one system is specialised in one or the other way, or that a system performs well—or badly. This is because the notion of optimality is absent from the SI approach. The notion of optimality stems from static equilibria and therefore is not applicable to processes of technological change. As the SI approach recognises the evolutionary character of innovation processes, it rejects the idea of optimality. Hence, comparisons between an existing system and an ideal or optimal system are not possible. That the notion of optimality is inappropriate in the context of innovation processes is a major contribution of evolutionary theory, which the SI approach has adopted.

Since comparisons—historical or between existing systems—are the most important means for understanding what is good or bad, or what is a high or a low value for a variable, they are crucial for policy purposes, e.g. for the identification of problems that should be subject to policy intervention. Such comparisons must be genuinely empirical and would therefore be similar to what is often called 'benchmarking' at the firm level. Large benefits could be reaped if comparisons between systems (national, regional and sectoral) were made explicit and systematic. This can be done within an SI conceptual framework.

The SI approach provides sign-posts indicating important characteristics of innovation processes, e.g. the crucial role played by institutions and by interactions between organisations within systems. These sign-posts constitute the bases for detailed comparisons in the analysis of innovation processes. They can also serve as rules of thumb, suggesting where to look for problems and possible solutions in innovation policy-making. In this capacity they can aid innovation policy-makers to 'learn by doing'—i.e. to improve their performance as problem-solvers by comparing it with past performance. In other words, policy can be used to improve the functioning of systems of innovation without there being any notion of optimality—given certain socio-economic objectives such as economic growth and employment creation.

3.1.6 Relevance of the Systems of Innovation Approach

The clear policy trends towards increasing complexity and the growing importance of policy co-ordination, indicate that implicitly, at least, EU policy-makers have already adopted, though perhaps only indirectly, some elements of a systems approach. This is certainly evident in the broader view of innovation policy that has recently been adopted in the 1995 Green paper on Innovation. This document has obvious parallels with the holism of the SI approach, its focus on processes of interactive learning, etc. A central challenge is now to explore the potential for making the learning elements in innovation policy as explicit as possible. The SI approach is also used as a framework for designing innovation policy at the national level in some EU member countries, e.g. Finland and Ireland.

3.2 *General Policy Implications of the Systems of Innovation Approach*

3.2.1 Introduction

Innovation policies, defined as those elements of public action that directly or indirectly affect the creation and diffusion of new products and processes, are aimed at learning, at how to do new things in new ways. Such learning has two important elements.

First, there are policies aimed at the process of learning itself. In practice, innovation policies support many different types of learning processes. We argue, however, that *interactive* learning should be targeted much more directly than is the case today. For example, technology procurement policies could be used more systematically to shape patterns of user-producer interaction. Or the knowledge infrastructure (including the system of intellectual property rights) could be used to develop R&D co-operation more fully, and so on.

Second, there is learning by the policy-makers themselves. New situations require new 'policy capabilities'. Learning feed-back from the conduct of innovation policy should be strengthened. The theories, practices, data bases, institutions, and organisations of innovation policy should also gradually be developed. To achieve this, innovation policy-making itself should be explicitly viewed as a process of learning. Further, direct innovation policy should become a natural part of general economic policy.

The Systems of Innovation approach facilitates this approach to policy issues. It shifts the focus away from actions at the level of individual, isolated units within the economy, towards collective underpinnings of innovation. It addresses the overall system which creates and distributes knowledge, rather than its individual components. It views this system as continuously developing, partly as a consequence of the process of policy learning, in terms of better and better data, improved institutions, organisations, and practices, and generally more competent policy-makers.

3.2.2 The rationale(s) for policy action

The standard rationale for policy action concerning learning and innovation follows from the market failure analysis developed many years ago. This simply argued that a completely competitive, decentralised market system would provide a sub-optimal level of knowledge, and that this leads to a case for public subsidies for knowledge creation, or for the creation of intellectual property rights. This links up with 'linear model' approaches, and leads, in practice, to policies consisting of subsidies for R&D. The market failure approach, however, is particularly weak in identifying where those subsidies should go, which organisations should be supported, and how large the subsidies should be. In other words, it is not very helpful for policy-makers from a practical and specific point of view.

Systems approaches would not necessarily drop such policies, recognising as they do the existence of generic knowledge bases, and the validity of arguments for ensuring the supply of non-appropriable generic knowledge. But, as we shall indicate below, systems approaches have a greater potential for identifying where such support should go. In large part, this is because they pay attention not only to market failures in knowledge creation but also to questions of where and how any market-based system is likely to generate other areas of systematically weak performance in terms of innovation. These systemic problems might provide a justification for policy intervention. They include institutional shortcomings and rigidities, problems in infrastructural provision and investment, and transition problems—to be discussed in the three following subsections.

3.2.2.1 Institutional shortcomings and rigidities

The ISE project has emphasised the fact that economic behaviour of organisations in general, and innovation behaviour in particular, is shaped by institutions which constitute the parameters within which firms act. Two institutions of particular importance for innovation are the system of intellectual property rights and the system of corporate governance. The first is important because privately pursued innovation would stall if firms were not able to appropriate the benefits of innovation. The second is vital because it affects the ability of managements to invest in the tangible and intangible assets upon which innovation depends. Many other institutions are also important for innovation decisions, such as labour law and customary labour practices, safety regulations, environmental regulation, technical standards, and so on.

In section 3.1.2, we distinguished between two types of institutions: those that evolve spontaneously and those that are specifically created or designed, e.g. by policy-makers. Whilst some institutions support and enhance innovation, there can be little doubt that others - both evolved and

designed - inhibit innovation, and thus hinder economic growth. Often this happens for quite good reasons. For example, there might be a very strong social and political consensus, based on ethical principles, supporting legislation that would forbid the 'cloning' of human beings. Institutional design and performance should become a much more conscious part of innovation policy, even when the relevant institutions are not directly concerned with innovation (such as in corporate law). In other words, design, change, or abolishment of institutions should be a conscious part of direct as well as indirect innovation policy.

3.2.2.2 Problems in infrastructural provision and investment

Systems approaches to innovation often stress the importance of infrastructures. Two types of interaction between firms and infrastructures seem to be important: first, with physical infrastructures usually related to energy and communications, and second with science-technology infrastructures (or non-firm organisations) such as universities, publicly-supported technical institutes, regulatory agencies, libraries and databanks, or even government ministries.

These infrastructures have a number of specific technical characteristics which lead to serious problems of investment appraisal. The features include large-scale indivisibilities, and very long time horizons of operation. These features lead to major problems in the financing of infrastructural investment and the infrastructures are very unlikely to produce adequate returns within the context of standard Return-On-Investment (ROI) investment appraisal techniques. This is a serious problem, since most studies of major technology creation or of the nature of industry knowledge bases indicate an important role for knowledge developed within the kinds of infrastructure identified above.

These problems indicate a role for public sector support, of which there are three basic modes: regulations to set up incentives and controls for private provision, subsidies for private provision, or direct public provision. This entire area is problematic at the present time, since increasing pressures on public expenditure in most EU countries have led to privatisation and/or marketisation strategies that have serious implications for infrastructural operations. But from a systems perspective, the insufficient infrastructural investment becomes a significant justification for public sector action. Rather than relying on optimal models, the SI approach can identify such insufficiencies through comparative analysis.

3.2.2.3 Transition Problems

Any innovation-based theory of the economic process must stress dynamics and transitions between technologies. For example, there may be major changes in technological opportunities or patterns of demand. At the same time, however, the notions of firm-level knowledge and learning which underlie systems approaches, imply serious problems for firms and sectors in adapting to transitions. There is considerable evidence suggesting that even relatively minor shifts can provide serious problems for firms with no background in the new technology. This is a problem in particular for small economies which possess relatively small numbers of firms in many sectors; relatively minor discontinuous shifts can provoke major changes in the industrial structure.

Then there are major technological shifts. These transitions can be particularly problematic since they often imply development of, or adaptation to, completely new generic technologies, often based on new scientific knowledge. Here, the relevant capabilities (which are usually not only technical but also organisational) may lie quite outside the existing structure of firms' competencies. What we might call transition problems are thus likely to occur, possibly motivating public policies.

A related feature of systems theories is the notion of path dependence and 'lock-in' to existing technologies. Just as firms find it difficult to evolve past their existing technologies, so industries and indeed the whole socio-economic system can be 'locked-in' to a particular scientific and technological paradigm. It is very unlikely that movements away from such a paradigm can be induced by—for example—tax policies on a particular input. Narrowly focused policy actions at the level of individual agents are unlikely to overcome lock-ins. External agencies with powers to generate incentives, to develop technological alternatives, and to nurture emerging technological systems are often required. This is therefore an important rationale for public action in a systems context. It is by no means a rationale which is likely to be frequently used, but on the occasions it is relevant it is likely to be of exceptional importance. An example is the case of public technology procurement of telecommunications equipment in France (to be further addressed in section 4.3.4). The public procurer there maintained technological diversity by supporting two different systems and thereby provided France with the capability to alternate between these.

3.2.3 Policy capabilities and knowledge bases

We spoke above of learning by policy-makers. What competencies or capabilities must policy-makers possess; what do they need to know, if they are to develop and implement policy actions within the overall framework suggested in this paper? Operating policies within a Systems of Innovation framework would seem to imply that new demands of knowledge and assessment are being placed on policy-makers themselves. In the following subsections we will look at these problem areas: identifying system specificities; identifying and mapping the scientific and technological knowledge bases of systems; assessing system dynamics; and integrating systems.

3.2.3.1 Identifying system specificities

At both the national and regional level, technological specialisation is a pervasive phenomenon, with wide variation between systems. Data on industrial structures, trade patterns, R&D investment patterns, patenting, and so on suggest that there is considerable diversity in the national systems which constitute the EU. The Community Innovation Survey results clearly suggest major 'innovation structure' differences across Europe. We also know that there are significant institutional differences with respect to the governance of firms in different sectors.

The existence of system specificities suggests that 'neutral' policies are likely to be so abstract and general that they have little effect within the distinct structures of specific systems. Policies should therefore be designed with system specificities in mind. This imposes fairly substantial analytical and methodological demands (both statistical and otherwise), regardless of whether policies are being made at the national level or at the regional level. Analytical capabilities need to be developed to identify those system specificities which constitute 'problems', and which should therefore be subject to policy intervention. Such capabilities are also needed to design policies that can mitigate these problems. As indicated earlier, the best way to identify 'problems' is by empirical comparisons between existing systems—European and other—since the notion of an optimal system is inappropriate in the context of innovation processes.

3.2.3.2 Identifying and mapping the scientific and technological knowledge bases of systems

There is clearly a need for policy-relevant knowledge concerning the broad knowledge inputs relevant to a system. Central to the systems approach is the view that the key resource of a firm, or an industry, is the *knowledge base* from which it draws its competence in refining, developing, creating, and selling new products. *Knowledge* in specific areas underpins the capabilities and specific competencies of the firm. It may hence be seen as one of the major factors that creates firm differences and hence firm competitiveness within specific industries. As well as diversity between systems, there is considerable structural differentiation within systems. Thus, the knowledge base of any specific industry tends to be highly complex.

Policies supporting innovation and technological change need rather precise information on the make-up of system knowledge bases. This is not at all a simple matter. Even the knowledge bases of apparently simple industries rest on quite different knowledges. For example, apparently 'simple' sectors such as the fishing or timber industries rely on very complex scientific knowledges—such as wave dynamics or GPS in fishing, or algorithms for optimal cuts in timber. The examples mentioned fulfil classic criteria for public provision; they are codified, non-appropriable, and have public-good properties. An important part of innovation policy design is to identify these knowledge bases and provide support for their development (if called for).

3.2.3.3 Assessing system dynamics

Systems are dynamic; it might even be claimed that they are turbulent in some respects. At the same time they are subject to inertia: for example, patterns of production specialisation change very slowly. Turbulence is reflected in the fact that European economies are characterised by high rates of turnover (job creation and destruction) in all sectors, and by high levels of firm entry and exit. This is particularly so among SMEs where birth and death rates are high, and also in sectors where large firms and economies of scale are present. However, in addition to these 'normal' patterns of change, radical changes in major technologies, in organisational forms, and so on also sporadically occur.

We have argued above that 'lock-in' failures imply a role for policy in adapting to shifts in new technologies and demand. But a more fundamental issue is to identify when such shifts are taking place spontaneously, or when they need to be promoted. It is often assumed that such changes are driven by new technologies, but this is at best an over-simplification—they are often pushed by institutional changes—e.g. various forms of policy regulation—by new demand, and so on. A key issue therefore is the choice between supporting existing systems (with their historically accumulated learning and knowledge bases) and supporting the development of radically new technologies and sectoral systems. In the second case, a key problem is to distinguish genuine transitions from the 'noise' generated by the normal dynamics of the system. It is clearly difficult to answer these questions in a practical way, but solving them is an important part of generating knowledge bases for system-oriented policies.

3.2.3.4 System integration

A key policy issue arising from systems approaches is the need to identify and perhaps support nodal points in the system of knowledge creation and distribution; these are likely to be changing over time. At the simplest level, the task would be to identify key points or functions within the system where public support would improve the overall knowledge distribution capability. Since knowledge systems are complex in practice (even in small societies) and usually managed by a number of separate and different organisations, there is a need for policy co-ordination, and for adequate information systems to ensure that such co-ordination is possible.

Although RTD policies are fundamentally discovery-oriented, they tend in practice also to involve other elements: to combine basic research policies with policies aimed at developing commercial applications, at diffusion, at training, and so on. The general question of policy co-ordination is a long-standing one in all advanced economies and remains largely unresolved. A systems approach suggests that developing information systems for policy co-ordination is a core priority; this function cannot be performed through directives, but must rely on dialogue between policy-makers, researchers, business leaders, unions, etc. and is therefore a key policy challenge arising from the systems approach. Such fora would, among other things, perform the function of linking expert knowledge to wider public audiences.

Specific Policy Implications of ISE and its Sub-projects

4.1 *The Role of Institutions*

In Section 3.1.2, and again in Section 3.2.2.1, we referred to an important distinction between 'designed' institutions, such as laws and technical standards, and institutions that have 'evolved spontaneously', for example common law, customs, traditions and various kinds of social rules or habits. Designed institutions are also normally 'formal' in the sense of being codified, while 'evolved' institutions are often 'informal' or tacit. Institutions that are specifically created or designed by policy-makers are, by definition, instruments of public policy. They constitute the 'rules of the game' or the 'framework conditions'. To be effective—especially in areas such as innovation policy where the aim is to promote learning—the design of institutions must take existing 'evolved' institutions into account.

4.1.1 Designed versus Evolved Institutions

For examples of the dynamic tension between designed and evolved institutions, we can refer to the ISE empirical work on public technology procurement as an innovation policy instrument. The findings indicate that, in Europe, there has often been a conflict between institutions designed by policy-makers and evolved 'co-operative' institutions concerning relations between buyers and sellers. The rules designed by policy-makers often promote anonymous market relations and 'perfect competition'. For example, the EU procurement directives encourage public agencies to conform to a norm of non-interactive, arm's length market relations in public procurement. The evolved institutions mean close interactive co-operation between procurers and suppliers; this co-operation is a necessary element in an effective public technology procurement (which involves the development of the technologies procured).

In Sweden, two cases of public technology procurement (high-voltage electrical transmission and electronic telecommunications switching equipment) have been very successful. These cases led to radical technological breakthroughs which were crucial for the consolidation and international competitiveness of the supplying firms: Ericsson and ASEA/ABB. The EU Procurement rules, rigorously applied, would have prevented such procurement processes from occurring. This is because they

would have worked against the long-term co-operative relations between procurers and suppliers that led to the breakthroughs in these cases.

To underline the tension between EU procurement rules and the need to accommodate informal co-operation in the context of user-producer interaction related to technical change is not to suggest a reversion to protectionist policies. It is rather to indicate that *too great an emphasis on 'perfect competition' can undermine competitiveness.*

Protectionist policies can, of course, also undermine competitiveness, as shown in the case study of telecommunications procurement in Italy. There, a short-term, reactive, protectionist policy that was intended mainly to enhance the market position of national firms dominated. This failed. It actually constituted an obstacle to a longer-term strategy that could have not only altered the direction and speed of technological change, but also increased technical diversity. A side-effect of this latter strategy might have been to enhance competitiveness.

Conversely, the Finnish study of telecommunications procurement has provided strong evidence for the importance of international competition between potential suppliers. The institutional rules (the procurement regulations and competition laws, etc.) were such that the Finnish PTT was prevented from pursuing a protectionist policy.

The French and Austrian case studies of telecommunications equipment procurement indicate the strategic importance of using institutions to create competition between alternative technologies. Responding to the competition between an emerging national champion and powerful foreign-owned subsidiaries, the French procurer converted the rivalry for market shares into a technology competition. The procurer organised technology projects in such a way as to allow for competition between the technologies being developed by different suppliers.

Both the French and the Austrian cases offer positive examples of how technology competitions can be promoted within an institutional framework that ensures gains from collaboration. France created not one but two 'national champions' representing alternative technological trajectories. Central co-ordinating mechanisms were used to orchestrate flows of knowledge and expertise between the two. Austria, pursuing a similar policy on a more modest scale, instituted an ongoing 'quality competition' between suppliers and procured two different solutions in a way that reflected the evolved institutional set-up of the Austrian 'social partnership'.

The policy conclusion is that 'perfect competition' should not be enhanced at all costs. A subtle balance between co-operation and competition in processes of technical change exists. The issue therefore is how long-term user-producer relationships in processes of technical change can be allowed and supported without this leading to protectionism. This issue is not taken fully into account in the existing EU procurement rules.

4.1.2 Mismatch among Designed Institutions

Other sub-projects point to the existence of a tension or mismatch between different kinds of designed institutions, that often represent different levels of policy-making. For specific examples, we refer to the sub-project "Science-Based Technologies and Interdisciplinarity".

Two specific institutional issues emerge from this sub-project. The first concerns the strongly disciplinary-oriented career schemes in public research organisations in most EU countries. The case studies conducted in France and Germany found that these schemes impeded the creation of interdisciplinary research networks within and between non-industrial research organisations and, to a lesser extent, between industry and public research. This mismatch is relevant for interdisciplinary technologies in general. An important policy issues is therefore that interdisciplinary components need to be integrated into academic career schemes.

The second issue is specific for one of the technological areas studied: the development of new pharmaceuticals. During this process, different institutions such as laws, rules, norms, codes and standards are important. So are certain organisations, especially the different authorities responsible for the implementation of these measures. The institutions include, for example, good manufacturing practice (GMP) rules for the production of drug candidates, good clinical practice (GCP) rules for testing and rules for the application and approval of new drugs. The authorities involved include organisations at the national level as well as the European level. Co-ordination between the different national institutions has been difficult, posing problems for the internationally acting industrial organisations.

Since 1995 organisations and institutions at the European level has gained additional momentum in this field through the introduction of a centralised scheme for approving innovative drugs. For these medicines it is possible to obtain approval for all member states at once as opposed to previous multistep national approval schemes. Possible mismatch between different national institutions can thereby be avoided.

To implement this European institutional framework, a new organisation based in London has been founded, the European Medicine Products Evaluation Agency (EMEA). Since relations with and proximity to regulatory authorities are important factors if the necessary testing and clinical trials during drug development are to be carried out efficiently, the creation of new institutions and the corresponding new organisations also influenced the innovation behaviour of the pharmaceutical industry: Britain has become more attractive as a location for clinical research compared to other European countries. It appears that the problems of mismatch between different national institutions have been mitigated by the creation of a higher level (EU) institutional framework and in addition, a higher level organisation responsible for the implementation of this framework. As an additional indirect effect of this development, there has also been a shift in which European locations are considered attractive for the execution of certain types of pharmaceutical research and development.

4.1.3 Institutions as Selection Mechanisms

Institutions play a very important role with respect to innovation processes by influencing the selection between technologies. At least two other empirical sub-projects—"Procurement" and "Technological Entry"—refer to technical standard setting as an institutional area where it is of crucial importance to make strategic selections. It is important to select 'good' standards, since they will act in turn to select 'good' technologies. The example used by both is that of the NMT standard in mobile telecommunications, which gave a competitive advantage to Finland and Sweden and crucially assisted Nokia's and Ericsson's entry into mobile telephony. (For further discussion of this example, see section 4.2.4.)

Early in the transition phase, when new technologies emerge, technical standards can be of great significance in influencing the content and speed of technological development. For many technologies, market forces will lead to the development of 'de facto' standards without the need for government intervention. In other cases, as in telecommunications, intervention by public (or semi-public) agencies may be needed to limit diversity in order to permit faster diffusion of a preferred technology. By limiting diversity, standards also reduce uncertainty. Thus, standards can create a stable environment for investment and growth. They may, however, also lead to lock-in situations.

4.1.4 Divergence of Institutional Frameworks

Convergence versus divergence in national systems of innovation is a theme that runs through all of the ISE empirical sub-projects. The results obtained from the sub-project on technological entry indicate that the characteristics of the national systems of innovation seem to matter significantly in affecting the patterns of innovative activities and the division of labour among large firms and small firms as well as among firms that are established innovators and firms that are new innovators in the various technologies and sectors.

The Technological Entry sub-project has found in Germany a national system of innovation that generates a highly stable innovative environment in terms of new innovators and innovative turnover. Here established innovators and a very concentrated innovative structure are present. The United Kingdom and Italy, on the contrary, have national systems of innovation that generate a more turbulent environment for innovative natality and mortality. France occupies an intermediate position between the extremes represented by Germany and Italy.

Corporate governance is concerned with the institutions that influence the ways in which business corporations allocate resources and returns: regulation systems, ownership and control structures, tax policies, financial systems, and so on. For example, these institutions influence the allocation of resources between physical assets (in the form of fixed capital) and intangible assets (such as human capital, skills, R&D, product design, new organisational forms, improved monitoring and understanding of markets, etc.). Intangible assets and investments in these are crucial for innovation. Hence the institutions of corporate governance are crucial for innovation processes and performance. In other words, the ability to learn, to change production processes and organisation, and to develop and introduce new products determines the long-run survivability and growth of firms. Therefore, the institutions of corporate governance shape the innovation and growth performance of firms and countries; they both enable and prevent strategic decisions concerning the types of investments that corporations make and to whom the returns on these investments should be distributed.

The key to formulating appropriate corporate governance policies in the EU is an understanding of the social conditions that support the commitment of financial resources to, and the integration of people into, the processes of organisational learning that are at the heart of the innovation process. The key social conditions are *organisational integration*, *financial commitment*, and *organisational control*. *Organisational integration* creates incentives for large numbers of people with different functional specialties and hierarchical responsibilities to engage in processes of organisational learning leading to innovation. *Financial commitment* ensures that organisational learning processes—and thereby innovation processes—will be sustained until they can generate financial returns. *Organisational control* permits co-operative relations between (a) those corporate participants engaged in the strategic allocation of resources and (b) those participants engaged in the processes of organisational learning directed toward innovation.

These conditions of organisational integration, financial commitment, and organisational control differ markedly across nations. A distinction is often made between an Anglo-American and a German-Japanese model of governance. Recognition of these differences should make one wary, for example, of notions that an Anglo-American model of corporate governance is in competition with a German-Japanese model. Comparisons of Britain with the United States or of Germany with Japan reveal pronounced cross-national differences in organisational integration, financial commitment, and organisational control. These differences affect both the responses of national corporations to challenges from innovative international competitors and the types of organisational learning in which these national corporations tend to invest.

Our analysis suggests that governmental policy should be designed to structure the institutions of corporate governance in a way that encourages strategic decision-making processes for the allocation of corporate resources and returns. These processes should:

1. involve those people engaged in innovation-related organisational learning.
2. reallocate both people and money from existing enterprises to new ones that can engage in innovation-related organisational learning.
3. encourage the integration of producers who have previously been excluded from innovation-related organisational learning processes.

To summarise, the sub-project on technological entry offers evidence of how institutions, by affecting the behaviour of firms, generate diversity, not only in terms of innovative performance but also in terms of innovative capabilities. The sub-project on corporate governance indicates that such diversity can be a critical source of competitive advantage.

4.1.5 Convergence of Institutional Frameworks

As stressed in the sub-project on governance, many aspects of public policy—including especially the operation of stock markets and their impacts on mergers and acquisitions activity—over the past decade have in effect been aimed at changing systems of corporate governance, i.e. at changing institutions. These changes have not, however, taken the innovation capabilities of companies sufficiently into account. Policy-makers need to consider more thoroughly how policy measures aimed at improving efficiency and innovation might affect long-term asset building.

There is a clear link here with the work of the sub-project on financing innovations. As stated in the scientific findings for that sub-project, relations between firms and financial organisations are often linked to the character, rules, and mechanisms of corporate control. Some observers claim that the low debt-equity ratios in the Anglo-Saxon countries could explain why exactly these countries have a more developed market for buying and selling firms, including a higher frequency of take-overs. In other words, firms in the Anglo-American 'world' tend to be more reliant on stock markets for financing than on banks. Therefore, their managements are more directly accountable to share-holders.

The sub-project on financing indicates a process of convergence between systems of financing but also, at the same time, the maintenance of a certain level of diversity. Thus, even though the scientific findings pointed to a clear convergence, we do not expect this convergence process to continue infinitely.

The development of financial systems is an example of a mix of designed and evolved institutions. On the one hand, policy-induced institutional changes do affect the evolution of financial systems. But on the other hand, the structure of the financial system is tied into the production structure through the historical development of the larger economic system. The competencies which financial systems have built up reflect the division of labour between financial organisations and the interplay between industrial firms and financial organisations. It is argued in the financing project that the evolution of financial systems must not be pushed too far away from this basis. These findings are important in view of the consideration that current EU policies appear to be pursuing convergence on a rather uncritical basis, almost as an end in itself.

4.2 Interaction between Organisations

4.2.1 Introduction

In section 3.1.3, we strongly stressed that interaction between organisations is one of the most important characteristics of the systems of innovation approach. Innovations are not only determined by the elements of the system but also by their relations with each other. In other words, innovation is an interactive learning process.

In this subsection, we will summarise some results of ISE research on interaction that are of direct policy relevance. Two modes of policy action will be differentiated. First we will discuss *indirect* policies, which are closely related to the public influence on the framework conditions or institutions mentioned earlier. Second, we will discuss *direct* policies—illustrated mainly by interactions related to public technology procurement where a public organisation is directly involved in the interaction. As noted in section 3.2.3.4, an important policy challenge is to identify nodal points in interaction patterns and support those that are not operating properly.

Interaction should be based on a balance between similarity and complementarity: the interacting partners need to be similar enough to be able to communicate well, yet different enough (i.e. complementary) to be able to learn from each other. Consequently policies designed to foster interaction need to be sensitive to the roles and interests of the interacting partners if interaction is to function well.

4.2.2 Indirect policies

The development of science-based and interdisciplinary technologies is characterised by very complex interactions between different organisations and in consequence raises the general questions of whether and how policies can act in this complex environment. It is obvious that profound knowledge, not only of the technologies but also of their organisational contexts, is necessary. In addition, this requirement arises in a situation of uncertainty about future paths of (technological and organisational) development.

A new aspect of the interaction theme is the entry of financing organisations in innovation networks. This phenomenon is fuelled mainly by the fact that scientific findings are now being attributed monetary values in the new knowledge-based economy. Interactions between these and the other major organisations—universities, research institutes, SMEs, large firms, public bodies—are presently in an experimental stage and have not explicitly been addressed by specific policies so far. Of particular interest in this context are the interactions between financing organisations and SMEs and also with universities/public research organisations, which play an important role as consulting organisations. These interactions are often shaped by institutions, which constitute part of the framework conditions for inter-organisational interactions.

Problematic aspects of these interactions relate mainly to the following two issues: first, the assessment of technological and scientific developments by financing organisations; and second, the understanding of the culture and evaluation criteria of the financing organisations by SMEs. Obviously, an interactive learning process is required between the different cultures. Innovation policies could and should play an important role in initiating and mediating such a process, for example, by facilitating the integration of financing organisations into innovation networks. Policies are required that would help financing organisations to develop the knowledge and expertise they need to evaluate properly the intangible assets involved in innovation processes. What is needed is 'intelligent' capital.

ISE research on science-based and interdisciplinary technologies indicates that, compared to direct intervention, indirect policies as part of a learning process might be better suited for supporting interactions in very complex situations. Several policy issues can be differentiated in this context.

First, supporting the knowledge-generating process in public research organisations and universities is an essential task, because building up advanced competencies is a central prerequisite for the formation of networks. This knowledge includes not only scientific or technological know-how but also problem-based learning skills that are essential for communication between organisations.

This leads to a second policy issue, i.e. education policies. Communication and interaction capabilities need to become an integral part of university education in science and technology.

A third policy issue concerns incentives for interdisciplinary interactions at universities. Disciplinary-oriented career schemes, which are the rule in countries like France and Germany, do not promote such interactions. Therefore, integrating interdisciplinary components into academic career schemes in such countries is an important policy task.

The initiation and sustainment of interdisciplinary co-operation strongly depends on interpersonal links and social networks. In consequence, a fourth policy issue is the question of whether to support such links and if so, how. The appropriateness of mobility and exchange programmes for researchers or communication events (e.g. conferences) needs to be reconsidered in this context.

A fifth issue is that institutions governing interactions leading to innovations are, in most cases, not specifically designed for that purpose. More emphasis on this role of institutions during their design—and even more importantly during their implementation—is a necessary policy task. One option for implementing such policies would be setting up fora for dialogues between the affected organisations—SMEs, large firms, universities, public research institutes, financing organisations, and public organisations responsible for creation of institutions. This should be done during the early design phases of new institutions but also with the aim of reshaping already existing institutions and, in particular, streamlining the relations among and operation of such institutions. These fora would constitute a part of the learning process which the innovation policy process should be.

4.2.3 Direct Policies

The indirect policies discussed in the preceding section can be complemented through direct policy approaches. For example, public technology procurement can be used as a direct innovation policy instrument. As a matter of fact, public technology procurement *is* a matter of interaction between (public) procurers and potential suppliers, i.e., it is a matter of interaction between elements of the system of innovation. The point of departure is a perceived socio-economic problem or need that is not solved or mitigated by private market actors. These may be, for example, of an environmental or infrastructural kind. In other words, public technology procurement is a policy instrument working from the demand side—and there are not many such instruments available.

ISE research on Public Technology Procurement has identified and studied several types of procurement. In the 'classical' case of public technology procurement, the public agency uses nothing but its own market demand to induce technical innovation. It simply acts as a demanding buyer. This has been the case in infrastructures (like telecommunications and rapid trains), when government agencies are the final users of the product or system. In other cases the government acts as a co-ordinator and catalyst for user-induced technical innovation. It then co-ordinates the demand and needs of actual users.

As will be argued in section 4.4, some kinds of public technology procurement are better transferred to a supranational level (such as the EU level in Europe). In other cases, it is more appropriate that the procurement continues to be organised at the national level. Another important policy conclusion of ISE research on public technology procurement—involving a wide range of empirical case studies—is that the development of competence is crucial within the procuring organisation as well as in the supplying one. Otherwise, the interaction between them will not be able to constitute a learning process of an interactive kind. In the procuring organisation, the competence concerns the formulation of functional specificities of the system or product wanted. In the supplying organisation, it is a matter of techno-economic capability to fulfil these specifications. These partly different kinds of competencies must be relational and reciprocally modified by the potential user and the supplier.

The rules and laws designed—by national governments and the European Commission—to govern the relations between procurers and suppliers must allow for close interactive learning between them. The main reason is that interactive learning is fundamental to innovation—and particularly so in the context of public technology procurement. The relation between the procurer and the (potential) supplier(s) must certainly not be confined to arms-length market relationships. In basic theoretical terms, 'perfect' market relations do not allow for exchanges of information and knowledge about anything other than prices and quantities. Obviously, this restriction of communication is inappropriate in cases where interactive learning processes about the nature of new systems and products are crucial to their development. This has radical implications with regard to existing regulation at the European level which currently does not recognise the need for such interaction, except in a negative way (see also section 4.1.1).

The present EU legislation merely *allows* such interaction to take place—and only in special cases. Under the EU procurement legislation, collaboration between firms and public agencies aimed at the development of new technologies with the ostensible goal of increasing public benefit

has only been tolerated as a 'necessary evil'. Implicitly, it regards interaction between procurers and suppliers as an aberration—a deviation from the legalised norm of autonomous 'market' relationships. Accordingly, it has restricted both the fields of economic activity in which such interaction will be allowed to occur and the circumstances under which it will be allowed to proceed. National rules must be compatible with EU procurement directives and therefore have the same character. In other words, possibilities for interactive learning have been diminished because of EU regulation.

The EU procurement rules have, it is true, allowed for the continuation of user-producer interaction in public goods markets through certain special tendering procedures, allowable exemptions from the regular procurement rules, and a flexible regime of enforcement. However, this has been done without an explicit policy rationale—only the implicit understanding that these are necessary accommodations of national and sectoral interests. Hence, for the benefit of innovation, the regulations should be changed. In a positive way, *the regulations should be changed to encourage, stimulate, and spur interaction between procurers and suppliers in fields where public technology procurement is appropriate.* A committee should be appointed to investigate possible revisions of the existing EU procurement rules in this direction.

4.2.4 Mix of Specific Policies and Instruments

The choice of an appropriate 'mix' of specific policies and instruments is a complex matter, varying to some extent from case to case and to a greater extent from one general area of policy to another. Below, we discuss two such areas, represented by the ISE sub-projects on technological entry and governance, in terms of mix of specific policies and instruments.

ISE research on technological entry covers examples of technological development in a complex and changing environment where successful technological transitions depended on both direct and indirect policies. The policy 'mix', moreover, had to accommodate progressive changes in the structure of industry and the configuration of innovation networks.

In transitions (for example between old and new technologies and products), processes of interaction between new small firms and large established innovators take place in various ways. New small innovators and large established firms frequently support each other in the early stages of transition through co-operation and division of labour. This has been the case, for example, in our study of telecommunications equipment. However, this interaction among independent firms does not necessarily remain stable over time. Often, it changes, and the small innovator is acquired by the large firm (as in the cases of Nokia and Ericsson). In other cases, with the evolution of technology and the development of the new industry, co-operation and division of labour may turn into competition between the small firms and the large corporation in some specific market segments.

Generally, the evidence from the Technological Entry sub-project—as well as the Science-based sub-project—indicates that small firms play a crucial role as intermediaries between universities and large established firms. In the autoimmune disease case studied in the Science-Based sub-project, small research firms constituted important interfaces between public research organisations and large firms. In the Technological Entry sub-project, Nokia's and Ericsson's diversification into mobile telephones depended critically upon the acquisition of small firms that had pioneered the development of this technology. Innovation policy needs to recognise the very dynamic role often played by new technology-based firms in processes of transition.

As both these examples demonstrate, small technology-based firms proved to be less rigid and less subject to inertia than did the large corporations. This accounts for the vital role they play in networks of innovation. The policy conclusion that can be drawn is that such firms should be supported by public innovation policy. One of the most important forms that such support can take lies in the area of financing. It is well known that SMEs generally and technology-based ones in particular face problems in securing adequate finance. This is partly because traditional financing organisations have problems in assessing the value of intangible assets. It would therefore be appropriate to consider the establishment of a *special fund* to provide such financing. We want to stress that such a fund should *not* support SMEs in general; it should *only* support advanced technology-based SMEs, particularly those involved in co-operation with other firms and organisations in strategically important areas of new technology development.

As was mentioned, in section 4.1.3, the cases of Nokia and Ericsson were also studied by ISE as examples of Public Technology Procurement. Moreover, it was indicated in this connection that the NMT stand-

ard in mobile telecommunications was of critical importance to these two firms' successful diversification into mobile telephony. Here, the establishment of technical standards, usually conceived of as an indirect policy measure affecting 'framework' conditions, was so closely co-ordinated with a direct policy measure, procurement, that standards creation may be considered to have been used as a means or element of procurement. Other indirect policies were also employed. In the case of Nokia, for example, competition policy creating incentives for innovation-based competition on the part of both 'users' and 'producers', the development of an exceptionally high level of competence in the 'buying' agency (the Finnish PTT), and provisions for the build-up of competence in 'supplier' firms were all important 'framework' conditions fulfilled through the use of indirect policies. In the Swedish case, co-operation in research between Ericsson and the research laboratories of the Swedish PTT (Televerket) were also very important in the early days of entry into the mobile phone industry.

The Science-Based sub-project, has argued in its conclusions concerning indirect policies, that it is necessary to have access to a wide range of policy instruments in order to address specific 'system' problems in a manner that combines the creation of diversity with selectivity and the generation of economic benefits. To exemplify this rather abstract formulation, we can refer to ISE research on governance. Obviously governance is mainly an institutional matter (and has been dealt with in section 4.1). However, these policies and regulations certainly have a bearing upon the relations between firms as well as between firms and non-firm organisations.

The entry and involvement of financing organisations in innovation networks was mentioned in section 4.2.2 as a problem of interaction that has remained largely unaddressed by policy-makers. The conclusion of ISE research on governance for this emerging policy issue is that Europe (exemplified by Germany) should attempt to learn from the successful Japanese model of industrial organisation, in which both management and financial resources have remained "committed" to innovation, due to strong patterns of organisational integration.