ORGANISATION FOR ECONOMIC
CO-OPERATION AND DEVELOPMENT

DIRECTORATE FOR SCIENCE, TECHNOLOGY
AND INDUSTRY

COMMITTEE FOR SCIENTIFIC AND
TECHNOLOGICAL POLICY

RESTRICTED

Paris, drafted : 15-April-1994
OLIS : 19-Apr-94
dist. :

DSTI/STP/TIP(94)4

Or. Eng.

WORKING GROUP ON INNOVATION AND TECHNOLOGY POLICY

ACCESSING AND EXPANDING THE SCIENCE AND TECHNOLOGY KNOWLEDGE BASE

COMPLETE DOCUMENT AVAILABLE ON OLIS IN ITS ORIGINAL FORMAT

(Note by the Secretariat)

1. The present report has been prepared by Professor Paul David (All Souls College, Oxford University; CEPR, Standford University), Professor Dominique Foray (CNRS, France; permanent consultant to the OECD) and the Secretariat in the context of the project on national innovation systems, in line with the work plan agreed by the Committee for Science and Technology Policy .

2. It proposes a conceptual framework for guiding comparative analyses of Member countries' innovation systems. This framework needs first to be tested before it can be applied in a comparative study involving all Member countries. Some (say, four or five) countries should volunteer to participate in this test, which would involve substantial national contributions.

Action required

3. The Group is invited to:

-- examine the report and comment on the relevance of the approach;

-- decide on the immediate follow-up, particularly with regard to lead-countries (see paragraph 2).

Deadline: written comments are requested by the 6 June 1994.

ACCESSING AND EXPANDING THE SCIENCE AND TECHNOLOGY KNOWLEDGE-BASE

A conceptual framework for comparing national profiles in systems of learning and innovation

Table of contents

List of tables and figures

Tables

Figures

Executive Summary

1 This report proposes a conceptual framework for guiding comparative analyses of Member countries' innovation systems. Such a framework can be characterized by: its theoretical foundations; its ability to be used as a tool for conducting empirical studies which would add to the current knowledge of the functioning of national innovation systems; and the policy relevance of the issues that, thereby, could possibly be considered or re-examined.

2. The theoretical options taken in the report are such as to :

-- ensure a convergence between the analysis of systems of innovation and the more general economic analysis of the implications of the emergence of a knowledge-based economy;
-- acknowledge the complementarities between knowledge distribution and innovation, rather than accepting a dichotomy between technology diffusion and generation; and
-- analyse national systems of innovation as they are enmeshed in larger, more complex transnational relationships.

3. The key organizing concept is the "distribution power" of an innovation system, which means its capability to ensure timely access by innovators to the relevant stocks of knowledge. The report identifies the characteristics of a distribution-oriented system, as well as the specific capabilities in the adjacent domains of education and training, financing, and industrial organization (Japan is taken as an example). Furthermore, the report demonstrates that a distribution-oriented system is not a transitory state, designed to meet the innovation requirements of a technological borrower committed to a strategy of "catching-up". It is an organizational mode of innovation that is able to support the various steps of the process of technological advance.

4. The report advocates that policy-makers of Member countries need to have a better picture of their country's (and other nations') performance with regard to the distribution of knowledge; and, symmetrically, of the magnitude of the loss of innovation potential due to the limitations of their knowledge-distribution and knowledge-pooling capabilities.

5. It is necessary to reconsider in this perspective available indicators on scientific and technological activities. The report contains proposals for interpreting existing indicators as well as for developing new ones, designed specifically to measure the "distribution power" of an innovation system.

6. The report points to a number of policy issues which could be reconsidered from the perspective of knowledge distribution. First, it stresses the need for domestic policies to adjust their objectives and instruments to the new paradigm for technological innovation, based upon more systematic and intensive exploitation of available knowledge bases and strategies of recombination and integration for the generation of novelty. This would involve in particular greater integration between S&T and information technology policies. Secondly, it identifies many areas for potential international economic liberalization and cooperation that would serve to strengthen the respective national innovation systems. Among the subjects that deserve further examination in this regard are intellectual property rights harmonization, international standards institutions, co-operation on electronic infrastructures and on megascience facilities, and coordination of arrangements for overseas training of scientists and engineers.

Section 1
Introduction and overview

1. The proposition that there exists as an attribute of modern economies a set of entities (or perhaps functional properties) that usefully can be characterized as their respective national systems of innovation, is a general notion which has been gaining wide currency. It has come to be seen as providing the conceptual foundation for undertaking comparative studies of scientific and technological development and its relationship to the dynamic economic performance of entire nations. While different writers employ the phrase "national systems of innovation" in various ways, a consensus seems to have emerged that whatever may be its precise meaning, it refers to structures of economic organization whose scope is far more comprehensive than the quantifiable aspects of R&D performance financed by private companies and the state, and which, through their bearing upon the generation and diffusion of innovations, contribute to the improvement of productive efficiency.

2. In the economics literature the concept of national systems of innovation has been given intellectual coherence and impetus through the formulation provided recently by B.-A. Lundvall and his colleagues in National Systems of Innovation (1992). There the systems in question are defined as being comprised of those elements of social organization and behavior, and the relationships among them, that are either "located within or rooted inside the borders of a national state", and that interact in "the production, diffusion and use of new, and economically useful knowledge". Since however sensible it is to link the innovative capabilities of a society with the ways in which its economic and social organization affects the acquisition and utilization of useful knowledge by its constituent members and agencies, these are neither strikingly original, nor rhetorically stirring propositions on their face. What, then, accounts for the sudden rise in the popularity of the national systems of innovation concept?

3. It would seem that the attention which discussions of national systems of innovation is coming to command outside purely academic research circles has derived in no small part from the association of the subject matter with the growth of interest in and sympathy for national economic strategies directed to enhancing "competitiveness" under conditions of ever-intensifying global economic rivalry. The phrase has come to evoke (and has, in turn, acquired some nuances from) the new spirit of "technonationalism" that during the past decade has been animating economic policy discussions in the industrialized and industrializing nations alike. Technonationalism, as described by Richard Nelson and Nathan Rosenberg, is what one gets by combining two beliefs, each of which have come to be more and more widely held: that the technological capabilities of a nation's firms are a key source of their competitive prowess, and that the formation of such capabilities is not only a process conditioned by national affiliation and location, but is amenable to governmental management -- that is, competitive capabilities "can be built by national action."

4. In this Report we re-examine the usefulness of the complex of ideas about the determinants of technological progress and knowledge-based economic growth that have come to be connected with the national systems of innovation concept. Building upon those foundations, we offer a framework of analysis

intended as a guide for future empirical research and policy discussions in this area. In the latter connection, we believe it is most important to recognize that the economic benefits of cooperation are especially great when one is concerned with the production and utilization of scientific and technological knowledge. We point out the danger that these may be jeopardized by "technonationalist" approaches to policy that emphasize only the private value of noncooperative strategies, and are essentially neo-mercantilist in their readiness to lend governmental encouragement and support for the development of capabilities best suited to the pursuit of rivalries over the commercial appropriation of economic benefits from the existing stock of knowledge and the additions that may be made to it.

1. From "national systems of innovation" to national profiles in learning systems for scientific and technological knowledge-based economic development

5. Before proceeding further it should be noticed that although one of our main goals is to develop a framework within which comparative studies (using both quantitative and non-quantitative data) can be carried out on a national basis, and that this is a purpose that parallel's the stated aim of Richard Nelson in organizing the set of national studies recently appearing in the volume entitled National Innovation Systems (1992) under his editorship, the approach we have adopted is far less all inclusive than the one Nelson proposes. However great the influence on the long-run "performance" of modern business firms and economies we attribute to their command over knowledge about technological and scientific opportunities and constraints -- and we accept the view that such knowledge is a critical factor in the capacity to remain competitive through successful innovation, the scope of the framework articulated here remains less comprehensive than would be required to accommodate Nelson's broad definition of "innovation" as "what is required of firms if they are to stay competitive" in industries where technological advance is significant. On this score our framework is rather closer to that of Lundvall, in being focused upon the effectiveness of private organization and public institutions, and on the ways in which they interact in the production and distribution of economically relevant knowledge throughout the economy.

6. Because we are ultimately concerned with the determinants of long-run economic performance, and because scientific and technological knowledge, in our view, is more cumulative in character and more durable in it economic relevance than are other kinds of knowledge that economic agents find valuable in the day-to-day conduct of their activities, we have not thought it necessary to follow Lundvall's effort, to extend the notion of learning to encompass all aspects of knowledge that are relevant to the successful conduct of economic activities -- however logically attractive that may be. Instead, the discussion that follows focusses on learning systems for scientific and technological knowledge, while accepting the scope and forms of such knowledge to be broad as well as varied enough to include both codified and highly abstract information and tacit knowledge of a very practical kind concerning methods of organizing and carrying out productive tasks.

7. Another distinctive feature of our general analytical orientation is that we apply a "systems-theoretic" approach in examining the relationship between a society's knowledge-base and its capacity to generate and utilize economically beneficial innovations. This entails explicitly identifying the functional requirements that must be fulfilled, in one way or another, by all social groups that reproduce themselves as productive entities, and thus remain capable of adapting to changes in the natural, technological and commercial environments in which they are situated. The systems-theoretic approach to learning activities in science and technology, furthermore, involves going beyond the enumeration and description of the ways in which a particular society satisfies each of those minimal requirements, and examining the interconnections and interdependence among them. There is an evident contrast between this and an

approach that has been most criticized but remains still common in modelling technological change -- namely, that of representing the process as a sequence of several independent stages, consisting of basic research, applied research and invention, market experimentation and commercial innovation, and lastly the diffusion of new methods and products throughout the economy. By focusing attention on each element or stage of the process in isolation from the rest, this simple linear construction ignores the wealth of empirical research at the microeconomic level which shows technological change does not proceed uni-directionally, through this step-sequence; it is a far more complicated dynamic process involving interdependence among successive changes, rather than the passage from a discrete scientific discovery into a distinct invention, and thence to a commercial product. Seen at the level of the innovating firm, influences emanating from information about market conditions and technological opportunities flow over a multiplicity of linkages and feedback loops among the various activities that are taxonomically distinguished in the linear, stage model.

8. Our framework of analysis thus discards the classical linear stage model, in favor of articulating the interdependence and interactions among the sub-process in the overall system governing the production, distribution and utilization of economically relevant knowledge, an approach that follows David's (1993) summary discussion of the systems dynamics of technological change, and the more richly elaborated picture drawn by the report to the Commission of the European Communities on "An Integrated Approach to European Innovation and Technology Diffusion Policy", prepared under the editorship of Soete and Arundel (1993). The process of scientific and technological advance, on this view, is seen within a general evolutionary framework to be a phenomenon of "organized complexity" that results in cumulative and irreversible long-run change, in which successive events are uncertain, highly contingent and difficult to forecast. Applied at levels of aggregation higher than the firm -- that is, to the way in which productive efficiency is transformed in a branch of industry or a block of interrelated industries -- emphasis of the approach accepted here is placed upon features that affect systemic performance, such as the feedbacks and interactions between advances in technology and science, the dynamic interdependence of innovation and diffusion processes mediated by markets, the indirect impacts of institutions and organizational arrangements designed to meet some functional requirement on the performance of other functions. One has to consider, for example, the way that the manner of funding basic science research impinges on the effectiveness of educational activities that would enable individuals to access existing bodies of knowledge, and the way that strengthening intellectual property protection measures to stimulate R&D in one branch of industry may effect investment in the development of technologies that are complementary to the ones that would have gained stronger protection.

9. Neither the idea of learning as central to the activities of individual economic agents and organization, nor the pertinence of the systems approach to analyzing the determinants of innovation and adaptive capability, imply that the national economy should be the relevant unit of analysis. To postulate that it is national systems that are the most meaningful entities for study would seem to imply an additional claim, namely that there exists a higher degree of systemic integrity for those processes in which participation is delimited on grounds of national affiliation, or where control is asserted by national governments. Now it is obvious that national governments do make policies and impose rules and regulations within their respective sovereign domains, and that influence the behavior of the individuals and organizations that operate there, and, further, that it is the nation states that must provide the wherewithal to enforce supranational agreements governing the activities of private corporations and individuals.

10. Moreover, geography matters. There is a significant spatial dimension to many kinds of learning activities which can substantially confine them within national boundaries. Particular industrial

agglomerations, located in one place, rather than some other, create environments in which production experience can be accumulated, exchanged, and preserved in the local workforce and entrepreneurial community. The ability to assimilate and transfer scientific and technological knowledge that is not completely codified, likewise, is greatly affected by the opportunities for direct personal contact among the parties involved. Informal and formal networks of association, linking scientists and engineers in private companies, and research workers in educational and public research institutions constitute important channels for the distribution knowledge -- supporting both applications and further inquiry, and these social communications channels are in great measure shaped by commonalities in language, educational system, academic and business culture, all of which come under the influence of the participants' consciousness of their national identity, as well as legal constraints and incentives created by national governments. Beyond this, the institutional infrastructures that shape the functioning of the more formally organized and financed R&D activities (both private and public) is very immediately affected by national policy action: most of the science and technology policy decisions are taken by governments, while corporate strategies in science and technology are affected by a large range of governmental measures. Thus, it is important to keep the national government as a relevant actor in the analysis, and to recognize the systemic influences of factors that are co-determined within the boundaries of the nation state.

11. Although systems, on the one hand, and national policies and infrastructures, on the other, are important elements of our conceptual approach to science and technology learning, we have felt some hesitancy about automatically coupling the two and speaking about "national systems" -- thereby tending to de-emphasize if not total obscure from view the significance of other, sub-national and supra-national systems whose workings may be no less critical in shaping technological opportunities and way the latter are exploited. Several reasons may be cited for our resistance to accepting "national innovation systems" (or systems of innovation) as the appropriate term of art to employ in describing the subject with which we are dealing. First, it is evident that much activity in science and technology is organized and conducted internationally; many key elements of institutional infrastructure are transnational in their sphere of operations, so it is a distortion to confine the analysis strictly within national boundaries. Second, it is apparent that it would be equally misleading to suppose that everywhere within those boundaries the educational infrastructures, research facilities, and formal and informal communication networks are homogeneous in their ability to support industrial innovation activities. Thirdly, corporate entities that co-ordinate economic activities that involve learning in the sphere of science and technology, increasingly, have become multinational in their nature -- even if they find it advantageous to appear in the role of "local" or "regional" enterprises in many different nations simultaneously. Furthermore, complementarities and linkage effects among the nations represent a great issue in the explanation of the emergence and development of different systems of learning in science and technology -- national policies and their impacts upon economic performance need to be interpreted, and their effectiveness assessed in the context of international interdependencies.

12. All this means that comparative studies should be careful not to treat implicitly national units of observations as though they were closed, independent systems, whose innovative "performance" could be related simply to their respective internal institutional structures and government policies. At very least it should be recognized that to the extent that national systems of innovation can meaningfully be identified, most of these will be seen to be embedded in (or entangled in) larger, more complex transnational relationships. Therefore, rather than an analysis of "national systems of innovation", our goal is to identify and reveal national profiles in systems of learning and innovation based on scientific and technological knowledge: How do the science and technology learning opportunities created by the industrial structure, the institutions, and the patterns of government and company expenditure that can be associated with a

specific country -- that is to say, its "profile" -- appear in relationship to the profiles of other countries? Do various country characteristics, such as economic and geographical size, the prevailing per capita income and wealth levels, the degree of economic integration with the international economy, and the density of involvement in international political arrangements, have discernable influences on these profiles? Are there clusters that can be associated with certain policy orientations, or which can be explained in terms of similarities in historical experience and consciously mimetic behaviors across national boundaries?

2. Broad theoretical orientations

A. Information-theoretic approach to the characteristics of knowledge

13. The information-theoretic approach as it will be displayed here (informally) focusses attention upon the characteristics of knowledge affecting generation, acquisition and distribution processes. There are three dimensions -- namely, (1) degree of codification, (2) completeness of disclosure, and (3) ownership status -- that we can use to define a space within which various types of economically relevant science and technology knowledge can be located. Following along the line developed in Dasgupta and David (1987, 1992), and David (1993), the distinctions between knowledge and information, and between codified and tacit forms of knowledge are elaborated to draw out the implications for the reduction of knowledge to commodity status.

B. Institutions

14. The limitations of markets in handling information as a commodity, and institutional devices that may solve some of the more difficult allocational problems, either by enlarging the scope for markets to function, or providing non-market allocative systems (e.g., the "open science" reward system based on priority of discovery and invention), will be viewed as inherent in all systems that concern the production and distribution of knowledge. The goal here is to give an explicit notice to the main institutional mechanisms for "repairing" the major defects of markets in allocating resources to the production and exchange of information, emphasizing the parallels with the theory of public goods provision discussed recently by David (1993), for example, under the headings of Patronage, Property, and Procurement.

C. The complexity of science and technology learning systems

15. Scientific papers, patents, instruments, tools and infratechnologies, expertises, software, new high-tech products, scientists and research engineers, etc., each represents a different form of knowledge-product, and each may be located in the "knowledge-product space" that is defined by the three dimensions just listed. These knowledge-products are generated in the course of carrying out various learning activities, such as R&D in firms, university research projects, public agencies programs, technology adoption in manufacturing lines, consultancies and technical expertises, production of infratechnologies, standards and testing procedures, etc. Although there are no strict "one-to-one" correspondences between the forms of knowledge-product and the learning activities (i.e. every learning entity generates an array of knowledge-products that take one or more of the different forms), the social organizations and the consequent reward and incentive structures under which those learning activities are conducted tend to determine some characteristic "knowledge-product-type" for each institutionalized form of learning.

16. The information-theoretic orientation suggests that the relevant functional elements to be identified are those involving the following processes: generation of knowledge (by means of cognitive exploration

and search), codification and reduction of knowledge to information, monitoring and perception of information (involving encoding, decoding, translation, filtering, and compression), communication and transfers of knowledge, storage, retrieval and reconstruction. The provision of means to carry out these functions is required of every social group which engages in production and exchange. Following Arrow's insights (1972), it may be argued that the advantages of more complex organizations consists in their being able to support information-generating and -handling routines that are more efficient than those available to individuals and simpler social groupings.

17. The learning entities, however, do not exist in isolation. Every learning entity needs to draw upon pre-existing knowledge generated in some other places in the system. Consequently, it is important to try to measure the extent to which knowledge is exchanged and the conditions of exchange, because these processes of distribution and transformation do not work automatically and smoothly. Some specialized institutions and non-market incentives structures are necessary; like market mechanisms these are imperfect for some purposes. Thus, a system of science and technology learning -- including various entities assuming specific functions with regard to the process of generating, transforming, transmitting and storing information -- must be characterized by its "distribution power", that is to say, by the system's ability to support and improve the efficient functioning of procedures for distributing and utilizing knowledge.

18. Thus, there are two (non-exclusive) ways of improving the performance of a system of science and technology learning: either by increasing the stock of knowledge (endogenous generation and acquisition from outside) or by making the existing stock more socially useful, i.e. by improving transfer, transformation and access to the stock of existing knowledge. Unfortunately, making the knowledge stock itself more socially useful, and making it more economically valuable to private parties will, in many instances, not call for the same policy measures; indeed in the short-run these two goals are likely to be in conflict.

D. Path-dependence

19. After assembling and preparing the foregoing ingredients, we add two further sets of considerations to the conceptual pot:

-- The first is the view that specific institutionalized mechanisms, which may be classified as being most closely associated with one or another class of knowledge-product, have emerged in particular historical circumstances and, elsewhere were imitated and adapted in still other, equally specific circumstances. So, they are products of an historical, evolutionary process and not results of rational exercises in optimal mechanism design by welfare-maximizing public authorities -- as David (1994) has emphasized in examining the specific problems of adapting intellectual property institutions to the economic exploitation of new technological opportunities.

-- The second takes the form of the proposition that institutions and organizational forms do not exist in isolation, but, rather are created by the innovative combination and recombination of previous institutions and organizational forms that, consciously or unconsciously, are viewed to be "salient" for members of that society when they consider alternative possible modes of coordinating the behavior of individuals in particular collective activities in the sphere of production and distribution. Individual persons and human organizations, in which are embedded in highly durable information structures that facilitate the development of learning and decision capabilities of the people involved, typically are found to be constrained by the very same information structures that enable them to function with reasonable effectiveness. Moreover, human organizations tend to resist reconfiguration in response to adverse signals concerning their own performance (which they often are prevented by their information filters from receiving). Institutions typically are less plastic, less malleable than material technologies, and the interrelatedness among their constituent parts, like their mutual interlocking dependence within a given societal context, only makes it more difficult to introduce radical changes in any individual part of the structure (see, e.g., Johnson (in Lundvall (1992)). As a result, there are strong aspects of complementarity among various features of the institutional landscape observed in any particular society and those complementarities tend to increase institutional stability (inertia), forcing successful institutional innovation to take an incremental form unless the society (or the organization) as a whole is disrupted or captured by one that is differently structured.

20. The framework we are elaborating attempts to integrate a treatment of educational and training institutions, and information filtering and distribution systems of relevance to economic activities, within the set of public and private institutions and organizational forms that have been made the center of attention in prior work on technological and scientific research and innovation. At the same time, it is capable of being more sharply focussed upon institutionalized modes of carrying out the fundamental system functions, and therefore aims to guide comparative institutional analyses -- as distinct from comparative studies of the economic performance of national economies. By developing the notion of "national profiles" in systems of scientific and technological learning we seek to indicate how various constellations of institutional solutions to problems in the production and distribution of economically relevant knowledge fit together with other, equally specific sets of institutions for the allocation of property rights, the financing of investment, the governance of corporations, and so forth, and to emphasize the need for both national and international policy coordination affecting these systems.

3. Emerging propositions

21. The analytical consideration given to the special characteristics of knowledge and information viewed as commodities, and of the problems of organizing the production and distribution of the rather peculiar "goods" through competitive markets, in Sections 2 and 3, below, has served to bring out two sets of propositions that we believe carry important implications for science and technology policy, broadly conceived. These emerging propositions, which are worth anticipating at this point, receive more extensive development and discussion in Section 4.

A. Distribution and the growth of economically valuable knowledge

22. Whether at the local, regional, national or international level, an efficient system of distribution and access to knowledge will increase the social value of both the knowledge that is being produced by experience-based learning and organized research conducted within those economic entities, and the knowledge acquired and assimilated from external sources. This effect is not confined merely to the application of existing knowledge in the production of conventional commodities; it extends also to the use of information to produce more information. Wider distribution and timely inexpensive access to new findings reduce wasteful duplication of effort in research, and, by putting information into the hands of a more diverse population of researchers, tends to increase the probability of useful new products and processes arising from novel and unanticipated combinations. In the case of knowledge, however, a condition of "efficient distribution and utilization" is not something that can be expected to arise

automatically from the interplay of market forces. The different incentive structures and social organizations typical of the different kinds of learning activities may interfere with this. That is especially to be expected when knowledge must be passed across institutional or organizational "boundaries", as almost inevitably will be required.

23. For a long time, the emphasis in science and technology policy has been on fostering the generation of new knowledge, rather than on the distribution of this knowledge and the possibilities of improving the performance of the system by improving the access to the existing knowledge stock. This thrust has been maintained for too long, in our view, and there is a pressing need now to restore some balance; in other words, to raise not only the marginal social rate of return on future R&D expenditures, but to increase the social payoff from such outlays made in the past by increasing the commercial exploitation of the knowledge that it created. Improving the "distribution power" of the system is seen sometimes as a desirable objective that has to be sacrificed in order to provide stronger market incentives for private investment in organized R&D, since copyright, patent and trade secrecy laws create obstacles to access which restrict the commercial utilization of knowledge. But, those same impediments also may stand in the way of the use of existing knowledge for innovation itself. Thus, individually and jointly, countries seeking to speed up the generation of new products and processes, might well consider modifying the workings of intellectual property institutions in ways that speed disclosure, reduce the marginal costs of access to new technological information for purposes of research in the same or technically related areas, and promote the management of intellectual property as a vehicle for cooperation and investment coordination in expanding productive capacities.

24. There may well be needs for specialized institutions and incentives, designed expressly for the purpose of supporting swifter and cheaper access to existing knowledge stocks in particular fields, such as the agricultural experiment and extension stations that were introduced to serve the technological needs of the U.S. farm industry. But even before turning to innovation in the institutional sphere of the solution strategy, it is important to explore the possibilities of making further use of the capabilities of existing institutional infrastructures. Two illustrative examples can be briefly indicated: (1) Universities are logical candidates for an enhancement of their function as nodes in global scientific and technological information networks. In the Western democracies' history, the universities have been concerned with the preservation, interpretation and transmission of knowledge. Furthermore, the traditions of cooperative, disinterested scholarship that the academies support, along with the institutional norms of open science communities to which university regulations have been adapted, makes these institutions (in their generic form) particularly well suited to the task of integrating internationally distributed sources of knowledge, and of training people how to locate and use it. (2) As a second point, it might be noted that within the curricula of many universities there are opportunities for changing the balance of resource allocation and prestige in favor of the so-called transfer sciences, to improve capabilities by training people in how to utilize established knowledge and research methods to solve practical problems arising from industrial needs -- which is not quite the same thing as undertaking research in the university to solve industry's problems.

B. Coordination across nations

25. In the larger system within which scientific and technological knowledge is being produced and distributed, the externalities involved are sufficiently important that positive steps of collaboration should be encouraged strongly. By contrast, a neo-mercantilist attitude toward control over scientific and technological knowledge seems particularly misplaced, inasmuch as knowledge is an infinitely expansible commodity; something which can be concurrently possessed and utilized by all is hardly fit to be treated

as if its transfer was a zero-sum proposition. Yet the promotion of national competitions in basic science, and R&D rivalries to appropriate the fruits of new discoveries, to which the rhetoric of technonationalism has lent support, is particularly prejudicial to successful knowledge-based economic development strategies. Four reasons for that conclusion can be enumerated:

(1) It interferes with the performance of "peer-review" evaluation of scientific activities on a wide, transnational scale, thereby depriving countries of the benefits of international expertise that can be shared at small incremental cost. It thus forces a choice on them between wastefully duplicative self-sufficiency (which few could actually afford), insulating areas of research from active competition between different teams that were not drawn into mutually supporting coalitions, or simply abandoning the pretence of maintaining a scientific capability in many sub-disciplines of science, engineering and medicines.

(2) It burdens attempts at international coordination for the support of big science projects and expensive collaborations in technological development, thus limiting the possibility of sharing the cost and increasing the utilization of "mega-instruments". The latter represent "lumpy", high fixed-cost investments, both domestically and internationally -- even though improved information technologies are making possible the effective sharing of such facilities.

(3) It works to curtail the scope of human resource mobility, and in so doing blocks channels of distribution and access to the knowledge base.

(4) It gives national sanction to efforts to harmonize the international intellectual property protection regime by pushing to higher levels the degree of protection accorded by all nations, thereby exacerbating the problems of access and utilization of existing knowledge.

26. The perspective developed here suggests the importance of reconsidering many areas for potential international economic liberalization and cooperation that would serve to strengthen the respective national innovation systems. Among the subjects that deserve further examination in this regard are intellectual property rights harmonization, international standards institutions, cooperation on electronic infrastructures and on megascience facilities, coordination of arrangements for overseas training of scientists and engineers.

Section 2
Knowledge, learning and information in the economy

27. Economic activities deploy knowledge of various kinds, and, in turn give rise to learning, that is, to the generation of knowledge among the participants. There are many conceivable ways in which one may categorize or classify the varieties of knowledge that people "produce" in the course of their economic activities. The taxonomic scheme to be developed here is one that is meant to focus attention upon the forms of knowledge that affect the ways in which it can be stored, accessed, and transferred among economic agents. Once we have arrived at a schematic representation of the profile that the new knowledge arising in individual learning entities will have, the next step is to apply it to the representation of collectivities of such learning entities that are functionally interdependent -- or, in other words, to profiling "systems of innovation".

1. Forms of economic knowledge

28. The term "economic knowledge-products" refers to the knowledge that is generated in the course of economic activities and is recognized to have some utility for productive purposes by the generating agents or others, either more-or-less contemporaneously or in the future. Productive purposes is taken here to include the generation of knowledge in forms that have economic value, as well as the production and distribution of tangible physical goods and services. A brief reprise of several points in the preceding discussion will be helpful in rendering more precise what is meant by "knowledge-products."

A. General forms of economic knowledge

29. Following Lundvall and Johnson (1992), we can identify additions to stocks of economically relevant knowledge, that take any of four common forms: "know-what", "know-why", "know-how", and "know-who".

- -- *"Know-what"* refers to knowledge of factual propositions, covering anything from the technical or conventional names of items of commerce, the provisions of regulatory legislation or tax codes, the balance sheet of an enterprise, and so forth. In the pure form of "know-what" we are limited essentially to dictionaries and inventories: the knowledge needed for identification and labelling, for decoding the labels assigned to objects, phenomena, and statements about the world.

- -- *"Know-why"* refers to knowledge as "understanding", explanatory structures which involve principles of more or less general applicability for predicting physical (and social) phenomena. Although it is often supposed -- quite reasonably -- that codified knowledge of fundamental scientific principles, having great generality of application, are the typical form for this kind of knowledge, that view seems to be a legacy of the misleading and now outmoded conceptualization of technological knowledge as "applied science". Generic explanations may emerge as an end-stage distillation from a variety of empirical regularities that have each shown themselves to be reliable for predictive purposes in very specific contexts.

-- *"Know-how"* is usually taken to refer to the forms of knowledge that enable the possessor to accomplish some observable task, without necessarily divulging (and without necessarily being conscious of) the instruction set for its execution. Manual skills fall under this rubric, but, equally, it may apply to organizational capabilities of individuals and social groups. Such entities may develop and refine competencies through experience in performing the task in question, and they may become aware of the existence and the limitations of their competence, without being able to explain to others how they produce the effects in question. But it should not be supposed that "know-how" is confined to tacit knowledge; possession of an algorithm for solving certain classes of dynamic control problems, or the procedures for performing and interpreting diagnostic tests to identify a specific type of neurological disorder that is suspected, are instances of procedural knowledge that may be thoroughly codified and yet belong the category of "know-how".

-- *"Know-who"* is the term assigned to knowledge about the identities of actors in social organizations, and the relationships among them, especially the informal, non-contractual relationships to which the possessor of the knowledge is a party. Quintessential of this category is knowledge about the reputations of other people. While it is quite conceivable that the greater part of an individual's knowledge about other human beings is gained in social transactions between them and is privately held, remaining unconfirmed by reference to the reported experiences of others, there is also a body of "know-who" that is collective in origin and distribution. Social know-who, thus parallels collective know-how, or organizational procedural knowledge, except that it is useless in economic activities unless the possessors are individually conscious of what they (collectively) have come to know. By contrast, an organization can be said to perform satisfactorily --albeit perhaps not optimally -- without knowing what its capabilities and competencies are *ex ante*. Know-who, therefore, may be seen as a complement to procedural knowledge that concerns itself with human organizations.

B. Functional types of scientific and technological knowledge

30. The systematic and rational search for advances in science and technology is conducive to the production of functionally differentiated types of knowledge: generic knowledge, infratechnology, applied knowledge, and process and product knowledge (Tassey, 1992).

31. Generic knowledge is the result of the first step in a process by which basic scientific discoveries are made increasingly more usable for commercial explorations. Generic technology research identifies and generally characterizes performance attributes and demonstrates (usually to the point of laboratory prototype) how these attributes will be bundled together as an eventual product -- in terms of general operating characteristics, product architecture, etc.

32. Infratechnology refers to the set of methods, scientific and engineering data, models, measurement and quality standards, which allow scientists to accurately determine the results of experiment and, through common agreement on these measurement methods, communicate the research results to potential users. Similarly, much research cannot be undertaken without critically evaluated data bases on, for example, the

physical and chemical properties of materials. Similar requirements of measurement methods and data bases arise when the first attempts to apply basic scientific knowledge are undertaken.

33. Distinct types of learning activities appear to develop comparative advantages in producing various arrays of knowledge. For instance, university research laboratories may generate both generic and applied scientific knowledge and infratechnology, while corporate R&D laboratories may generate a very wide range of knowledge, from generic advances to very specific product and process technology. Some specialized institutions, however, are designed to produce a certain type of knowledge. A case in point is, for example, the national institutes of standardization, specialized in the production of infratechnologies.

34. Although each of the foregoing forms of knowledge may be produced, either as a conscious goal of some purposive inquiry, or as a by-product of participation in economic and social activities, we shall refer to them as knowledge-product simply to underscore our concern with the activity of "learning" by the collectivity of interacting economic agents. The term "products" does not, in this context, carry any implication that the knowledge involved is the object of organized production for economic gain, nor do we mean to suggest that such knowledge is necessarily an exchangeable commodity. Indeed, it is useful to draw the distinction between knowledge and "information".

2. Knowledge-products and information commodities

35. In modern communications theory it is conventional to distinguish between "data" and "information": data refers to elementary units in communication and message transmission -- providing non-ambiguous bits of information (0 or 1). Information, then, can be considered, as structured or formatted data -- data ready for transmission. From that perspective "knowledge" is to be seen as the conceptual and factual contexts that enable agents to interpret and give meaning to "information".

36. We find it more useful, however, to adopt the rather different (but not logically incompatible) perspective of modern economic analysis in describing the relationships between "information" and "knowledge".

37. Following common usage in economics, the term "information" will be used here in referring to knowledge that has been reduced and converted into messages that can be easily communicated among decision agents. Messages have "information content" when receipt of them causes some change of state in the recipient, or action. Transformation of knowledge into information is a necessary condition for the exchange of knowledge as a commodity. "Codification" of knowledge is a step in the process of reduction and conversion which renders the transmission, verification, storage and reproduction of information all the less costly. Whether or not knowledge is put in codified form is in part a question of how costly it is to do that. The pre-existence of standards of reference (numerical, symbolic, pictorial, geometrical languages, taxonomies of any kinds) and performance, and a vocabulary of precisely defined and commonly understood terms contributes greatly to reducing the time and effort required to produce unambiguously codified messages. The lowest level of codification involves translation into standardized language (codes); the removal of dysfunctional ambiguities for purposes of communication may become progressively more exacting as the intended sphere of communication is enlarged, and the shared experiences of the audience thus become more heterogenous. Complete codification is most readily (least dearly) achieved when the knowledge is completely generic, rather than situationally specific in nature, because the description of the full context to which it refers need not enter into myriad aspects that may be highly idiosyncratic, calling for use of special terminologies, and difficult to describe unambiguously to the non-observer.

38. Yet, somewhat paradoxically, this transformation makes knowledge at once more of what is described (in the public finance literature) as a "non-rival" good, that is, a good which is infinitely expansible without loss of its intrinsic qualities, so that it can be possessed and used jointly by as many as care to do so. Thus, codified scientific and technological knowledge possesses the characteristics of a durable public good: it is (1) durable, in the sense of not deteriorating with use, although its economic value may be altered thereby, (2) capable of being enjoyed jointly by a number of agents, and (3) costly measures must be taken to restrict access to those who don't have a "right" to use it.

A. The codified-tacit dimension of learning

39. In contrast with codified knowledge, tacit knowledge, as conceptualized by Polanyi (1966), refers to a fact of common perception that we all are often generally aware of certain objects without being focused on them. This does not make them less important: they form the context which makes focused perception possible, understandable, and productive. No less than other human pursuits, science and technology draws crucially upon sets of human skills and techniques -- the ingredients of "scientific expertise", or "engineering expertise -- that are acquired experientially, and transferred by demonstration, by personal instruction and the provision of expert services (advice, consultations, and so forth), rather than being reduced to conscious and codified methods and procedures. The transfer process itself, as a rule, is a comparatively costly affair (in contrast to the case of codified knowledge) for both the provider and the recipient of tacit knowledge. But, like information, tacit knowledge can be swapped in transactions resembling "gift exchanges," or sold for money, rather than being shared freely.

40. Insofar as codified and tacit knowledge are substitutable inputs (at the margin) in the production of further knowledge, or in practical implementations, the relative proportions in which they are used is likely to reflect their relative access and transmission costs to the users. Similarly, differences in the extent to which knowledge generated by researchers in various fields gets codified for packaging as information, rather than retained in a tacit form, will reflect the reward structures within which researchers are working, as well as the costs of codification. Hence, variations in the relative importance of codified and tacit knowledge in the work of different research communities has no necessary connection with the "hardness" or "softness" of their respective disciplines. This perspective stands in contrast with the disposition of some philosophers and historians of science to associate a relatively high degree of codification with occupancy by the discipline in question of a superior position in some epistemological or methodological hierarchy.

41. Some recent discussions of the economics of R&D and technology transfers (e.g., Pavitt (1987), Nelson (1990), Rosenberg (1990)), continue to assign special significance to the tacit elements in technological knowledge, calling attention to the fact that the information contained in patents, blueprints and other codified forms of knowledge often are insufficient for successful implementation the technical innovations they purport to describe; much complementary "know-how" may be required, the acquisition of which, typically, is a costly business. While uncontestable this does not imply the existence of underlying, intrinsic differences in the nature of "technological" as opposed to "scientific" knowledge. Nor does it follow that technological knowledge should be assigned a subordinate epistemological status, or that the tacit knowledge of either technologists or scientists necessarily takes the form of skills that are specific, rather than "generic" in their applicability. As Dasgupta and David (1992) have argued, making reference to Polanyi's (1966) perceptual analogy, "what gets brought into focus (and codified) and what remains in the background (as tacit knowledge) is to be explained endogenously, by considering the structure(s) of pecuniary and non-pecuniary rewards and costs facing the agents involved". Although the position of the boundary between the codified information and tacit knowledge in a specific field of scientific research may

be shifted by economic considerations and prevailing institutional constraints, the complementarity between the two kinds of knowledge has important implications for the way research findings can be disseminated.

B. Social organizations of research and the disclosure-secrecy dimension

42. The foregoing text at some points refers to scientists and technologists in ways that might suggest they are to be viewed as different kinds of knowledge-workers, and that an important distinction to be made is on the basis of characteristics of the individual agents. This is not what we intend. Instead, the critical differentiation in our view is one that can be made among the alternative social organizations, or social modes of production and distribution of knowledge. What fundamentally distinguishes various communities of scientific researchers in the modern industrial societies is not so much their methods of inquiry, nor the nature of the knowledge they obtain, nor the sources of their financial support -- although differentiations can be drawn along those lines -- but are the socio-political arrangements and the consequent reward structures under which they work. A crucial separation exists, in this view, between "open science" communities, and "proprietary research communities". The former are organized around the activity of augmenting the stock of reliable "public knowledge", whereas the latter communities exist for the primary purpose of generating stocks of "private knowledge", the economic value of which can be appropriated by the organizations that sponsor them. The basis for the categorical distinction made between the two social modes of knowledge production is to be found in the nature of the respective sets of ultimate goals that are openly avowed and accepted as legitimate within the two communities, their respective norms of behavior in regard to the disclosure of knowledge, and the features of the reward systems that provide individual incentives compatible with the pursuit of the organizational objectives under the norm-imposed behavioral constraints. It is important to emphasize that in accepting the distinction made by Dasgupta and David (1992), we do not associate "public knowledge" in a definitional way with the products of publicly funded research, any more than we associate "private knowledge" with the results of business-financed R&D.

43. Loosely speaking, "open science" may be associated with the world of academic research, including government-sponsored, and even business-sponsored research conducted under "university-like" organizational norms affecting the autonomy of individual researchers, the freedom to select collaborators, to enter informal modes of cooperation, to determine when and what findings should be published -- and a reward structure that is based upon collegiate reputations, established through priority in publication of verifiable research findings. At the opposite pole stands the world of the researcher engaged in "restricted" military research conducted in secure government-run laboratories, and the proprietary R&D organization, whose employed scientists and engineers must record their work in notebooks that are the property of the company, and who cannot disclose knowledge they have acquired in the course of their employment without explicit permission if they wish to be indemnified against legal actions for the theft of trade secrets. What makes a knowledge-worker a "private-knowledge researcher" rather than a "public-knowledge researcher" in this usage, is not the particular cognitive skills or the content of his or her expertise. The same individual can be either, or both within the course of a day. What matters is the socio-economic rule structures under which the research takes place, and, most importantly, what the researchers do with their findings. In the world of "proprietary science", research is undertaken with the intention and quasi-contractual pre-commitment of the researchers to the organizational goal of extracting economic rents from the knowledge gained, either by keeping it secret and using it in directly productive activities that end in the sale of conventional commodities, or by converting some or all of the knowledge acquired into assets that, as legally protected forms of property, can be readily owned and alienated for valuable consideration. Secrecy, however, is more readily effected when knowledge is not codified in proprietary documents (e.g.,

blueprints, receipts for chemical syntheses) that can be purloined and published, but, instead, is retained in a tacit form. Training services that convey tacit information, and access to contracting with the trained, are commodities that can be and are exchanged for value by business organizations operating within the private knowledge domain; and also by academic research organizations, although the enforceability of contracts tends to differ between the two cases and the terms on which tacit information can be sold are correspondingly different.

44. None of this implies that profit-seeking business firms would not find it to their advantage on occasion to invest some resources in "basic" research, or organize research facilities in ways that emulated the open, cooperative environment characteristic of university campuses. Furthermore, it is obvious that for charitable purposes, too, as part of a strategy of associating themselves with sources of freely disclosed knowledge, private individuals and business entities may become patrons of "open science" institutions. Conversely, although it is the case that "open science" institutions and organizations are constrained by the norms of disclosure from seeking to maximize the economic rents they extract from the knowledge within their possession, and must therefore draw their main support through public and private patronage, it is quite possible for institutions that support the production of public knowledge also to engage in the transformation of research findings into private properties that can provide them a source of income. The problem, to which the work of Dasgupta and David (1987, 1992) draws attention, is whether any one organization can function effectively when harboring two quite antithetical sets of norms and cultural orientations when more or less equivalent legitimacy, and comparable organizational resources are devoted to each. But even recognition of such intra-organizational contradictions and conflicts does not imply that academic scientists will never seek to benefit materially by patenting their inventions, or copyrighting their works, nor even that, in their conduct of open science, they always refrain from rivalrously withholding research findings and methods from university-based researchers in their field.

3. Modes of learning and organizational issues

45. Knowledge can be gained through accidental discoveries, or it may emerge from systematic, rational inquiry and observations. To differentiate these situations it is useful to consider the process of knowledge generation as a compound event (A) which consists of the joint happenings:

- -- state a is true, which means, for example, that a new alloy may be possible to create (basic research allows agents to assign probabilities (βa, $1-\beta a$) to the underlying states of the world);
- -- and, this fact is successfully exploited (the alloy is actually created). Thus, $\beta A < \beta a$.

46. Thus, a discovery by accident corresponds top generation of knowledge which is not based on the systematic exploration of the states of the world (there is no information about the probability βa). By contrast, a discovery based on a rational exploration corresponds to the compound event described above (discovery occurs after having gained information about βa): in this schema, specific functions are assumed by basic research (assigning probabilities to the states of the world) and by applied research and development (exploiting successfully the basic informations about the states of the world).

47. In the domain of systematic and rational explorations, science and technology learning takes the form of different methods of search and improvement processes. The formulation of these different methods can be organized with respect to two main categories:

-- *Deliberately controlled experimentation versus experiential learning as by-product of economic activities*

48. These are the two polar forms of knowledge generation. The former occurs in the organized research process, whereas the latter occurs in the course of the diffusion into use of new methods and products. Experimentation consists in developing prototypes and demonstrators and carrying out simulation and real experiments to collect and record the performance characteristics of technologies under examination. The resulting scientific and engineering knowledge forms a basis for systematic technological development. The knowledge produced by experiments and simulation is supposed to ensure the formation of generalizing rules and hypotheses and ultimately to support the construction of predictive models for the performance of a new technology. Thus, experimentation plays an important role in deepening scientific understanding of technological operations and processes.

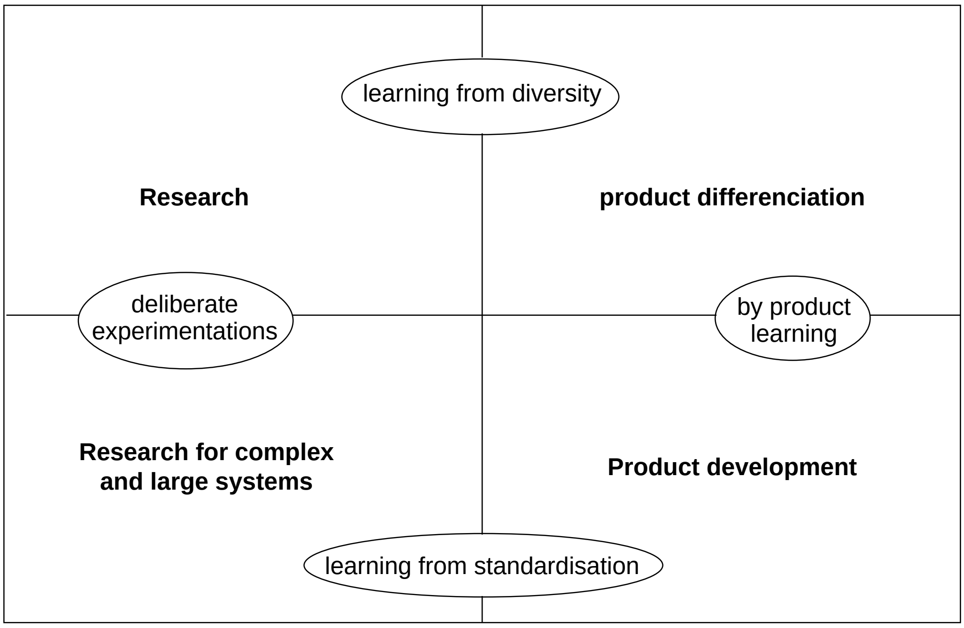
49. By-product learning appears as the other main mechanism for reducing uncertainty about the characteristics of a new technology. As a by-product of economic activities, this mode of learning has two main aspects: (a) learning-by-doing, which is a form of learning that takes place at the manufacturing stage; and (b) learning-by-using, which is a form of learning that is linked to the irreplaceable role of users and adopters in the process of creation of knowledge. The user has specific, sometimes idiosyncratic knowledge, and masters those situations requiring the local implementation of the technological processes and objects. By inter-acting with the producer, he will engender learning-by-using mechanisms whose significance has been discussed by Rosenberg (1982), Lundvall (1988) and Von Hippel. Users and adopters are a decisive link in the chain of positive feedbacks that is inherent in the dynamic evolution of technology.

-- *Learning from diversity and learning from standardization*

50. These are the two sources of learning, which may be thought of as operating at different moments in the development of a particular area of technological (or scientific) practice. When there is great uncertainty about the technical functions and economic merits of a new technology, its first introduction typically ushers in a period during which many variants are formulated and tried out. After this period of experimentation, one, or perhaps a small number of variants will emerged as "standard practice". The selection can be passive, through the competitive market mechanism, for example; or active, as in the case when a dominant economic or political actor decides that a particular variant should become the standard. When the development of a technology conforms to this pattern, two kinds of learning are distinguishable. The first kind is extensive learning or "learning from diversity"; which involves experimentation with a variety of options, and through the (negative) results of the experimentation, leads to the elimination of certain avenues of development. The second type of learning can be called intensive learning or "learning from standardization", in which attention is concentrated on one technological variant, making it easier to identify empirical irregularities and problem areas deserving further investigation, correction and elaboration (David and Rothwell, 1991).

51. *Figure 1* represents a tentative schema within which we may locate different modes of generating knowledge. The vertical axis deals with the evolution from diversity to standardization, while the horizontal axis concerns the progression from deliberately controlled experimentation to by-product learning. There are two principal modes, combining diversity and experimentation (which correspond to the basic definition of research) on the one hand, and standardization and by-product learning (which corresponds to the basic definition of product development), on the other hand. Two other modes are possible, however: combining

Figure 1 **Modes of generation of knowledge**



by-product learning and diversity means that some learning-by-using processes can lead to product differentiation (Von Hippel, 1990); combining standardization and experimentation reveals a specific process of knowledge generation in the case of large complex system, where each new plant, or system or program -- although produced in a recurring manner -- is in fact an experiment.

-- *Organizational issues*

52. The foregoing observations concerning the characteristics of the process of knowledge generation raise various organizational issues:

53. First, a system of by-product learning that is not explicitly financed means that market processes as a rule do not lead to socially optimal rates of learning: (a) private producers may be financially constrained to minimize short-run production costs, which makes them myopic in their evaluation of the learning component of production; (b) externalities and spillovers mean that (even with foresight and perfect capital markets) private strategic behaviors do not yield socially optimal learning rates.

54. Second, the different types of knowledge to be produced (generic and applied, on the one hand, infratechnologies, on the other hand) raise the problem of finding a balance between two organizational priorities: One way of characterizing the activity of research and development is as an exploration of the spectrum or distribution of technological varieties. Thus, it is necessary to design an organizational system involving multiple decentralized projects, in order to facilitate experimentation in different directions and

to decrease the risk of missing the best design (i.e. learning from diversity). On the other hand, it is necessary to integrate the research units into a single entity, in order to support the production and to share the costs of the infratechnologies and instrumentations -- required to do the research -- as these possess strong public good's feature. Thus, an organizational structure combining the following features -- the expansion of measurement, standards and testing activities of the public institutions, on the one hand, and the design of sub-organizations involving multiple, decentralized high tech consortia, on the other hand -- might be the indicated way to manage the tension between diversity and standardization in technological research programs.

55. A market with many firms, each doing its own R&D will contain considerable technological diversity, as each firm is likely to have a slightly different approach to the technical challenges it encounters. A market faces a dilemma, however, when trying to capture the benefits from this diversity. In order that a diversity of approaches in the early stages of a technology be valuable in its future development, the information or knowledge generated by the different experiments must become relatively public. Only when this is the case does the experience of one agent reduce the uncertainties of other agents, and play a part in cross-fertilization. But if information will be made public, there is an incentive to free ride.

56. A final organizational issue deals with the problem of the optimal timing of a changeover from a diversity of technical solutions to standardization on one technical approach. Introducing a standard too early could prematurely end the period of experimentation and lead to the diffusion of an inferior technology, whereas late introduction may result in excess of variety which will delay the benefits from standardization.

Section 3
Institutional infrastructure and the knowledge-product space

57. The foregoing, highly stylized view of the scientific and technological world may be arrived at *via* another route, namely, by starting from a consideration of the main alternative resource allocation mechanisms that can be used to produce and distribute scientific knowledge, and considering the efficiency with which they will perform those tasks. Of all possible resource allocation mechanisms, the one that has been most studied in economics is the "market mechanism". As it is now well known, if the market mechanism is not aided by further social contrivances, such as, for example, intellectual property rights, there is no basis for supposing it can sustain an efficient production of knowledge. The market mechanism has a tendency to discourage the production of public goods because of an inability on the part of producers to appropriate fully the value of the fruits of their efforts.

1. Public economics and generic institutional devices

58. Three generic remedies have been devised to overcome the deficiency of the market in this regard: two of them do so by seeking to rectify the problem at its source, whereas the third solution applies correctives in the form of supplements to the market outcomes. Let us briefly look at each of these schemes in turn.

A. Public production

59. The first scheme consists in the government engaging itself directly in the production of knowledge, allowing free use of it, and financing the production cost from general taxation. This was at the heart of Samuelson’s (1954) analysis of the efficient production of public goods. Government research and development (R&D) laboratories that publicly disclose their findings, such as agricultural research establishments, are an example of this. It is as well to note that under this scheme the volume of public expenditure in the production of knowledge, and the allocation of expenditure for the production of different kinds of knowledge, are both decisions made by the government.

B. Private property and markets

60. A second class of solution is for the society to grant intellectual property rights to private producers for their discoveries, and permit them to charge (possibly differential) fees for their use by others. This creates private markets for knowledge and gives rise to "private knowledge-products". Patents and copyrights are means of defining and protecting intellectual property rights, and as their strengths and weaknesses have been discussed extensively by economists over the years, their character need not be expanded upon here, save to say that the nature of the rights conveyed may differ widely from one system to another in ways that affect both the incentives to engage in research and the extent of access afforded to the information that is disclosed.

61. It may be remarked, nonetheless, that the producer (or owner) of a piece of information in this scheme, ideally, should set different prices for different buyers, because different buyers typically value the information differently. One problem with such markets is that they are inevitably "thin" (each market is essentially a bilateral monopoly, i.e. consisting of the seller and a single buyer), and, therefore not a propitious environment for the emergence of prices that will sustain an efficient allocation of resources, as has been pointed out by Arrow (1971). Another problem with them arises from the fact that transactions in knowledge are shot through with leakage. The point is that for an exchange to be conducted efficiently both parties need to know the characteristics of the commodity being transacted, which, in the case of information, can hardly be done in a complete way without vitiating the purpose of the transaction itself. This feature of knowledge, that its value is often very difficult to quantify, means that the economic use-benefits of knowledge are often hard to appropriate privately, and therefore difficult if not impossible to market efficiently. That is so even when legal protection of ownership rights in knowledge that has been publicly disclosed (e.g., patents and copyrights) gives the owner transferable legal rights to exclude others from using that knowledge in many specified contexts.

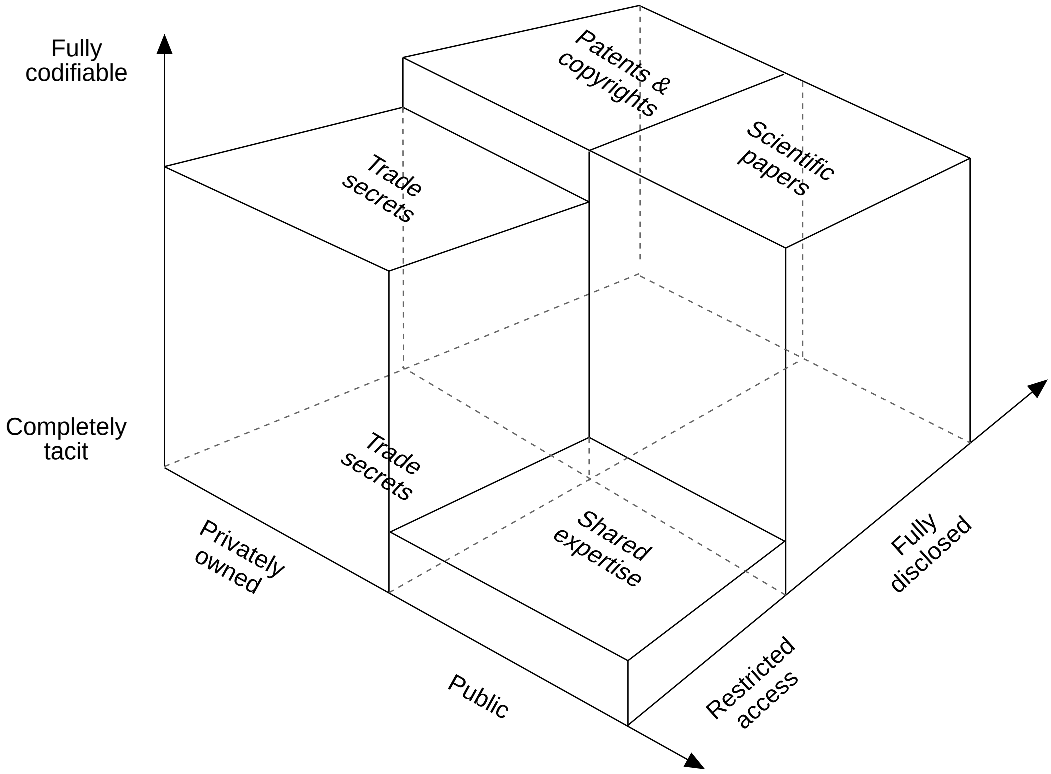
62. The foregoing tells us that despite the limitations of the institutions of patents and copyrights (and, for that matter, the legal protections for secrecy among individuals and organizations), those "property-like" contrivances provide means for privately appropriating profits from discoveries and inventions. In short, while information can in principle be used jointly, joint use can be prevented by legal prohibitions, or through the practice of secrecy. This can be socially desirable, because even though monopoly in the use of knowledge is inefficient (it involves the underutilization of knowledge), it can be offset by the fact that the lure of monopoly profits makes researchers undertake R&D activity today. Therein lies the value of instituting patent laws, and of allowing secrecy to be practiced by discoverers.

C. Subsidies, procurement and regulated private production

63. A third possible scheme is for society to encourage private production of knowledge by offering public subsidies for its production, and by relying upon general taxation to finance these subsidies. A critical feature of this arrangement is that producers are denied exclusive rights to the output of their R&D activity: once it is produced, the knowledge is made freely available to all who care to use it. In albeit imperfect forms, this scheme characterizes research activities carried on in public and private non-profit entities, such as universities, where much of the knowledge that is produced is prohibited from being patented by the private individuals involved in creating it, and where salaries and promotions and equipment are paid out of public funds. Here, there is an intimate association between the source of funding and the public character of the knowledge-products.

64. Under this class of arrangements the university, or research institute is required to act as the agent of society, or the state as the principal, and it is necessary to devise monitoring schemes, auditing procedures and other regulatory measures to assure that the asymmetry in the distribution of knowledge about the specialized tasks in which the agents are engaged does not permit them to behave in ways that are incongruent with the principal’s interests. An unfortunate complication is that in matters touching the production and distribution of scientific and technological knowledge, modern societies must turn to members of the same specialized communities to help articulate the interest that they will be engaged in promoting.

Figure 2 **The Knowledge-product space**



2. The Knowledge-Product space: a taxonomic construction

A. The dimensions of Knowledge-space

65. The foregoing discussion has identified three characteristics of economically relevant knowledge. The dimensions of degree of codification, completeness of disclosure and ownership status define a space within which types of knowledge and the agencies creating them can be located. One may use the descriptive device of Figure 2 in several distinct ways: a) to represent the mix of knowledge-products generated by particular learning entities during a specified time interval; b) to trace the transformations that may occur in the process of distributing and applying knowledge which is generated initially with characteristics described by a point or small region in the space; (c) to represent the knowledge "inputs" and "outputs" of given economic entities, at various levels of aggregation. We consider these applications in the course of commenting briefly on the dimensions of the Figure itself.

66. Codification and tacitness may be treated as locations along a continuum whose endpoints are represented by complete systematization of the cognitive content, using a vocabulary of defined terms, such that the interpretation of the text is unambiguous and for all intents and purposes, independent of the identity of the reader. We can say that practical considerations render this, almost certainly, an unattainable

extreme, even without embarking upon discussions of hermeneutics and an explanation of the tenets of deconstructionism. Some relevant knowledge, regarding the physical processes, procedures and materials referred to in a scientific paper, or a set of engineering specifications will be assumed to be understood; scientific and engineering reference standards are important bits of background knowledge that are complementary to the newly codified information but, frequently, are omitted on that account.

67. At the opposite pole one may find procedural knowledge that is not systematized, and which exists as expertise that particular individuals possess. The creation of an expert-system, therefore, represents the process of transforming knowledge so that a new "product" appears in the space.

68. The extent of disclosure, likewise, is a continuous variable, bounded by full disclosure at one limit and total secrecy at the other. For the present discussion, we take the status of publicness and privateness (in the sense of being legal property) to be discrete states. This is an enormous simplification, to be sure. If one views "property" status as conveying both indefinite right to exclude trespass (i.e. to monopolize access) and a right to alienate ownership, it is clear that different intellectual property systems provide possessors of such knowledge with bundles of rights that approach the idea of "perfect property" to varying extent. Patent rights, for example, are temporally delimited, and may be granted subject to requirements of compulsory licensing at "reasonable" fees, leaving the determination of reasonableness to be adjudicated. Copyrights, likewise, exist for only a fixed period, and do not protect against use of the material by independent originators -- whereas patents do offer recourse against the latter form of trespass. Both patents and copyrights, however, are categorized in Figure 2 as "private", and since some degree of disclosure is required for either to be secured, the Figure shows them as situated in the domain of disclosure knowledge. Here we make another oversimplification, because the degree of disclosure required is not uniform across intellectual property regimes, and even with a given regime, different kinds of text may be protected with different completeness of disclosure. Computer software, for example, may be copyrighted without revealing the source code, and in some instances even the full body of object code does not have to be disclosed. Trade secrecy law, according to some legal theory, does not create property rights -- in as much as a secret is something which cannot be disclosed in public without destroying it, and so cannot be described sufficiently to enable identification of its nature, or a determination of who possesses it at any point in time. Hence, on this interpretation, knowledge can be protected as a trade secret because the law protects the right to enter contractual relationships of confidentiality. On such a reading, we would not have placed trade secrets in the "private" knowledge region. Note, however, that if, on the legal theory just set out, we were to assign trade secrets to the "public" portion of the knowledge-product space, we would have to explain the paradoxical positioning of it in the region of "restricted access and public", that is, a non-owned, yet privately awarded, form of knowledge, which usually must have been sufficiently codified to permit it to be improperly removed from its possessor and transferred to some other party.

69. The upshot of the foregoing discussion might be restated as follows: the situation of knowledge-products in the space defined by Figure 2 is, in reality, a complex matter which is defined by the detailed stipulations of the intellectual property regime, and by the norms governing knowledge disclosure among members of different social organizations engaged in research activities. It might also be added that the standards of disclosure may be defined not only by the statute laws and the intellectual property agencies (Patent Offices) but, in the case of scientific papers, by the policies of the journals in which professional papers are published. The latter, for example, may or may not insist upon disclosure of the exact coordinates of complex proteins whose molecular structure is being reported; or the computational algorithm used in analyzing experimental observations. Thus, a great deal of detailed institutional information would be demanded if one were to undertake comparative studies that called for an exact

positioning of the knowledge-products being generated by different research communities (especially the different national research communities) with reference to the axes of Figure 2.

B. Flows versus stocks of knowledge

70. Economic agents draw upon stocks of knowledge that exist, either in their own conscious or unconscious mind, or are held by others and may be acquired by resort to transfer mechanisms of varying degrees of formality. In referring to knowledge-products, however, we specifically indicate flows, that is knowledge which is being generated within the economic entity under consideration. Formal instruction, via the medium of reading a description of a technological process, or a set of specifications of the components of a complex piece of machinery, or the chemical constituents of a compound listed on a commercial product label, represents the acquisition of new knowledge by the learning individual. To say whether the flow observed at that individual level represents an increase in the gross stock of knowledge is not possible until we have defined the boundaries of the social entity under analysis. If the latter is confined to the individual, there is obviously a correspondence between flows and stock changes. Otherwise, if what going on corresponds to a transfer of knowledge between agents, we may justly say that the social stock of knowledge has not automatically been increased thereby, even though the existing knowledge was being more intensively utilized by virtue of becoming more widely disseminated.

C. Durability, maintenance of accessibility and obsolescence of knowledge stocks

71. The reference made to the gross stock of knowledge (in the preceding paragraph) recognizes that there are other questions that would have to be resolved before the generation of one or another form of knowledge-product can be equated with the growth of the corresponding stock of available knowledge. In general it is much more difficult to identify the processes of physical depreciation, destruction, and obsolescence that could be thought to result in depletions of knowledge stocks. Information can be lost because the medium in which it is stored is subject to depreciation or destruction, and adequate reproduction and maintenance has not been carried out. Tacit knowledge, residing in humans will be lost if, from lack of practice their skill deteriorates, or their facilities of recall become impaired by age. Collective knowledge that is tacit, in the form of organizational competencies disappears when firms are merged into other organizations, or are simply disbanded. The discarding of tacit knowledge, and even the loss of access to codified information required for the operation of productive routines, may even be an important precondition for learning new things. But it is easier to see how a case could be made for the value of forgetting when considering the matter at the level of the individual agent or the organization, rather than at the level of the society. The longer the time horizon that is relevant, and the greater the potential range of situations that can be encountered, the more compelling are the arguments for maintaining the option of future access to knowledge that has been costly to acquire in the first place; and the more extensive and complex is the social entity, the greater are the possibilities for preserving that option without interfering with the acquisition of new knowledge. Complex societies, like large families, are usually better able to afford large attics and other repositories, to which temporarily outmoded (economically obsolescent) information may be removed for "deep" storage when the living space has become too cluttered to admit new acquisitions. But, it should be noticed that this applies to "information", which is far less costly to reproduce and to store than is knowledge which remains tacit within individuals and social organizations.

72. Codified information may require less resources to preserve for retrieval. Yet it may require the expensive maintenance of educational facilities to train people to read languages that have ceased to be used, and to be sufficiently familiar with the cultural, social and technological context in which the

information was generated, to be capable of accurately interpreting it. More generally, the point needs to be made that the accessibility of the stock of knowledge, even knowledge in forms that lend themselves to codification, is as much a question of the capability that intelligent agents possess for interpreting and manipulating it as it is of the facilities for locating and retrieving what has been stored. Consequently, one might view the investment made in the formal education of the members of an organization, or of societies more generally, as required not simply to transmit what is presently thought to be useful knowledge, but to equip economic agents to retrieve and utilize parts of the knowledge stock that they may not perceive to be of present relevance but which have been stored for future retrieval in circumstances when it may become relevant. In other words, the accessibility of the extant codified knowledge stock may be indicated by the portion of the population that has been trained to access and interpret it, which suggests a different view of indicators of a society's educational activities that corresponds to a world in which economically relevant knowledge was largely tacit and required being imparted to each new generation by demonstration and training through personal experience.

73. In the world where knowledge increasingly is codified in forms that permit machine manipulation, it may be more and more possible to maintain a stock of machines that are can perform the counterpart of the task of formal educational institutions, in ensuring societies' capacity to retrieve and decode the data for processing and interpretative display. Even so, that will not be done without cost and organizational forethought. There already are many instances in which stored computerized information is essential lost because the medium of storage (e.g., punch cards or computer tapes) is incompatible with the capabilities of the surviving stock of machines. The U.S. Census Bureau has no access to computers that can read the magnetic tapes to which the data from the original schedules of the 1950 and 1960 population censuses were transferred from processing before the schedules themselves were destroyed.

74. There are some fine "metaphysical" issues that could be debated under the present heading of the durability of stocks of knowledge, but which will only be noticed briefly here. Should one say that inasmuch as information can be used indefinitely without "wearing out", it is an infinitely long-lived asset which does not depreciate by being purposefully discarded? Is it appropriate to think of the stock of knowledge at the disposal of an economy as the total existing stock in all extant forms, or only that part which it can afford to access and interpret? If, say, a corporation's files contains document reporting the findings of a private geological survey of several potential plant locations, but nobody interested in its contents is aware of its existence, and the files have not been archived in a manner that identifies the subject of the report to someone not already acquainted with it, should we not say that the information in question has been lost from the knowledge stock? Or would it be better to say that, as it is stored in a durable form, it is not lost, but the cost of accessing that part of the knowledge stock has become so high that the potential utilization rate of the stock has been reduced?

75. Under the latter convention, we would have to recognized that the "effective stock" of knowledge might increase very dramatically without the expenditure of resources on learning activities by the organization involved. For example, a much enlarged stock of codified knowledge could be put at the firm's disposal as a consequence of alterations in technological practices (encoding it digitally and storing it magnetically for search and retrieval by electronic means) or in organizational procedures (having all filing supervised by a competent archivist) that would reduce the marginal costs of access to extant databases.

76. For most purposes it will not matter which convention one chooses to adopt, so long as it is explicitly understood. The important substantive point deserving emphasis here is that learning, defined

as the acquisition of knowledge-products, can take place either through the generation of new knowledge, or accessing parts of knowledge stocks that hitherto had not been utilized by the agents in question.

Section 4

Information access, knowledge distribution and the institutional infrastructure

77. As an economic good, knowledge possesses particular properties (perfect expansibility, cumulativeness, see Section 2 above) which lead us to observe that the value of a given item of knowledge is basically determined by the extent of its use and distribution within the system.

78. Thus, at both national and international levels, an efficient system for accessing and distributing knowledge will increase the social value of the knowledge produced (endogenously) and acquired from outside sources:

- by reducing the risk that the knowledge would be held without the resources needed to exploit its potential fully;
- by allowing individual agents to gain rapid access to the knowledge required for their specific needs;
- by reducing the amount of duplicative investment in innovation;
- by lowering the cost for the possessors of technological information to contract with other firms possessing complementary knowledge and tangible resources;
- in summary, by increasing the likelihood of forming new combinations and accumulations of information.

79. It is clear, therefore, that public policies directed to the improved functioning of national innovation systems should give much greater attention to the processes of knowledge access and distribution. By knowledge distribution processes, we mean those incentive structures and modes of coordination, that have the effect of expanding the potential space for the use of knowledge. Historically, it may be seen that much of public policy for the support of educational and vocational training institutions, of libraries and archives, of communications facilities, was directed towards just those ends. But, during the past several decades, by contrast, the primary emphasis in science and technology policy has been placed upon more and more fostering the generation of new knowledge rather than on the processes of distribution and the possibilities of improving the access to the existing stocks of knowledge. This thrust may have been maintained for too long; there may be now a case to be made for restoring some balance, not only in order to raise the marginal social rate of return on future R&D expenditures, but also to increase the social payoff from such outlays that have been made in the past -- by increasing the exploitation of the knowledge to which they gave rise. Improving the "distribution power" of the system of innovation often has been portrayed as a desirable objective which must, unfortunately, be sacrificed in order to provide stronger market incentives for investment in organized R&D. Most notably, this "trade-off" is proposed by those advocating

strengthening regimes of intellectual property protection. But it also may be seen to underlie proposals to separate university research from teaching functions, to provide ostensibly better conditions for faculties specializing in basic research activities. Both tendencies warrant careful and skeptical reconsideration, for they spring from a failure to appreciate the strength of the complementarities between knowledge-access and diffusion processes and innovation generation processes. The foregoing statement of our views, quite naturally, provokes one to ask: Why is the distribution problem so crucial for expanding the knowledge-base in a given country? How could one assess and compare the "distribution power" of the various national systems? What are the institutional innovations allowing a system to improve its "distribution performance"?

1. Distribution and growth of economically valuable knowledge

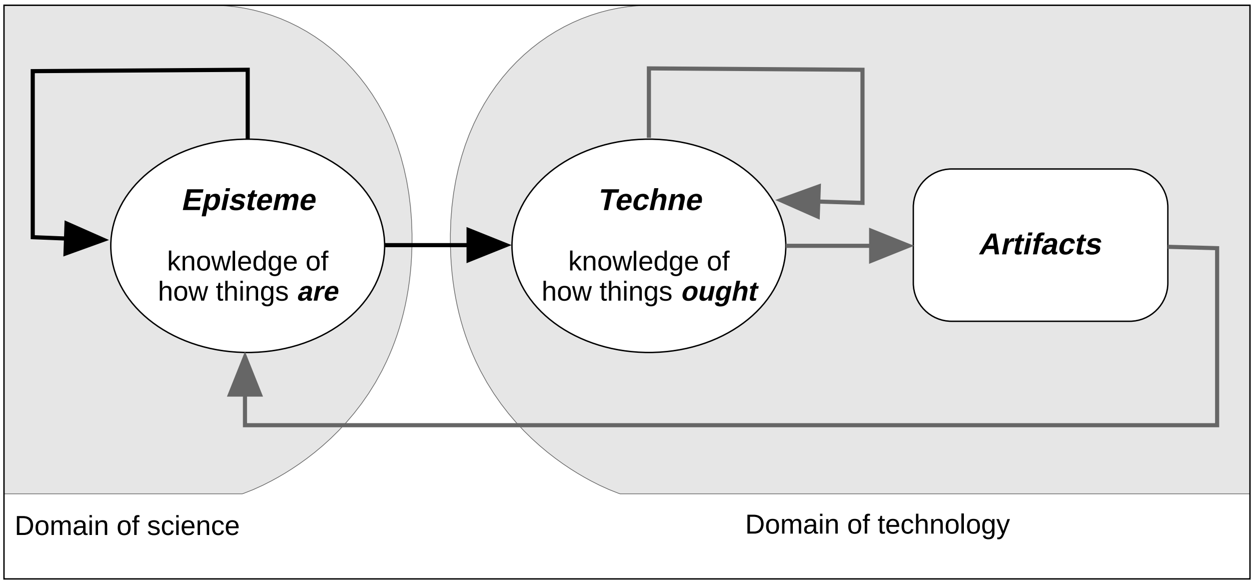
A. Five processes of distribution

80. Five distribution processes seem to be particularly important in an innovation system, by enlarging the potential space of exploitation of knowledge at various levels. These processes are not really new, but their importance is being augmented by the advance of codification techniques, the progress of information technology and the consequent evolution of innovation styles.

-- *The distribution of knowledge among universities, research institutions and industry*

81. The dissemination of information among agents situated in various learning entities creates opportunities for both cooperation and competition among institutions that are characterized by different organizational norms and incentive structures (see Section 2 above). One important feature of knowledge distribution processes is that they frequently entail what we might call "institutional border crossings", involving possible transformations in the form of knowledge-product in the course of their distribution: laboratory technique, scientific paper, patent, prototype, instrumentation, expert system, high technology product, etc. Each of these forms is characterized by a highly specific combination of the three basic characteristics listed above: degree of codification, completeness of disclosure and ownership status. The other important aspect of this circuit resides in the complex feedback systems between basic research conducted in the institutional domain of "open science" and industrial research development devoted to the creation of proprietary technologies. The complementarities between activities in the two spheres form numerous "virtuous circles", which play an essential role in raising the performance of innovation systems. As David, Mowery and Steinmueller (1992) have demonstrated, one can impute to basic research an informational payoff that raises the efficacy of resources allocated to applied research. Applied research, in turn, produces instruments, prototypes and data (infratechnology) -- as well as new observational phenomena -- that improve the marginal social efficiency of investments in basic research (see Figure 3, below). The production of scientific instrumentation lies at the heart of these feedback complexes, and has contributed to accelerating the pace of productivity improvement in research activity itself, as David (1993) has pointed out. However, the potential benefits of these feedback loops will only be realized if there is a smooth flow in the intensive distribution of knowledge between the entities involved in the different forms of research.

Figure 3 **Feedback loop between science and technology**



-- *The distribution of knowledge within a market and between suppliers and users*

82. This circuit may concern participants in both the world of open science and the world of proprietary technology. Its crucial aspects reside, on the one hand, in the creation of rapid access by all the entities to information concerning current "best practice", and, on the other hand, in the stability of environments for "learning" (incremental improvements, learning by doing, by using) based upon the experience afforded by the process of diffusion itself.

83. This form of distribution is becoming more and more important due to the involvement of "users" in the process of innovation for complex technologies. Ensuring knowledge interactions between users and suppliers, as well as the passage of innovation along a sequence of potential adopters, are important features of the new style of "user-guided", if not of "user-driven", R&D. The latter has come to characterize innovation in certain industries, the software industry being a most striking case in point.

84. Distributing knowledge according to this scheme is, however, difficult because secrecy, retention of information and strategies of private appropriability create access problem that impede distribution. The weakness of the institutionalization of the links between suppliers and users is also an important obstacle.

-- *Re-use and recombination of knowledge*

85. One may observe in a certain number of sectors the emergence of a new model of innovation, based on the ability to exploit more intensively the enhanced information distribution capabilities of the system. In this new model, advances in technology are based more than ever before on the dynamics of

mutual strengthening and reciprocal consolidation of (competing) innovation projects. This model implies routine use of a technological base allowing innovation without the need for "leaps" in technology.

86. One should emphasize that the notion of innovation, which regulates intellectual property laws, and thus largely influences trade relation practices in the area of technology, is based on principles of absolute novelty and priority of invention (or disclosure). It has often been pointed out that much innovation does not correspond to either of these principles, but, rather, involves adding small elements of novelty, or novel arrangements of known elements of design. Not only do we recognize the so-called "shoulders of giants" phenomenon in technological progress, whereby small improvements in one part may enhance the performance of a system whose basic principles are well established and fundamental -- as for example, in the case of a superior catalytic agent being found for a chemical reaction process, which speeds its rate and increase its yield. What is perhaps more significant is the recent movement towards the systematic explication of the effects produced by new combinations, which has emerged as the new research paradigm in some industrial sectors. In biotechnology, innovation now proceeds through the concentration of all known characteristics plus a difference: "instead of multiplying independent approaches, we put them together". The software industry suggests similar trends where re-utilization of existing codes or algorithms (representing sub-processes) has now become an essential form in the R&D process. The important differences among sectors, notwithstanding, these examples show that the production of knowledge seems to be more and more marked by its cumulative and continuous nature, and that the resulting innovation has a strong collective dimension. This new innovation model (or recombination model) -- the routine use of a knowledge base -- requires systematic access to the state-of-the-art; each industry must introduce procedures for the dissemination of information regarding the stock of codes, technologies and programmes available, so that individual innovators can draw upon the work of other innovators.

87. This mode of knowledge generation -- based on the recombination and re-use of known practices -- must confront the problems of the impediments to accessing the existing stock of information that are created by intellectual property rights laws. Even though the principal forms of intellectual property protection (patents and copyrights) can be seen as securing public disclosure, and therefore, as constituting an advance over systems of private appropriation based upon secrecy, their effect upon the costs of access is such as to strongly increase the entropy of the information system.

-- *The distribution of knowledge among decentralized R&D projects*

88. The appearance of a new technology typically is followed by a period during which many variants are tried and experimented with. After a period of experimentation, one, or perhaps a small number of variants is selected as standard practice. When a technology fits this pattern, two kinds of learning are important. The first is extensive learning, or learning from diversity, which involves experimentation with a wide variety of radically different alternatives and leads to the selection of certain avenues of development and the elimination of others. The second type of learning can be called intensive learning, or learning from standardization or rationalization, in which attention is concentrated on one technological variant from the outset, making it "easier to identify empirical irregularities that point to underlying structural conditions deserving further investigations" as a means of design improvement (David and Rothwell, 1991).

89. Indeed, the selection of the best design is frequently fortuitous, being a result of historical circumstances or the strategic capacities of certain agents, rather than the product of a systematic exploration of the merits of all possible variants. It is thus necessary to build organizational systems, involving a coordinated set of decentralized experimental projects, mechanisms and procedures for

exchanging and distributing information produced in the course of these projects, and a centralized procedure of assessment to decide the timing for switch (to the standardization phase) and the standard to be selected. The case of HDTV is a case in point: the FCC (Federal Communication Commission) organized the development of six decentralized experimental projects, and then, in collaboration with the ATTC (Advanced Television Center Test), carried out the testing works in order to select the future standard.

90. Such an organizational design is, however, rather difficult to establish. In order that a diversity of approaches in the early stages of a technology be valuable in its future development, the information or knowledge generated by the different experiments must be shared. Only when this is the case does the experience of one agent reduces the uncertainties of other agents, and play a part in cross-fertilization. But if it is known that such information is to be widely shared, there will be an incentive for agents to free-ride, by avoiding the cost of participating in any of the experiments.

-- *Dual development*

91. The dual development of civilian and military technologies is an important factor of the performance of innovation systems. It is particularly efficient and fruitful in two sets of circumstances (Cowan and Foray, 1994): (1) in the case of emerging technologies, where all users, military and civilian might be said to exhibit a similarity of ignorance, and the information generated is of direct use to both; and (2) in the case of R&D projects that are process-oriented rather than product-oriented (again the generated knowledge is valuable for both domains).

92. But with this mode of innovation, too, one must be concerned that various factors can impede information distribution: restricted access to the military results, strong and too rapid divergences of the technical specifications between military and civilian products, and absence of dual organizations and institutions (mixed laboratories, common use of big scientific instruments, networks of engineers, integrated departments in firms).

B. Information technologies and research networks

93. The perception of an emerging new paradigm for technological innovation, based upon more systematic and intensive exploitation of available knowledge bases and strategies of recombination and integration for the generation of novelty, is reinforced by considering ongoing developments in information and telecommunications technologies that are extending the power of electronic networks as research tools. During the past decade there has occurred a remarkable expansion in digital research networks, especially in the United States (where, with the introduction of NSFNET, in the mid-1980s, the volume of traffic, number of interconnected networks, and functionality of the networks, has been rising at dramatic exponential rates) but, extending, through the use of the IP communication protocols throughout 60 countries, to form a network of networks referred to as the Internet. The network connects some information sources that are a mixture of publicly available (with and without access charge) information and private information shared by collaborators, including digitized reference volumes, books, scientific journals, libraries of working papers, images, video clips, sound and voice recordings, raw data streams from scientific instruments and processed information for graphical displays, as well as electronic mail, and much else besides.

94. These information sources, connected electronically as they are through the Internet, represent components of *an emerging, universally accessible digital library*. Prospective advances in technology will make economically feasible the digital conversion of massive bodies of extant and new data from variegated and spatially distributed sources, and will permit them to be stored in networked databases, whence they can be readily searched, processed and retrieved by intelligent software; collaboration in technologies are being developed to support multi-media information exchange, multi-user editing, annotation and display. There is every reason, then, to anticipate that a new epoch of "library research" lies ahead of us, from which the scientific and technological research communities that already are pioneering the use of the Internet (and specialized data networks, such as those to support high energy particle physics and oceanography research) may expect to benefit. The power of computer-linked instruments to enhance the task-productivity of laboratory researchers in generating, recording, analyzing and displaying data has been amply demonstrated during the past two decades. What appears to lie ahead is the fusion of those research tools with enormously augmented capabilities for information acquisition and distribution beyond the spacial limits of the laboratory or research facility, and consequently a great acceleration of the potential rate of growth of the stocks of accessible knowledge. It would seem to follow that cooperative research organizations will be best positioned to benefit from the information technology-intensive conduct of science and technology research.

C. The economics of distribution of knowledge

95. All the distribution processes listed above have an economic particularity. They are fundamentally based on a particular class of externality -- diffuse externalities -- stemming from the interactions among competitive or complementary learning entities. In developing a new project, entities depend on other entities' knowledge and must be aware of the available stock of knowledge. Innovation processes, thus, require systematic access to the state-of-the-art and thus the establishment of procedures for dissemination of existing knowledge, so that each entity can benefit from the work of each other.

96. From a social point of view, the innovation process will be accelerated if competitors are able to support rather than ignore or even block one another. This perspective raises a major challenge for the organization of the innovation system: the system's ability to distribute existing knowledge for recombination becomes the critical strategic factor determining its capacity for generating new technologies.

97. Our analysis of the economics of knowledge in the following pages rests upon a particular conception of economically valuable knowledge, which highlights the three characteristics of knowledge-products discussed in Section 3: degree of codification, completeness of disclosure, and ownership status. We have argued, in Section 2, that these characteristics are not inherent in the knowledge itself but are, instead, the products of social organization and of the attendant reward structures of those institutions supporting the production of knowledge. As a result, the critical factor governing distribution does not deal with any intrinsic differences in the nature of "technological" as opposed to "scientific" knowledge. Rather, this critical factor is the differentiation that may exist among the alternative social organizations, affecting the social modes of production and distribution of knowledge. One striking example of the latter proposition is furnished by the recent discovery of a new prime number, composed of 258,716 digits. This result, a symbol of very basic research efforts, had an immediate commercial outlet in the domain of computer security, since very large prime numbers are considered the most effective security tool. Thus, the improved Adelman-Rumely method, which originally enabled one to discover within 12 hours whether a 100-digit number was prime, became a process for the production of technical software tools. This discovery was made by David Slowinski and Paul Gage, from Cray Research, who published their results

in the review "Science". In one fell swoop, analogously, a biotechnology, or genetic engineering researcher can deepen understanding of the nature of the universe, and at the same time create technical devices that have commercial applications. Thus, the economically relevant characteristic of this new knowledge (such as the newly-discovered prime number) will depend on the identity of institution or organization within which the knowledge was produced, and the rules for disclosure that obtain within that organization. The nature of the transferability of knowledge (for example between university and private firm) is therefore directly dependant upon the problems of social organization and incentive structures which characterize those two different institutional forms.

98. The activity of diffusing economically relevant knowledge is not itself a "natural" one. Rather, it is socially constructed, through the creation of adequate institutions, such as those of open science and of intellectual property rights (David, 1991a). The particular economy of knowledge distribution is based thus on the two particular conditions: (1) individual incentives to enter into cooperative games based on the exploitation of positive externalities (complementarities); and (2) the ability of the agents to search for the relevant information within the entire possible space of distribution. Now, these two conditions may be difficult to satisfy. Efficient distribution is not something which will happen automatically in the case of knowledge for at least four reasons:

-- First, building up information structures generates access costs, which become higher as these stocks evolve and become more specialized, requiring mastery of new technologies, notational conventions, conceptual apparatuses. Beyond the contextual set-up costs, there are further costs of managing the ever-bigger data streams arising from the exponential expansion of the volume of codified knowledge. Thus, the actual search for information carried out by any particular research project is most often quite localized; that is to say, will only be carried out within a limited portion of the total space that could in principle be explored.

-- Second, a great deal of knowledge is tacit (that is inseparable from the agents and organizations which developed it, see Section 2, above), and the transfer and acquisition of tacit knowledge constitute costly operations that require the active participation of the knowledge-holders.

-- Third, the creation of property rights -- designed in order to allow agents to capture rents from their innovative efforts -- create access problems that impede distribution.

-- Fourth, there may be barriers to knowledge transfers due to some institutional incompatibilities between organizations having distinctive rules of disclosures, institutional goals, and reward structures. The compatibility problem is especially severe when the knowledge distribution calls for institutional "border crossings".

99. The obstacles identified above result in knowledge being used only in a tiny part of the potential space for its exploitation, and in the benefits of diffuse externalities being only partially enjoyed. This creates an unfortunate loss of energy in the system of innovation. But these four difficulties are not all identical in nature; rather they are of two types. The problems raised by the search for pertinent information and by the existence of tacit knowledge are essentially problems of costs. These problems will therefore be addressed to the extent that societies allocate sufficient resources for developing the means and skills they will need to cope with an information-rich world. The two last obstacles are of a different nature. They are generated by a certain conceptualization of the process of knowledge generation; one in which the production of knowledge is considered to generate negative externalities, in the same fashion that

catching a fish ("undiscovered ideas are like fish in the sea") reduces the probabilities for other fishermen to catch a fish. In research, as with fishing, it may appear desirable not to reveal anything about one's research domain. Thus, a fisherman will not tell his rivals about his most productive fishing spot -- so long as its whereabouts remain certain and it is not likely to be quickly "fished out". (Where individuals' search capabilities are limited, however, and the location of opportunities is uncertain and transitory, information pooling becomes an attractive form of (minimum yield) insurance and fishing boat captains will be found to enter voluntary cooperative arrangements to announce when and where they find good shoals of fish).

100. There is, however, another conceptualization in which the production of knowledge is considered to generate positive learning externalities: in this case, the relevant analogy compares production of knowledge to the discovery of new mineral deposits. It has been observed that exploration is most intense where mineral deposits are found, and so, at least for some time mineral reserves become larger in the territories where exploitation is underway (see David and Wright, 1992). When discovery increases the probability that other will undertake exploration in the neighborhood, producing knowledge is likely to generate positive externalities for the explorers, each agent has an interest in diffusing the product of his discovery so as to profit from the results of others. At very least, information about where others have failed to make a discovery will be valuable in guiding one's own search. Under such conditions it is pro-innovative to reduce the obstacles to information dissemination due to intellectual property rights and institutional incompatibilities, and to replace these with devices for coordinating the actions of innovative agents. For example, as we shall see, intellectual property systems have disclosure features and need not be used in ways that impede the pooling of knowledge.

D. A new agenda for assessing and comparing systems of innovation

101. Thus, a system of innovation cannot only be assessed by comparing some absolute "input" measures such as R&D expenditures, with "output" indicators, such as patents or high-tech products. Rather innovation systems must be assessed by references to some measures of the use of those knowledge which they produce or could acquire -- i.e. ratios between what is produced and what is used (by recombination, diffusion, dual development, change of form, etc.) and how efficiently they allocate resources between accessing existing knowledge bases and undertaking (potentially duplicative) independent programs of discovery and invention. It is necessary that national policy-makers have a better picture of their own country's (and other nation's) performance in this regard; and, symmetrically of the magnitude of the losses of innovative potential due to the limitations of their knowledge distribution and knowledge-pooling capabilities.

102. According to the usual indicators (R&D expenses, patents and bibliometrics, high-tech products), it is difficult to know: (a) what is the proportion of scientific knowledge discoveries that are accessible to industrial innovators; (b) what is the proportion of current additions to engineering knowledge rapidly transferred to researchers in basic science; (c) what is the extent and rate of diffusion of specific new technologies in particular branches of industry; (d) what is the importance of the transfer of knowledge between military and civilian domains; (e) what is the comparative importance of additions to stocks of tacit knowledge requiring transfers through movements of personnel, knowledge kept secret, knowledge as joint-product of expertise and consulting services; (f) what is the rate of obsolescence of the stock of codified knowledge; etc. With the development of such measures, national and transnational systems of innovation could be characterized by their "distribution power", or, at least, their profiles could be described in ways that would reveal the relative "distribution-orientation" of their institutional infrastructures.

2. What is a "distribution-oriented" innovation system?

103. The identification of the characteristics of a "distribution-oriented" system raises three important questions that will be addressed in this section: what kinds of capabilities in the domains of training and education, finance and industrial production are required for such a system? Since such a system is likely to facilitate the generation of a certain category of innovation (incremental innovation, re-design, recombination), can we consider this system essentially as a "transitory state", designed in order to meet the innovation requirement of a "technological follower" committed to a strategy of "catching up"? Does the co-existence of a small number of "distribution-oriented" systems and a large number of systems characterized by a weak distribution power introduce some important distortions in the global economy? After identifying analytically some institutional characteristics of systems with high "distribution power", it may be helpful to try to develop these points by examining the concrete case of Japan, for the latter seems to present one paradigm of a national system of innovation that has been "distribution-oriented".

A. Identifying the characteristics of a "distribution-oriented" system

104. We take a "distribution-oriented" system to be one whose institutions, incentive mechanisms and coordination arrangements have the following four proximate objectives:

(a) Encourage innovative agents to enter into cooperative games, based on the reciprocal and successive production and exploitation of complementary additions to the stock of knowledge.

105. The functioning of these cooperative games is based on a common representation of the production of knowledge, which engenders positive externalities (see above). This representation guarantees that production will be colored by a distribution-oriented mindset, which will play the role of a structure of mutually consistent expectations. "I disclose my knowledge because I know that the agent who will use it will disclose the result of his effort, etc.". This element, however, addresses the question of how do such jointly held expectations become established? Where does such a mentality of distribution come from, if not from shared history and some fine institutional mechanisms (as suggested by the example of Japan below)?

106. Intellectual property rights are not themselves a natural obstacle to distribution of knowledge. They can be designed in order to induce the agents to enter into cooperative arrangements. To do this it is necessary to diminish the private value of individual increments to the privately owned knowledge base, by restricting the duration and especially the scope of patent protection; by introducing *sui generis* legislation adapting property rights specifically to meet the needs of sectors where the recombination model of innovation is particularly important; by extending the principles of compulsory patent and copyright licensing at "a reasonable cost", especially for "research" uses, and so forth. For example, in the case of biotechnologies, the successful introduction of the system of prepaid, lumpsum access fees attests to the possibility of according protection to an inventor, while at the same time maintaining zero marginal costs of access to knowledge-products required for research. This model maintains a free circulation of genetic resources by a system of dependency licenses in the case of dependent innovations (Joly and Hermitte, 1993).

107. On the other hand, trade secrecy and the various forms of access restriction (within the firms and scientific institutions, in the case of military research, at the international level) are important obstacles that impede knowledge distribution. Two strategies are possible to address this problem: one approach is to

make the forms of intellectual property protection that require detailed disclosure more attractive (by providing some assistance, and expertise for the operations of patenting); the other approach is to promote collective forms of "pre-competitive" R&D (high-tech consortia, industrial collective research), and interfirm cooperation in development of anticipatory technical standards.

108. The dynamics of using intellectual property as a means of promoting innovation via cooperative knowledge sharing is characterized by positive feedbacks and multiple equilibria. The properties of the system can be considered in terms of the linkages illustrated in Figure 4a: as the number of patents rises, the quantity of information available increases. As a result, the economic returns on innovations will rise in response to the increased probability that the innovator will be able to profit from new knowledge adapted to his specific project. The number of innovators, and thus the number of patents filed, will subsequently rise. The strength of the system lies in the fact that not only is the number of patents a function of the number of innovations, but the number of innovations would also seem to be a function of the number of patents. The two curves representing supply of innovations and patents in Figure 4b both slope upwards. The system is therefore characterized by the possibility of different equilibria. It will be trapped in a low-level equilibrium if, for example, one of the relations is not assured and prevents the cycle from being completed. This is what happens, for example, when an increase in the number of patents does not give rise to an increase in the amount of knowledge available (if the access costs of patents and inventions is too high). It also occurs when the increase in the number of innovations is not accompanied by a similar increase in the number of patents (if patenting costs are high and the existence of trade secret laws makes these a more advantageous means of appropriating knowledge).

109. Under a different set of circumstances, however, the economy will be situated within a virtuous circle of generation and diffusion of new knowledge. Thus, in the case of Japan, the link between the number of patents and the amount of knowledge available is provided by the early disclosure requirement, while the link between innovation and patents is governed by the provisions relating to the low cost of patents, their lower exclusionary value, as well as the absence of legislation on trade secrets (see below § 117-119).

110. This specific institutional design of patent mechanisms plays a significant role in increasing the distribution power of the system, by increasing the amount of available technological knowledge. The current construction of electronic data interchange networks on patents will greatly reinforce this role.

Figure 4a **Patenting, innovation and the growth of knowledge**

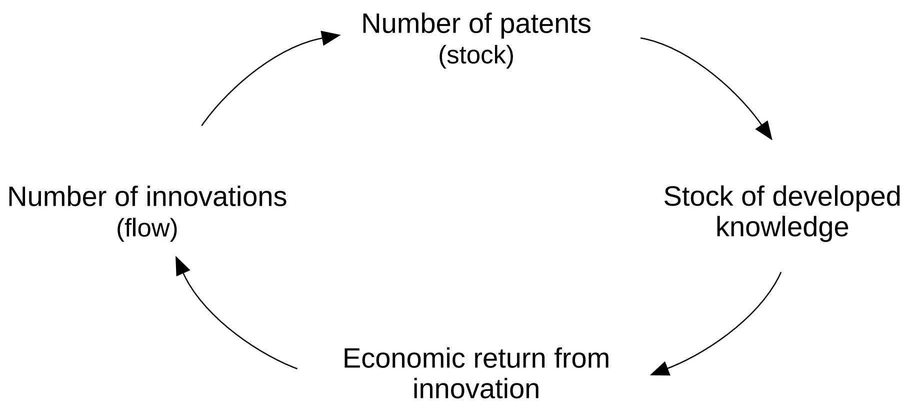
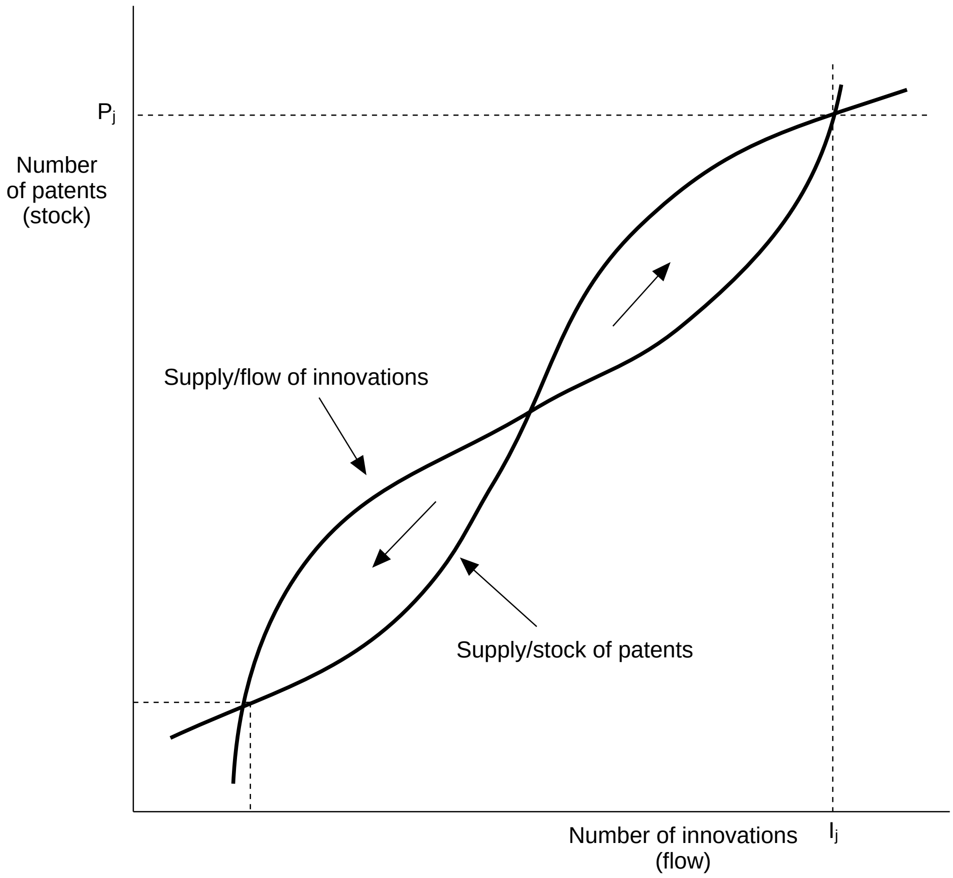


Figure 4b **Positive feedback and multiple equilibrium in the supply of patents and innovations**



(b) Reduce the problems of institutional incompatibility.

111. The university-industry research relations raise questions on the allocation of property rights: how does one decide what part of cooperatively-produced knowledge is covered by university intellectual property norms and what part by private firm norms? This question is all the more difficult in those cases when knowledge-production is intrinsically cumulative and the initial stock held by the university laboratory is marked by a sort of "genetic program" for development, the results of which are difficult to apportion between university and industry. This obstacle makes it necessary to set up new institutional arrangements, which may be done by:

-- making available contractual tools which enable the partners to come to agreement on various critical issues, such as the attribution of property rights and their enforcement. The institutions must elaborate compromises between their differing norms for disclosure and appropriation of produced knowledge;

-- creating zones of institutional compatibility (for example, in bridging institutions such as the Fraunhofer Society, or interdisciplinary centers for science and engineering research in which university and corporate researchers are brought together on limited duration projects) or supporting technology transfer by programs that facilitate the founding of firms by researchers.

(c) Enlarge the space of the search for information so as to increase the potential area of knowledge exploitation.

112. The search for pertinent information which is adapted to particular project is most often localized, that is to say, limited to the relations of proximity between entities, and will only rarely be carried out within the totality of potential space for the existence of the sought-after information (Jaffe, Henderson and Tratjenberg, 1993). It is therefore necessary to pass from the localized-knowledge distribution process to more general interactions, which lead to a more optimal allocation of knowledge among innovative firms.

113. A problem is therefore raised, related to the cost of searching for information. How can an agent, having defined an innovation project, efficiently discern which items of knowledge it needs, by exploring the entire knowledge space? Which potential innovation project will depend for its success on the acquisition of this knowledge? The problem, according to the argument expressed by Richardson (1990), is one of increasing the total mass of information available for each agent. To this end:

-- systems of intellectual property rights can be transformed into tools for the creation of information and the coordination of investments in R&D, enabling an increase in the total mass of information, as is suggested by the Japanese example;

-- the learning capacity of firms in basic research should be developed so that these can learn to "read" the literature (Rosenberg, 1990);

-- bridging systems which facilitate interconnectivity between industrial research and academic research must be implemented so as to enable university researchers to obtain "academic credit" for published contributions to technology, e.g., in the form of patents; and to enable industrial researchers to carry out regular investments in university training, particularly in those sectors where knowledge becomes obsolete rapidly;

- -- transfer sciences and engineering technologies (in chemistry, genetics, mechanics, electronics) should be encouraged, because these are devoted by definition to seeking the optimal allocation of scientific knowledge in potential industrial applications (Blume, 1994);

- -- modularity and divisibility of knowledge should be systematically generated, because they are the most valuable properties of knowledge and products in that they facilitate recombination and re-use. Thus, in the case of software, new practices make it necessary to identify characteristics of software components that make them suitable for re-use; identify techniques to translate a software component with marginal re-use potential into one that can be re-used, and develop systems for classifying and identifying software components to make it easy to retrieve them from databases when they are needed (OTA, 1992).

(d) Increase the relative importance of codified knowledge.

114. A great deal of knowledge remains tacit (that is, inseparable from the agents and organizations which developed it). The transfer and acquisition of tacit knowledge constitute costly operations, requiring the active participation of the knowledge-holders. This obstacle may be overcome in several fashions: by the codification of procedural knowledge (for example, in expert systems); by endowing entities with a learning capacity (which enables them to generate the tacit knowledge corresponding to codified knowledge which has been acquired); by sponsoring personnel mobility, may be the quickest means of widely spreading of tacit knowledge, and encouraging the standardization of practices which, in turn, makes codification easier and cheaper; by creating the expertise and contractual tools, including intellectual property licenses, necessary to "accompany" the transfer of technology that has a strong tacit knowledge content; by supporting standardization of industrial facilities, which increases the total base of available operations and codified technology and at the same time diminishes the costs of acquiring new knowledge.

* * *

115. In a "distribution-oriented" system, the proportion of public and private knowledge that is disclosed should strongly increase in relation to restricted-access knowledge. The principal problem -- if we follow the line of thought of H. Simon (1982) -- resides in the storage of information and its accessibility: "designing organizations for an information rich world". To operate in such an environment, entities must make substantial investments in skills, interfaces, and research tools (Steinmueller 1992). Although financial markets have not developed instruments to support these intangible modes of capital formation, to a greater degree than ever before, it is these investments and capacities which are the source of enterprises competitive advantage. Table 1, which indicates the volume of published technical information relevant for the firm Ansaldo, suggests that the information management problem becomes the main feature of the emerging economy of innovation.

Table 1 **Volume of published technical information as an illustration of the information management problem**

Computer and control	65 000 entries/Yr.
Electric and electronic	79 000 entries/Yr.
Physics	145 000 entries/Yr.
TOTAL	289 000 entries/Yr.
Equivalent to 2 million pages of full text each year	

Source: Dialog Data Banks

B. Japan: a distribution-oriented system?

116. A certain number of indicators regarding the organization of the innovative activity suggest that Japan’s policies and institutions are oriented toward making intensive use of existing scientific and technical knowledge for the purposes of generating technological innovations.

117. Regarding the use of intellectual property rights, one may draw notice to the importance assumed by patenting activities in Japan, as measured by the ratio of intellectual property rights to total R&D achievement (Table 2). This feature, which runs counter to one of the main findings of recent Western innovation surveys, can be explained by (i) the absence of any legislation relating to trade secrets; (ii) an ensemble of three features of Japan’s patent regime: low costs of filing, the priority given to the first to file, as opposed to the first to invent; and the freedom given to applicants to make changes to a proposed patent for a limited period of time after the initial application has been filed, all of which encourage innovators to file patents as quickly as possible.

118. However, the high rate of patenting should be interpreted in this case as the "victory of a method of coordination" rather than the "triumph of a mode of exclusion". Thus, Table 3 suggests that the most important effect of the patent system for industry is the increase of the amount of scientific and technical information, allowing this industry to coordinate the R&D activities carried out by the competitive firms.

119. How can we explain the apparent paradox that Japanese firms intensively use patents while considering patenting activities to be an efficient mechanism for the disclosure of information to competitors? The explanation resides in the operation of a collective behavior, based on the rapid diffusion of knowledge and the opportunity of mutual reinforcement and consolidation of innovative efforts. All parties are aware that by making their own knowledge available through licensing they will very rapidly be able to benefit from reciprocal arrangements to gain access to the knowledge of others. It is essential to stress the role played by the structure of mutually consistent expectations, which emerges from some shared history and is supported by a fine institutional mechanism, combining limited exclusion rights, relaxed novelty requirements and a constraint of early disclosure (pre-grant disclosure): early disclosure (prior to the granting of a property right) is a highly effective means of disseminating information and has

Table 2 **Ratio of R&D expenses resulting in intellectual property rights to total R&D expenditures**

(Japan, 1993)

Food manufacturing	49.7
Fibers	62.7
Lumber and wooden products	44.5
Paper & pulp	49.2
Printing & publishing	84.7
Chemicals (excl. pharmaceuticals)	74.0
Pharmaceuticals	80.4
Oil & coal products	79.0
Plastic products	61.6
Rubber products	61.8
Ceramics	62.2
Iron & steel	70.0
Non-ferrous metals	68.1
Metal products	82.9
Electrical machines & appliances	64.8
Communication & electr. instruments	89.1
Automobiles	55.1
Other transport machinery	73.9
Precision machinery	70.1
General machinery & appliances	50.7
Other industry	78.3
Construction	59.5
Broadcasting	85.0
Software & information services	71.5
Other services	56.1
Test & research institutes	91.0
TOTAL	71.1

Source: Japan Institute of Intellectual Property, Survey (November 1993)

Table 3 **Relative importance ascribed to various economic effects of intellectual property rights**

(Japan, 1993)

Economic effects	*Rating*
1. The competitor's published information becomes a source of information for R&D activities	5.6
2. Profit increases by our exclusive practice	5.3
3. Risk of R&D efforts is smaller since the achievements are protected by law	4.9
4. Injunction can be obtained against the infringer	4.8
5. Becomes a source of exchange of technology and cross licensing	4.2
6. Claim for damages to the infringer	3.9
7. Can receive royalty and profit from technology transfer	3.7
8. The number of acquired rights can be used to measure the performance of the researcher	3.4

Source: Japan Institute of Intellectual Property, Survey (November 1993) some dynamical effects on the accumulation of knowledge, since the scope of property right is limited and the requirements of novelty relatively undemanding. Indeed, Ordover (1991) notes that: "potential competitors who have 'reverse engineered' the invention during the laying-open and opposition phases can file their own patent applications, thanks to the narrow scope of patent coverage and very relaxed novelty requirements". Early disclosure, combined with the limited exclusion rights conferred by the patent, lie at the heart of collective invention. In a survey of some 600 firms covering approximately 2 millions employees, conducted by the Institute of Intellectual Property of Japan, in November 1993, the average respondent firm licensed-in 12.6 domestic patents and licensed-out 24.2 patents to domestic firms; in agreements involving overseas firms the numerical balance of licensing-in and -out was more equal as was the balance of royalty payments and receipts (both of which were much larger in absolute value per patent and in total). The system seems well designed to encourage the rapid dissemination of knowledge and the exploitation of such knowledge by competing firms, which helps to foster mutual reinforcement and consolidation of innovative efforts.

120. Other series of indicators available for Japan, describing more conventional phenomena relating to R&D (see Figure 5), can be re-interpreted with regard to the knowledge distribution problem. These indicators show that in Japan, compared with the United States, the United Kingdom and Germany, there is:

- a greater relative importance of published papers by researchers engaged in "Development", vis-a-vis by personnel engaged in "Research";

- a greater absolute and relative importance of patenting by "Development" personnel vis-a-vis personnel in "Research".

121. Both observations are consistent with the relative emphasis placed upon codified knowledge products as the basis for cooperative information-pooling approaches for industrial innovation in the Japanese system.

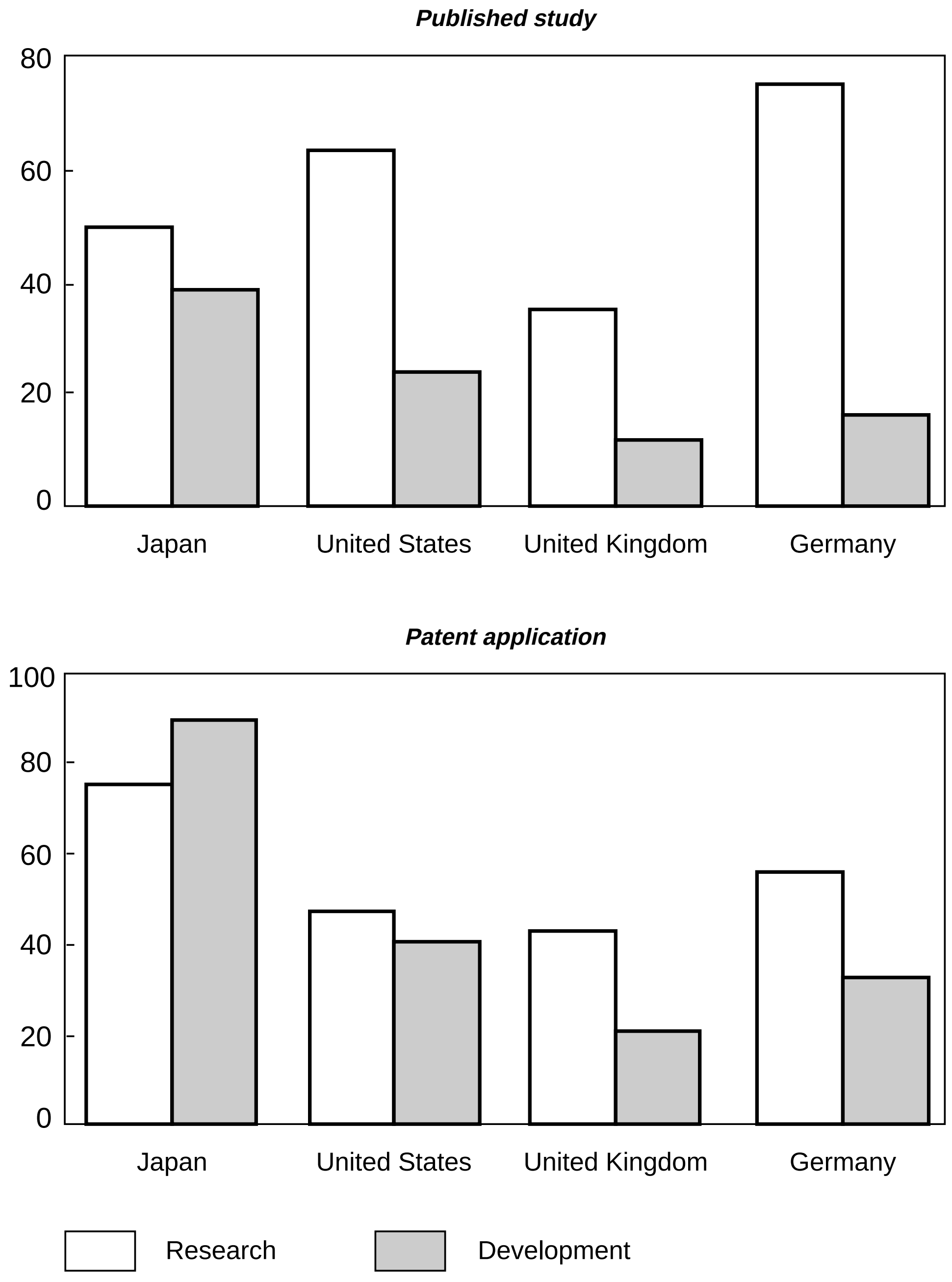
C. Consistency between the institutions of knowledge distribution and capacities for training and education, finance, industrial manufacturing

122. The viability of a distributive system is dependent upon the availability of specific capabilities.

(a) Knowledge distribution and industrial manufacturing system

123. By definition, a distribution-oriented system of innovation increases the frequency of innovations, while diminishing their individual private economic values. These innovations focus on the conception of products and processes and are generated in the framework of design analysis, development and engineering activities rather than research. Now, there are strong interdependencies between design innovations and the economics of industrial manufacturing: the system of innovation needs an industrial manufacturing system capable of integrating continuously a flow of innovations in design and engineering. This requires, on the one hand, structures of horizontal coordination inside the firm, and, on the other hand, capabilities of coordinated adjustments among the industrial subsets to the successive technical improvements and engineering innovations. In the case of Japan, these capabilities are very well described, analyzed and represented formally under the heading of the J firm. The capability of the industrial systems to adjust

Figure 5 **Percentage of researchers having published studies and patent applications**



Source: AIST

continuously to a flow of incremental innovations is based, according to Imai (1992), on the operation of "micro-macro information loops". These coordination devices facilitate the rapid propagation of new technical knowledge and systemic innovations (the rapid migration of each industrial sub-sets and partners to the new organizational norm) and support the collective learning of the necessary adjustments.

(b) Knowledge distribution and training capabilities

124. The education and training problem was addressed above. It includes two main points: on the one hand, education and training in the domains of engineering and transfer sciences (Table 4); on the other hand, education and training supporting the acquisition by economic agents of the capability to interprete, manipulate, locate and retrieve codified knowledge. Consequently, one might view the investment made in the formal education of the members of an organization, or of societies more generally, as required not simply to transmit what is presently thought to be useful knowledge, but to equip economic agents to retrieve and utilize parts of the knowledge stock that they may not perceive to be of present relevance but which has been stored for future retrieval in circumstances when it may become relevant. In other words, the accessibility of the extant codified knowledge stock may be indicated by the portion of the population that has been trained to access and interpret it. This suggests a different view of indicators of a society's educational activities from one that corresponds to a world in which economically relevant knowledge remained largely tacit and required being imparted to each new generation by demonstration and training through personal experience.

Table 4 **Research personnel in major countries**

		Science			Engineering		
		Bachelor	Master	Doctor	Bachelor	Master	Doctor
Japan	(1977)	10,234	1,663	717	69,221	6,925	1,079
	(1984)	12,698	4,361	2,485	71,396	18,868	2,223
United States	(1975)	88,990	17,560	8,040	53,520	18,400	3,130
	(1980)	78,246	13,829	7,587	90,121	20,927	2,813
United Kingdom	(1974)	11,878	1,719	2,241	6,897	2,092	1,043
	(1981)	20,151	5,056		14,616	3,416	
Germany	(1974)	5,839		2,258	20,972		801
	(1982)	6,387		2,427	6,551		919

Source: Wakasigi (1990).

(c) Knowledge distribution and financing structure

125. The emergence of new models of innovation and the establishment of distributive systems of innovation raise important financing problem. The Report of the Secretariat on National Systems for Financing Innovation (DSTI/STP/TIP(93)3/REV1) shows very well that such evolution is liable to destabilize institutions and rules designed for a different conception of technological development. Especially sorely tested is the adaptability of the innovation financing system. From the finance point of

view, the evolution towards a distribution-oriented system increases the uncertainty regarding the appropriability conditions of innovation and determines a shorter lifespan of products. Now these tendencies combined with the increased cost of R&D -- due to the multidisciplinary character of research, to the impossibility to transfer a scientific result from one exploration's level to another level when research is undertaken at the frontier of knowledge, and to the high lumpiness (indivisibility) of research activities -- will have major effects on the organization and behavior of the financing system. There is, thus, a critical problem of adaptation of the finance structures to the new priorities of the innovation systems. The report quoted above addresses this problem exhaustively, which mainly relates the methods of financial system surveillance to the new innovation models.

D. Is a distribution-oriented system likely to favor a particular style of innovation? Should such a system be viewed as a "transitory state"?

126. Innovations based on re-use, recombination, analytical design and reverse engineering -- i.e. on the routine use of a technological base -- are often viewed as representing derivative rather than fundamental or fundational novelties. This raises two important questions. Is such a system of innovation, the institutions of which are designed to facilitate the generation of "derivative" novelty, also conducive to support radical innovations -- in the economic sense of "radical", i.e., having the potential for widespread application with profound impacts on productivity and welfare? If not, is this kind of system essentially of a transitory nature, very well designed for "catching up economies"; but including institutions and incentive mechanisms which are rather inappropriate to a "forging ahead" economy, to use the terminology?

127. The conclusion of Ordover's study (1990) of Japanese intellectual property institutions are non-ambiguous: at the micro level, the distributive system "rewards those who reverse engineer and modify, often in minor ways, the existing inventions and penalizes those who wish to protect their major technological breakthroughs". At the macro level, "this system is less designed to meet the intellectual property protection requirements of an economy that has become a technological leader, as opposed to a technological borrower". This system would be, thus, adapted to a particular historical period of economic growth. As a result, much attention is now being directed by Western economic commentators to the necessary evolution of the Japanese pattern of innovation, allowing the system to escape from this transitory phase, by changing the institutions and degrading their "distribution power".

128. There is, however, an apparent paradox in the current evolution of the Japanese system, which warrants re-examination of Ordover's argument. The thrust of policy in Japan today is towards the reinforcement of the institutions and mechanisms designed for distributing knowledge, the fact that the Japanese economy is no more a "catching up economy" notwithstanding. This new emphasis in science and technology policy on the knowledge distribution problem has a dual aspect (Imai, 1991): (i) the increasing ability of the firms to master the interdisciplinary character of research by connecting themselves to a broad range of external R&D institutions; and (ii) the spatial process of agglomeration of the biggest corporate R&D institutions in the Tokyo area, allowing the system to benefit from recurrent interactions on each of three dimensions -- between users and suppliers; R&D, marketing, and manufacturing; and physical products, software and services -- which generate rapidly changing streams of information and give insight for further research. As expressed by Imai: "the character of the new industrial society is one of continuous iterative innovation generated by linkages across the border of specific sectors and specific scientific disciplines".

129. How can we explain the apparent paradox that the increasing necessity of generating systemic innovations induces an increasing emphasis in Japan on distribution-oriented institutions? The resolution resides in exposing misunderstanding concerning the notion of radical innovation, resulting in an inaccurate view of the nature of innovative institutions adapted to a leading economy. In other words, the "paradox" arises from the supposition that there is a necessary contradiction between the production of radical innovation and a distribution-oriented institutional structure. That proposition, however, has not been demonstrated.

130. What is a radical innovation if not the non-linear effects (architectural or revolutionary) from the cumulative process of knowledge advances and from the convergence of technical structures previously non-linked? Thus, the generation of radical innovations is dependent upon distributive capabilities. Some distribution's schemes analyzed above are particularly oriented towards the generation of radical innovation, like the distribution of knowledge among decentralized research projects. There are no strict one-to-one correspondences between one mode of organization and one style of innovation.

131. It does appear, nevertheless, that historically there was some under-allocation of resources to basic research in the Japanese system, as well as institutional weaknesses in the university-industry research links (Hicks, 1994). The latter institutional failure, however, is one that can only be eliminated by increasing the knowledge distribution power of the system. What would be a contradiction of the principles of a distribution-oriented system is the isolated growth of basic research capabilities, without any linkages to engineering capabilities. Unbalanced development of scientific research capabilities would result -- as in France and in the U.K. -- in the situation Pavitt (1993) described to the British Science Council: "not too much science but too little technology!".

132. Thus, there is no reason to think that a distributive system would only be adapted to certain particular growth trajectories. It is an organizational mode of innovation which is able to support the various steps of the process of technological advance.

E. Distributive systems and the global economy

133. A system -- qualified as distributive from the point of view of the internal circulation of knowledge -- is a system displaying efficient absorptive capabilities from the point of view of the acquisition and appropriation of knowledge from outside. This ability to assimilate quickly the technological advances generated within other systems may be a source of frictions in the global economy, since the asymmetries generated by the strong absorptive capacity of one country is amplified by the difficulties of the others to acquire external knowledge. These asymmetries can invite protectionist and neo-mercantilist policies, in other words a negative-sum policy game. Yet these are by no means necessary, and the most pernicious policy responses arise not from the logic of the economics of science and technology, but rather, from the misguided application of mercantilist arguments and what Krugman (1994) recently has castigated as the "dangerous obsession" with "competitiveness". There is a better solution to this problem, which resides in the evolution of each country towards particular version of the distribution-oriented system. However, as our introductory remarks on path-dependence (Section 1.2.D) suggest, re-positioning a system in order to increase its distribution power is a difficult process, entailing the transformation of the institutions and incentive structures that are interlocked with one another. Simple imitation of other nations solutions are likely to fail.

Section 5
A framework of indicators to study national profiles

1. Useful indicators to assess the distribution power of a system of innovation

134. We tentatively identify five blocks of indicators, devoted to the assessment of the distribution power of a system of innovation (Figure 6). The first one concerns the measure of the proportion of the knowledge "ready for distribution" in the system (c.f. the taxonomy of the knowledge-products presented in Section 2 above). The second block concerns three "critical domains" of distribution; which are the transferability to industry of scientific knowledge, the absorptive capacities of the firms, and the role of the public sector and public policy. The third block concerns the various institutional mechanisms for distributing knowledge, according to two main categories: the market transaction capabilities (technology licensing activities, other contractual tools, acquisition of small science-based firms, etc.) and the non-market transaction capabilities (research networks, bridging institutions, etc.). Block 4 provides the indicators of connections, that is some synthetic measures allowing countries to assess and compare their "distribution power". The last block links the distribution power to some more general indicators on economic performance (technological competitivity, style of innovations and the position of the system in the international flows of knowledge).

A. Block 1: the proportion of knowledge "ready for distribution"

(a) Mechanisms supporting the expression of knowledge in "forms facilitating distribution"

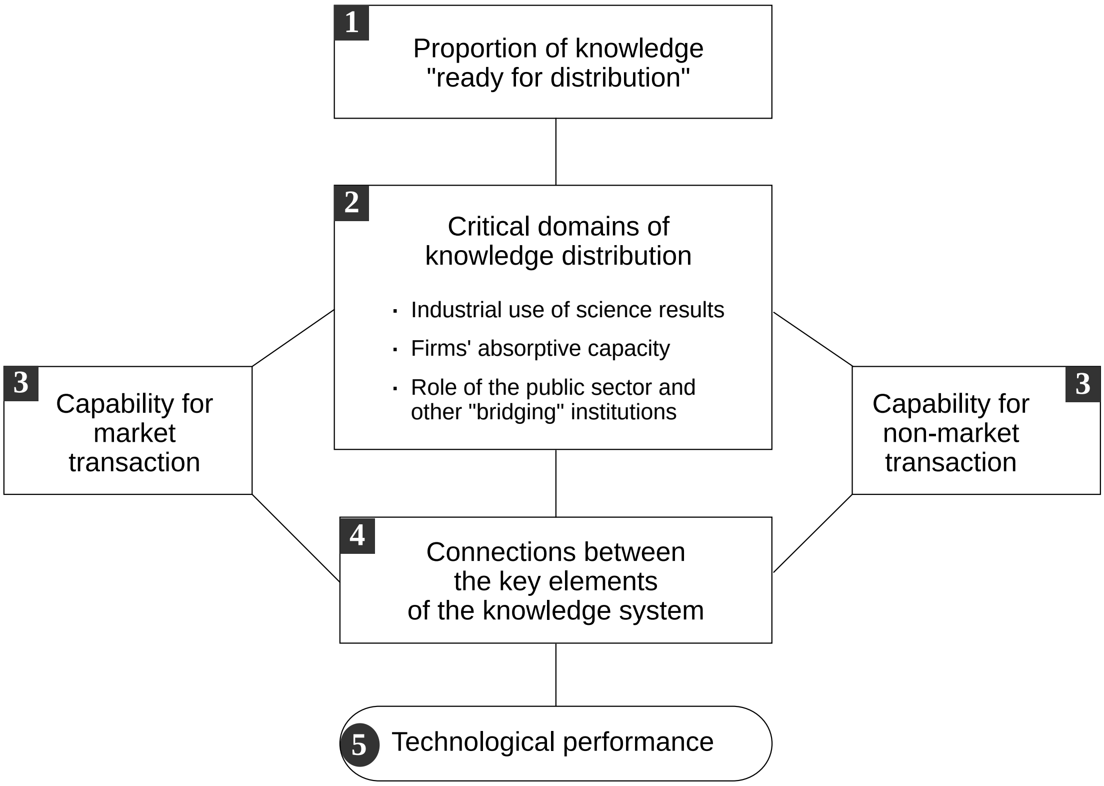
-- knowledge-products which take codified forms like scientific publications (e.g. TEP Fact Sheet 4, p.299). It is desirable to estimate a ratio: number of publications/research expenses in scientific institutions (e.g. NSF science indicators) as a measure of the recourse of academic researchers to publication;

-- knowledge-products which take codified forms through intellectual property rights items (patents, copyrights, utility models) (TEP, Fact Sheet 2, p.297). It is desirable to estimate a ratio linking the importance of patenting activities to the importance of trade secrecy, as alternative appropriation strategies (e.g. Innovation surveys);

-- knowledge-products embodied in prototypes, software, instrumentations and research tools, and high-tech products (e.g. TEP Fact Sheet 5, p.300).

-- indicators of the intensity of codification (production of expert-systems, engineering publications, etc.)

Figure 6 **Indicators of the distribution power of a national innovation system**



(b) synthetic indicator referring to the knowledge-product space

135. It is useful to estimate a ratio relating: (i) the weight of knowledge-product "ready for distribution", either through intellectual property rights and scientific publication items or via embodied knowledge; to (ii) the weight of knowledge produced without explicit goal of distribution (only proxy-measures are available here, like firms' expenses concerning technical expertise, services which essentially provide specialized engineering information, structured training provided and sponsored by employers, etc.). Clearly, the measures which should be produced are based on indicators which are not available yet and should be the subject of additional work and expertise for their quantification.

B. Block 2: critical domains of distribution

(a) indicators of industrial transferability of scientific research

-- importance of patenting activities of universities (e.g. data from EPO-CESPRI);

- -- bridging and transfer institutions (including mixed laboratories, mixed research positions, framework agreement, agencies and organizations to support information exchanges);
- -- importance of spin-offs (e.g. the data base of CSI in France);
- -- indicators of specialization in transfer and engineering sciences (e.g. the data compiled by Archibugi and Pianta);

(b) indicators of absorptive capacities of the firms

- -- in-house R&D;
- -- acquisition of science-based firms by domestic companies;
- -- trends in scientific and research employment in firms;
- -- technology licensing and transfer activities;
- -- importance of cooperation for sharing knowledge (dynamics of research networks -- inside and outside the firm);
- -- mobility of scientists and researchers towards firms.

(c) the role of public sector in knowledge distribution

- -- indicators of technology policy: resources allocated to programs explicitly oriented towards diffusion at both national and regional levels;
- -- indicators of dual development, such as mixed laboratories, co-publications, dual use of large scale instruments;
- -- importance of big technological programs, including universities, public agencies and large firms.

C. Block 3: transfer mechanisms (market and non-market)

(a) capabilities of market transaction (synthesis of indicators of block 2, dealing with market knowledge transactions)

(b) capabilities of non market transactions (synthesis of indicators of block 2, dealing with non-market knowledge transactions)

D. Connection indicators

(a) patents, publications: indicators of co-citations (e.g. data from EPRO-CESPRI)

(b) coherence between scientific and technological specialization profiles (e.g. the data compiled by Archibugi and Pianta)

(c) indicators of inter-sectoral connections for convergent technologies (e.g. the data compiled by Kodama)

(d) indicators of technological diffusion (diffusion rate of new products and processes)

E. Performances

(a) innovation styles

The purpose of this category of indicators is to depict a given country's propensity to innovate and dominant procedures of seeking novelty. The indicators could be the following:

- -- number and type of innovations (new product for the firm and the market; new product for the firm but already existing on the market; major development of an existing product for new markets; major development of an existing product for existing markets);

- -- innovation intensity (the fraction of sales corresponding to recently introduced innovative products)

(b) technological competitivity

(c) position of the system in the international knowledge flows

- -- technology balance of payment (e.g. TEP Fact Sheet 3, p.298)

- -- acquisition of foreign science-based firms and sale of science-based firms to foreign companies

- -- international migration of scientific and research personnel.

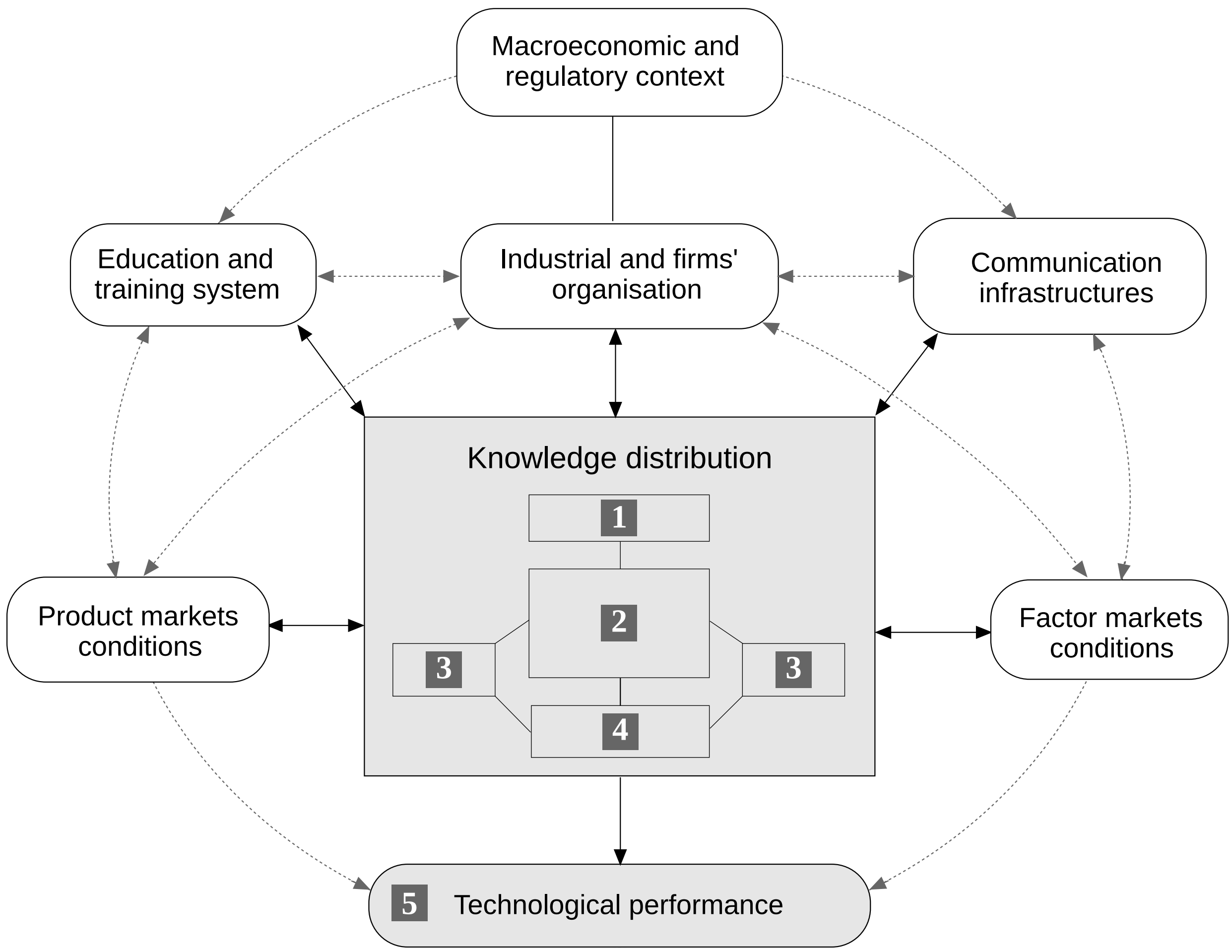
* * *

136. The core of indicators dealing with the distribution power of the system is related to the characterization of training and education capabilities, finance structures and industrial manufacturing capabilities. The general model of this indicators system could be represented as suggested in Figure 7.

2. Introduction to the study of national profiles

137. Figure 6 represents a sort of agenda allowing a given country to have a better picture of their own country (and other nation's) status in this regard; and symmetrically, of the magnitude of the losses of innovative potential due to the limitations of their knowledge distribution and knowledge-pooling capabilities. It is relatively easy to fill up block 2 and thus to have a better picture of the performance of the system of innovation regarding the distribution of knowledge. Some strengths are revealed (e.g. the

Figure 7 **Overall indicator framework**



industrial transferability of scientific knowledge in the case of the US, the role of public sectors for France, the absorptive capacities of the firms and the role of public sectors for Japan, a fine combination of the three factors for the Nordic countries and Germany; etc.).

138. The general transferability capabilities (market and non-market) can be derived from block 2 by summation and aggregation, and are synthesized in block 3. These capabilities are then expressed in terms of "indexes of distribution power" in block 4 and can be related to the general performances of the system (block 5). The most difficult task is probably to fill up block 1; i.e. to quantify the stock of knowledge "ready for distribution".

Concluding comments

139. Reconsidering international policy issues from the perspective of knowledge distribution systems, the general thrust of the analytical arguments and empirical observations we have made, regarding national institutions and policies that are critical for innovation processes, point to the importance of resisting neo-mercantilist "techno-nationalist" tendencies affecting the exchange of information and the sharing of the scientific and technological knowledge bases. International cooperation and coordination should be pursued wherever possible to ensure that institutions that presently function in an "open mode" should not become closed, whereas present national policies that interfere with the transfer of economically relevant knowledge should be modified in a direction of open exchanges. As example of the first policy it seems desirable, as argued recently by David, Mowery and Steinmueller (1994) that university-industry research collaboration should not become a pretext for reducing the ability of universities to function as nodes in international scientific networks. In connection with the second policy prescription, national restrictions on the acquisition by foreign firms of domestic science-based enterprises should be resisted where the intention is to block the transfer of knowledge; and the participation of foreign enterprises in government-financed programs of engineering and technical development should be facilitated under reciprocal agreements.

140. More broadly, the perspective developed here has suggested the importance of reconsidering many areas of potential international economic liberalization and cooperation, which would be conducive to strengthening the innovation systems of participating national entities. Among these topics that could be taken up in this connection, we note the following five:

-- *Intellectual property rights harmonization*

  Harmonization can benefit informational aspects of patents and copyrights; it does not imply anything about the necessity of providing a high level of protection for intellectual property.

-- *Standardization and standards institutions*

  International reference standards, and the metrology movement to facilitate exchange of information among engineers and scientists, serve to increase inter-operability of systems designed in different countries, by reducing non-strategic sources of variety in design. Standards institutions are fora for exchange of technical information, and vehicles for collective R&D in the design of future systems.

-- *International cooperation on electronic infrastructures*

  Communication satellites, electronic networks, conventions on trans-border data flows for S&T should be separated from the general debate on the North-South issues (privacy, security) concerning the transmission of commercial data.

-- *International cooperation for Megascience*

Large projects create common practices, and personal contacts among researchers, from which efficient formal and informal networks for the distribution of scientific knowledge can emerge and be maintained through modern electronic communications and collaboration technologies.

-- *Overseas training of scientists and engineers*

Training as specialized function of some countries creates basis for continuing connections which can link countries of origin with S&T activities in training centres.

References

Cowan, R. and Foray, D. (1994), "Quandaries in the economics of spillovers and dual development", *Research Policy,* forthcoming

Dasgupta, P. and David, P.A. (1992), *The new economics of science*, CEPR Working Paper, Stanford University

David, P.A. (1991a), *Reputation and agency in the historical emergence of the institutions of "open science"*, CEPR, publication n˚261, Stanford University

David, P.A. (1991b), *Why are institutions the "carriers of history"?*, Stanford Institute for Theoretical Economics, Summer Program, July

David, P.A. (1992), *Knowledge, property and the system dynamics of technological change*, World Bank Annual Conference on Development Economics, Washington D.C.

David, P.A., Mowery, D.C. and Steinmueller, W.E. (1992), "Analyzing the economic payoffs from basic research", *Economics of Innovation and New Technology*

David, P.A., Mowery, D.C. and Steinmueller, W.E. (1994), "University-industry research collaborations: managing missions in conflict". Paper presented to the AAAS-CEPR Conference on "University goals, institutional mechanisms and the industrial transferability of research", held at Stanford University, 18-20 March 1994.

Ergas, H. (1987), "The importance of technology policy", in Dasgupta and Stoneman (eds.) *Economic policy and technological performance,* Cambridge University Press

Foray, D. and Llerena, P. (1994), "Information structure and coordination policy; the case of the FRG", *Evolutionary Economics*, forthcoming

Imai, K. (1992), "The Japanese pattern of innovation and its evolution", in Heertje and Perlman (eds.), *Evolving technology and market structure*, The University of Michigan Press

Joly, P.B. and Hermitte, M.A. (1993), "Plant biotechnology and patents in Europe: an economic analysis of alternative models of intellectual property rights", *Biotechnology Review*, n˚1, November

Loasby, B. (1986), "Organization, competition, and the growth of knowledge", in Langlois (ed.), *Economics as a process*, Cambridge University Press

Metcalfe, S. (1992), *Competition and collaboration in the innovation process*, University of Manchester, Discussion Paper n˚79

Krugman, P. (1994), "Competitiveness: a dangerous obsession", *Foreign Affairs* (March/April)

Lundvall, B.A. (ed.) (1992), *National systems of innovation,* Pinter Publishers

Nelson, R. (1992), "What is 'commercial' and what is 'public' about technology, and what should be?", in Rosenberg, Landau and Mowery (eds.), *Technology and the Wealth of Nations*, Stanford University Press

Nelson, R. (1993), *National systems of innovation, a comparative study (17 countries)*, Oxford University Press

OECD (1992), *Technology and the Economy: the key relationships*

OECD (1992), TEP Conferences, the two books prepared as a follow-up to the Stockholm Conference (Deiaco and Vickery (eds.), *Technology and investment; crucial issues for the 1990s,* Pinter Publishers) and to the Paris Conference (D. Foray and C. Freeman (eds.), *Technology and the wealth of nations,* Pinter Publishers)

OECD (1994), *National systems for financing innovation*, forthcoming

Pavitt, K. (1992), "How useful is basic research?", in D. Foray and C. Freeman (eds.), *Technology and the wealth of nations,* Pinter Publishers

Richardson, G.B. (1990), *Information and investment,* Oxford: Clarendon Press

Rosenberg, N. (1990), "Why do firms do basic research (with their own money)?", *Research Policy*

Simon H. (1982), "The economics of information processing", Part VI, in *Behavioral economics and business organization,* The MIT Press

Steinmueller, W.E. (1992), "The economics of production and distribution of user-specific information via digital networks", in Antonelli (ed.), *The Economics of Information Networks*, North-Holland