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SCIENCE TECHNOLOGY INDUSTRY

Special Issue on Innovation and Standards

Accessing and Expanding the Science and Technology Knowledge Base

Interactions in Knowlege Systems: Foundations, Policy Implications and Empirical Methods

Characteristics of Innovation Policies, Namely for SMEs

An Innovation Survey in Services: The Experience with the CIS Questionnaire in the Netherlands

The Public Sector and Information Technology Standards

The Role of Users in Information Technology Standardisation

The Informatisation of Government: From Choice of Technology to Economic Opportunity

No. 16

STI REVIEW

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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FOREWORD

Prepared by the OECD Directorate for Science, Technology and Industry, the *STI Review*, which is published twice yearly, presents studies of interest to science, technology and industry policy-makers and analysts, with particular emphasis on cross-country comparisons, quantitative descriptions of new trends and identification of recent and future policy problems. Because of the nature of OECD work, the *STI Review* explores structural and institutional change at global level as well as at regional, national and sub-national levels. Issues often focus on particular themes, such as surveys of firm-level innovation behaviour and technology-related employment problems.

New forms of innovation prompt us to re-examine the way the strengths and weaknesses of national innovation systems are diagnosed, with a view to guiding government policy on backing innovation and shaping the general conditions in which scientific and technical knowledge is put to economic use today. Issue 16 of the *STI Review* covers all these areas, which it illustrates using the example of policies for encouraging innovation in SMEs and the standards process.

The views expressed in this publication do not necessarily reflect those of the Organisation or of its Member countries. The *STI Review* is published on the responsibility of the Secretary-General of the OECD.

TABLE OF CONTENTS

INTRODUCTION

The concept of "creative destruction", as popularised by innovation economics, conveys a fundamental aspect of the mechanisms of economic and social development. It is a concept which strikes a deep chord at the present time, when the social consequences of transforming our economies in response to the acceleration of globalisation and the rapid development and diffusion of information technologies are causing serious concern. The emergence of a knowledge-based growth model has not proceeded without setbacks and the immediate costs of such a model are far more obvious than its benefits. Governments are under pressure to show that this metamorphosis will rapidly deliver substantial, evenly-distributed gains and to implement policies which will facilitate the necessary changes. In order to do so, they need to be given reliable diagnostic tools and guidelines to help in formulating their policy responses. The conceptual framework upon which they have traditionally relied, however, has been seriously weakened by the sheer breadth and depth of the economic changes now occurring. The challenge confronting economics research is to help provide greater insight into the workings of an increasingly knowledge-based economy, so that governments can take informed action to promote growth that is likely to generate more, high-grade jobs.

Innovation, a federative process

Such action calls for a wide range of initiatives in very diverse fields, all of which must be made to work towards a common end. The challenge in any analysis of the determinants and benefits of innovation is as much to facilitate the convergence of such initiatives as to inform aspects of government policy specifically geared to supporting research activities. The reason for this is that innovation is a process which encompasses all the elements that must be taken into account in order to improve the integration of government policies and the linkage between the different levels of action involved (local, national, regional, global). For example:

- the micro-macro link (innovation is the result of a firm's desire to minimise the uncertainties of competition subject to the constraint of general equilibrium factors);
- the link between economic and social factors (innovation requires social adaptation since it is generated at the interface between culture and technology, at the level of either the firm or of society as a whole);
- consistency among the different territorial dimensions of the development process (innovation is the process by which a firm integrates know-how of various sorts gleaned from its environment at local, national or world level);
- the interaction between the logic of the market and that of other institutions in determining development trajectories (*cf.* the concepts of national innovation systems, technology trajectories and interactive learning among the economic agents in the system);
- the link between the financial and the real economy (the ability to manage innovation-related risks is fundamental to the efficiency of financial markets);
- the respective role of standardisation and institutional variety as a source of economic and social progress;
- the inertia of the economic structure and the dynamics of its transformation (*e.g.* the concept of path-dependency).

Research into innovation has gradually equipped itself for the task in hand. Initially by departing from the narrow view which equated innovation to R&D, and later by breaking with the linear model for the commercialisation of scientific and technical knowledge. Lastly, it resisted the temptation to develop itself as an alternative, rather than the necessary complement, to the predominant and primarily neo-classical approach to the analysis of macroeconomic phenomena. The OECD's current work on innovation systems is part of an eclectic approach which draws on both neo-classical economics and innovation theory (the evolutionary school, for example) and introduces hypotheses inferred from the unprecedented problems that decision-makers experience in managing a knowledge-based economy.

New workable concepts

The work reported in this review is guided by a number of major considerations. The first of these is the importance of consolidating the conceptual bases for the analysis of innovation systems, to give a more accurate picture of the changes that are now affecting innovation modes, chiefly as a result of the increasing ease and plummeting costs of accessing and processing information in all forms. From this perspective, innovation and standardisation are becoming so inextricably linked in the knowledge-based economy that the inclusion of papers on both innovation and standardisation in this review is fully justified.

The approach proposed in the report by P. David and D. Foray is to:

- consolidate the concept of a knowledge-based economy by analysing the interactions within innovation systems as a network of flows of knowledge in various states (technology-embodied/product-embodied, codified, tacit, public, proprietary, etc.);
- transcend the knowledge generation/diffusion dichotomy by defining the notion of "knowledge distribution";
- acknowledge the variety of forms of innovation and of the ways in which they can contribute to welfare, by establishing causal links between "knowledge distribution power" and performance, at different levels within the economic system.

The second consideration is to make these concepts workable, starting by testing them empirically, thereby paving the way for the development of a new generation of indicators. This is the aim of a project recently launched by the OECD and outlined in the paper by K. Smith.

The importance of "framework conditions"

The third consideration is the need to reach a better understanding of the influence of certain environmental factors (or "framework conditions" to use a term very much in vogue) on the innovation process: factors such as the workings of the education system, the labour market and the financial market. R. Chabbal's paper gives an example of such a comprehensive approach to the problem of promoting innovation in SMEs.

Of these framework conditions, innovation infrastructure warrants close attention. Some of the infrastructure is tangible (modern communication equipment), some intangible (intellectual property rights, or standards). Standards play a role all too often neglected in the creation of technological trajectories, and of the links which develop between them, to shape the innovation system. This role is exemplified in the paper by E. Brouwer and A. Kleinknecht in the case of the services sector.

Governments must henceforth take into consideration a wide range of factors which are determinants of technical progress and of the diffusion of technological advances throughout the economic and social fabric – a range which is much wider now than even quite recently, when research and development were the sole focus of attention. Governments can no longer afford to ignore the fact that the system that exploits the results of research involves whole series of technical stages – ranging from testing to full-scale trials, by way of demonstrations, quality control checks and certification to standards – upon which the application of new technologies depend.

The role of standards

Standards have assumed even greater importance with the advent of the "information superhighway" and the new world-wide economic implications of information and telecommunication technologies (IT). These technologies can only reach their full potential when their applications are integrated into networks which can be easily accessed and in which information circulates easily. This gives some idea of the enormous economic influence wielded by the standards system, which governs the critical interfaces between different types of hardware and software.

The standards system has traditionally been based upon the voluntary participation of interested parties (private and public sector) and upon a process of consensus-building aimed at responding to market stimuli. The voluntary nature of the resulting standards is an important factor in their effectiveness. The formal procedures which have worked satisfactorily since the 19th century must now be overhauled to allow for the rapid pace of technical progress in the IT field, the political and economic implications of the relevant standards and the increase in the number of actors involved. Three of the papers in this review address certain of these aspects.

The institutional framework of standardisation

Although standardisation procedures are of a voluntary and consensual nature, governments have a role to play in improving them. R. Hawkins outlines the prerequisites for a country to have the institutional instruments and procedures which will allow it hold its own in discussions which could have a major impact on its competitiveness. If a country is to do so, those involved at national level must be made aware of the issues and must have the necessary mechanisms and apparatus to enable them take a stance on the options under discussion. National bodies must also be able to defend their position in a number of international bodies. Lastly, the success of standardisation is dependent upon a set of conditions (awareness of the business community, adequate human resources, development of services, consistent decisions by the administration, etc.) which call for particular attention.

Role of private and public users

IT standardisation has long been the almost exclusive province of hardware manufacturers and service operators or suppliers. A profound change now taking place is the growing voice given to different user groups. Involving users is not always easy, owing to the proliferation of national regional and international bodies, the complex procedures and substantial costs which such an effort entails. J. Rankine cites various examples showing that it can be worthwhile to give users a voice, albeit to greater or lesser effect, within the appropriate bodies. Progress in this area, encouraged by electronic networks which facilitate user-involvement, also depends upon the openness of the standards bodies.

In most Member countries, as R. Cowan points out, governments are among the largest IT users. The technology choice that the public sector makes inevitably has an impact on private sector choice. Hence the importance of public procurement, which can be decisive in determining the standards of the future. These implications are not always clearly perceived and taken into account by decision-makers. That is why it is important to weigh the impact of government procurement more carefully and to determine what strategies will best take account of the technological, economic and political implications. As far as standardisation goes, the stakes and the conflicts between players are increasing, and there may well be a case for governments to step in as mediators.

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ACCESSING AND EXPANDING THE SCIENCE AND TECHNOLOGY KNOWLEDGE BASE

CONTENTS

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I. INTRODUCTION AND OVERVIEW

That there exists as an attribute of modern economies a set of entities (or perhaps functional properties) which it is useful to characterise as their respective national systems of innovation, is a proposition that has been gaining wider and wider currency among academic economists and science and technology policy experts. It has come to be seen as providing not only the conceptual foundation for undertaking comparative studies of scientific and technological development and its relationship to the dynamic economic performance of entire nations, but also as a rationale for the investment of national resources in supporting a nation's "innovation system infrastructure". Although the phrase "national systems of innovation" is employed in various ways, a consensus seems to have emerged that it refers generally to structures of economic organisation 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 (see, for example, the article by K. Smith in this volume).

In the economics literature the concept of national systems of innovation originally introduced by C. Freeman (1987) has been given further intellectual coherence and policy 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 organisation and behaviour, 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". However sensible it is to link the innovative capabilities of a society with the ways in which its economic and social organisation affects the acquisition and utilisation of useful knowledge by its constituent members and agencies, one must observe that these are neither strikingly original, nor rhetorically stirring propositions on their face. What, then, accounts for the current rise in the popularity of the national systems of innovation concept?

It would appear that the attention that discussion of national systems of innovation is coming to command outside purely academic research circles derives 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 "techno-nationalism" which, during the 1980s especially, began animating economic policy discussions in the industrialised and industrialising nations alike. Techno-nationalism, as described by Richard Nelson and Nathan Rosenberg (1992, Chapter 1), is what one gets by combining two beliefs, each of which have come to be more and more widely held: *i)* that the technological capabilities of a nation's firms are a key source of their competitive prowess; and *ii)* 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" (see Foray and Freeman, 1992).

In this essay we re-examine the usefulness of the cluster of ideas regarding 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 recognise that the economic benefits of co-operation are especially great when one is concerned with the production and utilisation of scientific and technological knowledge. We point out the danger that these may be jeopardised by "techno-nationalist" approaches to policy that emphasize only the private value of non-co-operative strategies. We caution against the mis-appropriation of the concepts and terminology of "tacit knowledge" and "localised innovation" by policy advocates who are essentially neo-mercantilist in their readiness to lend governmental encouragement and support for the development of capabilities best suited to the pursuit of national rivalries over the commercial appropriation of economic benefits from existing stocks of scientific and technological knowledge, and that seek to restrict access and limit "spillovers" of new knowledge created by the investment of national resources.

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

One of our main analytical purposes in this undertaking is to develop an economic framework within which comparative studies (using both quantitative and non-quantitative data) can be carried out on a national basis. That objective parallels the stated aim of Richard Nelson in organising the set of national studies recently appearing in the volume under his editorship entitled *National Innovation*

Systems (1992). But the approach we have adopted is far less all inclusive than that proposed by Nelson. However great the influence on the long-run "performance" of modern business firms and economies that may be attributed 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 will be seen to be rather closer to that of Lundvall, in being focused upon the effectiveness of private organisation and public institutions, and on the ways in which they interact in the production and distribution of economically-relevant knowledge throughout the economy.

Yet, because we are concerned ultimately 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 its 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 focuses 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 organising and carrying out productive tasks.

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 utilise 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 criticised 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 that 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.

Our framework of analysis thus discards the classical linear stage model, in favour of articulating the interdependence and interactions among the sub-process in the overall system governing the production, distribution and utilisation of economically-relevant knowledge, an approach that follows David's (1993*a*) 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, in this view, is seen within a general evolutionary framework to be a phenomenon of "organised 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 – the 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 organisational 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 affect investment in the development of technologies that are complementary to the ones that would have gained stronger protection.

Neither the idea of learning as central to the activities of individual economic agents and organisation, nor the pertinence of the systems approach to analysing 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. Of course, national governments do make policies and impose rules and regulations within their respective sovereign domains, thereby influencing the behaviour of the individuals and organisations that operate there. Furthermore, it is the nation states that must provide the wherewithal to enforce supranational agreements governing the activities of private corporations and individuals. So, quite obviously, national policy and state intervention matter.

Moreover, geography also matters. There is a significant spatial dimension to many kinds of learning activities which may substantially confine them within particular national boundaries. 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 organised 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 recognise the systemic influences of factors that are co-determined within the boundaries of the nation state.

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 totally obscure from view the significance of other, sub-national and supranational systems whose workings may be no less critical in shaping technological opportunities and the 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 organised 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, private corporate entities co-ordinating 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 simultaneously in many different nations. Furthermore, complementarities and linkage effects among the nations represent a factor of potential great importance in the explanation of the emergence and development of different systems of learning in science and technology national policies.

All this means that comparative studies should be careful not to treat national units of observations implicitly 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 recognised that to the extent that national systems of innovation can meaningfully be identified in the modern world, 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 salient 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 discernible 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 behaviours across national boundaries?

Broad theoretical orientations

Information-theoretic approach to the characteristics of knowledge

The information-theoretic approach as it will be implemented here (informally) focuses attention upon the special characteristics of knowledge as an economic commodity, which will be seen to affect its generation, acquisition and distribution. There are three dimensions – namely, *i)* degree of codification; *ii)* completeness of disclosure; and *iii)* ownership status – that we can use to define a space within which addition to stocks of economically-relevant science and technology knowledge can be located. Following along the line developed in Dasgupta and David (1987, 1994), and David (1993*a*), 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. 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 readily-transmissible information, monitoring and perception of information (involving encoding, decoding, translation, filtering, interpretation 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 (1971), it may be argued that the advantages of more complex human organisations 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. 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 organisational forms that have been made the centre of attention in prior work on technological and scientific research and innovation.

Institutions

The limitations of markets in handling information as a commodity will be viewed as inherent in all systems that concern the production and distribution of knowledge. Various institutional devices may solve some of the more difficult allocational problems wholly or partially, either by enlarging the scope for markets to function, or by providing alternative non-market allocative systems (*e.g.* the "open science" reward system based on priority of discovery and invention). The goal here is to give explicit notice to the possibilities of elaborating 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*a*), for example, under the headings of Patronage, Property, and Procurement.

Path-dependence

After assembling and preparing the foregoing conceptual ingredients, we still need to bring two additional sets of considerations to the table:

- The first is the view that specific institutionalised 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-maximising public authorities. This is a proposition whose force is brought out quite clearly by considering the specific problems encountered in adapting intellectual property institutions to the economic exploitation of new technological opportunities (see, for example, David, 1993*b*).
- The second takes the form of the proposition that institutions and organisational forms do not exist in isolation. Rather they are created by the innovative combination and recombination of previous institutions and organisational forms that, consciously or unconsciously, are viewed to be "salient" in particular social and cultural contexts, among the many alternative possible modes of co-ordinating the behaviour of individuals in production and distribution. Human organisations which are embedded in highly durable information structures that facilitate the development of learning and decision capabilities of the people involved, quite typically are constrained by the very same information structures that enable them to function with reasonable effectiveness (see, for example, Foray and Llerena, 1995). Moreover, human organisations tend to resist reconfiguration in response to adverse signals concerning their own performance (which they often are prevented from receiving by their own information filters). Institutions generally are less plastic, less malleable than material technologies, and the inter-relatedness 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, for example, Johnson in Lundvall (1992); David, 1994*b*].

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 organisation) as a whole is disrupted or captured by one that is differently structured. The feasible space for institutional innovations in a given society, thus, is likely to be tightly constrained by its history, which is to say its institutional structure is path dependent.

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. There is, consequently, a need for both national and international policy co-ordination affecting these systems, and even before turning to consider the possibilities of fundamental innovation in the institutional sphere, it is important to explore the possibilities of making further use of the capabilities of existing institutional infrastructures.

Emerging propositions

The special characteristics of knowledge and information viewed as commodities, and the problems of organising the production and distribution of these rather peculiar "goods" through competitive markets are considered in greater analytical detail in Sections II and III, respectively. That analysis serves to bring out two sets of propositions that we believe carry important implications for science and technology policy, broadly conceived. These emerging propositions will receive more extensive development and discussion in Sections IV and V, but they may be anticipated at this point.

Distribution and the growth of economically valuable knowledge

An efficient system of distribution and access to knowledge, whether at the local, regional, national or international levels, will increase the social value of both the knowledge that is being produced by experience-based learning and organised 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 reduces wasteful duplication of effort in research. By putting information into the hands of a more diverse population of researchers, these conditions tend to increase the probability of useful new products and processes arising from novel and unanticipated combinations. 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 characterised by its "*distribution power*" as much as by its capabilities for generating new knowledge, that is to say, by the system's ability to support and improve the efficient functioning of procedures for distributing and utilising knowledge. In the case of knowledge, however, a condition of "efficient distribution and utilisation" is not something that can be expected to arise automatically from the interplay of market forces. The different incentive structures and social organisations 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 organisational "boundaries", as almost inevitably will be required in complex systems where there is division of labour, including innovative labour.

Evidently, there are two (non-exclusive) ways of improving the performance of a system of science and technology learning: increasing the stock of knowledge (endogenous generation and acquisition from outside); and making the existing stock more socially useful, *i.e.* by improving transfer, transformation and access to the stock of existing knowledge. In science and technology policy formulation in the West during the past three decades, attention increasingly has centred 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 organised R&D, since copyright, patent and trade secrecy laws create obstacles to access which restrict the commercial utilisation 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 co-operation and investment co-ordination in expanding productive capacities, rather than for the capture of monopoly rents. There may well be needs for specialised "bridging" institutions and technology transfer incentives, designed expressly to facilitate 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 US farm industry in the 19th century. But specific reforms of legal and other institutions cannot be undertaken without considering how they will interact with other elements of the institutional infrastructure. Sweeping reforms impose heavy costs in terms of uncertainties about formal and informal property rights and incentive structures; incremental changes are therefore more likely to be favoured. The process of change in the institutional infrastructure of politically stable societies tends to be evolutionary and path-dependent.

Co-ordination across nations

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 especially misplaced, inasmuch as knowledge is an infinitely expansible commodity; something which can be concurrently possessed and utilised 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 techno-nationalism has lent support, is particularly prejudicial to successful knowledge-based economic development strategies. Four reasons for that conclusion can be enumerated:

- 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 on them a choice between, on the one hand, 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, on the other hand, simply abandoning the pretence of maintaining a scientific capability in many sub-disciplines of science, engineering and medicine.
- It burdens attempts at international co-ordination for the support of "big science" projects and expensive collaborations in technological development, thus limiting the possibility of sharing the cost and increasing the utilisation 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 by researchers distributed among quite remote sites.
- It works to curtail the scope of human resource mobility, and in so doing blocks channels of distribution and access to the knowledge base.
- It gives national political sanction to efforts to harmonise 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 utilisation of existing knowledge.

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

Précis of the argument and exposition

Section II, immediately following, examines (from the vantage point of modern microeconomic theory) the principal characteristics of information affecting knowledge generation, acquisition and distribution processes. Section III then deals with the construction of the knowledge-product space, which has three principal dimensions: codification *versus* tacitness, disclosure *versus* secrecy, public accessibility *versus* private ownership. The focus of these two sections on the economics of knowledge conduces us quite naturally to address the problem of the "optimal use of a non-rival good", and therefore to develop the notion of the "distribution power" of an innovation system. The theoretical options taken in Section IV acknowledge the complementarity between knowledge distribution and generation rather than accepting a dichotomy between innovation and diffusion. This leads us to the argument that utilisation of existing knowledge stocks (both for direct application in production and as bases for further learning) needs greater attention, counterbalancing the conventional emphasis on giving incentives to innovators by enabling them to appropriate economic rents on new knowledge. The fifth and final section 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 liberalisation and co-operation that would serve to strengthen the respective national innovation systems.

II. KNOWLEDGE, LEARNING AND INFORMATION IN THE ECONOMY

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 categorise 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.

Knowledge-products and information commodities

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".

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".

The codified-tacit dimension of learning

Following common usage in economics, we use the term "information" 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 all contribute greatly to reducing the time and effort required to produce unambiguously codified messages. The lowest level of codification involves translation into standardised 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 heterogeneous. 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.

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: *i)* it is durable, in the sense of not deteriorating with use, although its economic value may be altered thereby; *ii)* it is capable of being enjoyed jointly by a number of agents; and *iii)* costly measures must be taken to restrict access to those who do not have a "right" to use it.

In contrast with codified knowledge, tacit knowledge, as conceptualised 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 mean that they are the less important: they form the context which makes focused perception possible, understandable, and productive. Like 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 may be swapped in transactions resembling "gift exchanges", or sold for money, rather than being shared freely.

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 are 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.

Some recent discussions of the economics of R&D and technology transfers (*e.g.* Pavitt, 1992; Nelson, 1992; 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 incontestable 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 (1994) 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".[1] 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.

Social organisations of research and the disclosure-secrecy dimension

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 organisations, 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 organised 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 organisations 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 behaviour in regard to the disclosure of knowledge, and the features of the reward systems that provide individual incentives compatible with the pursuit of the organisational objectives under the norm-imposed behavioural constraints. It is important to emphasize that in accepting the distinction made by Dasgupta and David (1994), 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.

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" organisational norms affecting the autonomy of individual researchers, the freedom to select collaborators, to enter informal modes of co-operation, 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 organisation, 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 organisational 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 organisations operating within the private knowledge domain; and also by academic research organisations, 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.

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 organise research facilities in ways that emulated the open, co-operative 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 organisations are constrained by the norms of disclosure from seeking to maximise 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, 1994) draws attention, is whether any one organisation can function effectively when harbouring two quite antithetical sets of norms and cultural orientations when more or less equivalent legitimacy, and comparable organisational resources are devoted to each. But even recognition of such intra-organisational 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.

Public economics and generic institutional devices

The foregoing, highly stylised 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.

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.

Public production

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.

Private property and markets

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.

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 leakages. 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.

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 organisations), 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 under-utilisation 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 practised by discoverers.

Subsidies, procurement and regulated private production

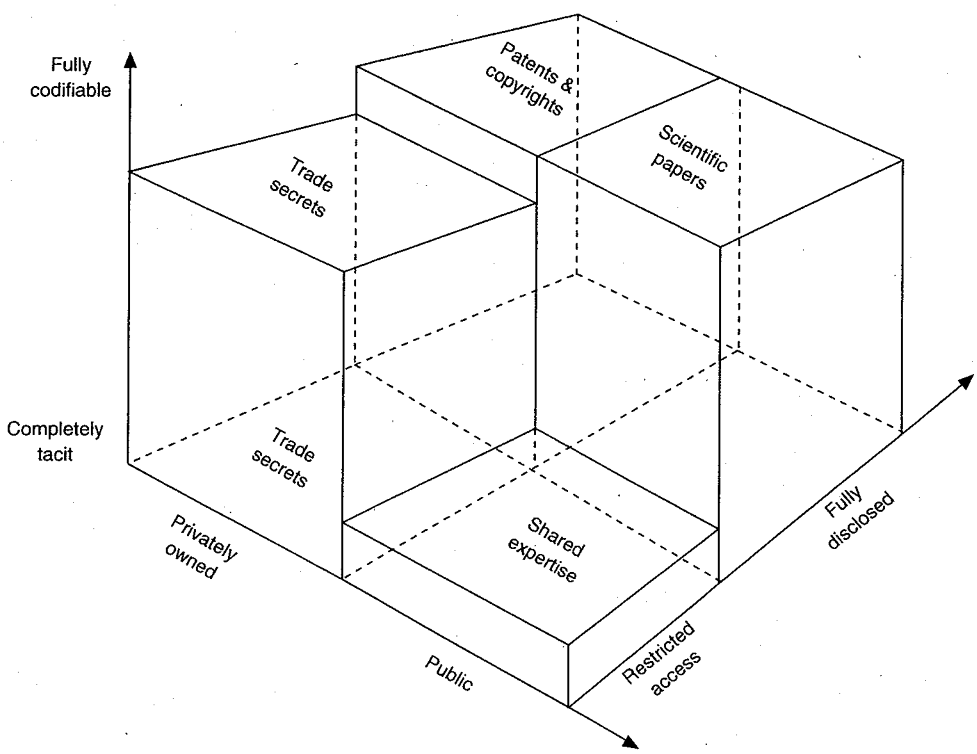
A third possible scheme is for society to encourage private production of knowledge by offering public subsidies for its production, and by relying upon general taxation to finance these subsidies. A critical feature of this arrangement is that producers are denied exclusive rights to the output of their 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 characterises 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.

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 specialised 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 specialised communities to help articulate the interest that they will be engaged in promoting.

III. INSTITUTIONAL INFRASTRUCTURE AND THE KNOWLEDGE-PRODUCT SPACE

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 1 in several distinct ways: *i)* to represent the mix of knowledge-products generated by particular learning entities during a specified time interval; *ii)* 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; *iii)* 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.

Figure 1. **The knowledge-product space**



The dimensions of knowledge space

Codification and tacitness may be treated as locations along a continuum whose endpoints are represented by complete systematisation 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. At the opposite pole one may find procedural knowledge that is not systematised, 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.

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 monopolise 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. 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.

The extent of disclosure, likewise, is a continuous variable, bounded by full disclosure at one limit and total secrecy at the other. Both patents and copyrights, however, are categorised in Figure 1 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. 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 co-ordinates of complex proteins whose molecular structure is being reported; or the computational algorithm used in analysing experimental observations.

The upshot of the foregoing discussion might be restated as follows: the situation of knowledge-products in the space defined by Figure 1 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 organisations engaged in research activities. There is, however, no deterministic characterisation of a knowledge-product with respect to the institution that supports its generation. In fact, institutions and norms of behaviour have a certain degree of suppleness, which means that a knowledge-product generated in a given institution (say, a university) can be expressed in a broad range of forms (scientific papers, patents, shared expertise, access restricted or delayed, etc.), depending upon the incentive structures and the institutional compromises which characterised the institutional context considered. 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 1.

Flows versus stocks of knowledge

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 utilised by virtue of becoming more widely disseminated.

Durability, maintenance of accessibility and obsolescence of knowledge stocks

The reference made to the gross stock of knowledge (in the preceding paragraph) recognises 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 organisational competencies disappears when firms are merged into other organisations, 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 organisation, 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.

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 organisation, 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 utilise 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.

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 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 organisational forethought. There already are many instances in which stored computerised 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 US 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.

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? Or would it be better to say that the potential utilisation rate of the stock has been reduced? Under the latter convention, we would have to recognised that the "effective stock" of knowledge might increase very dramatically without the expenditure of resources on learning activities by the organisation 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 organisational procedures (having all filing supervised by a competent archivist) that would reduce the marginal costs of access to extant databases.

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 utilised by the agents in question.

IV. INFORMATION ACCESS, KNOWLEDGE DISTRIBUTION AND THE INSTITUTIONAL INFRASTRUCTURE

The purpose of this section is to show that the "distribution power" of an innovation system is a key determinant of economic performance, and policies should be directed to providing potential innovators with timely and easy access to relevant knowledge bases. The "knowledge-distribution power" is becoming a more critical attribute of innovation systems for three distinct reasons:

- science and engineering knowledge-based industry is continuing to grow in economic significance;
- openness of the information system is vital for efficient use of costly research resources in creating reliable knowledge because *i)* independent replication of findings is facilitated by open access; *ii)* generalisation of results proceeds faster when they are widely distributed; *iii)* excessive duplication of research is avoided by rapid disclosure;
- the science and technology research paradigm is shifting towards greater collaborative use of distributed dynamic databases as tools for creativity.

The economics of knowledge distribution

Knowledge interactions and positive externalities

Viewed as an economic good, knowledge possesses particular properties which lead us to observe that an efficient system of distribution and access to knowledge will increase the social value of both the knowledge that is being produced endogeneously, and the knowledge required and assimilated from external sources.

- First, knowledge is usually described by economists 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.
- Second, the process of knowledge generation in science and technology is cumulative and integrative; that is, knowledge can hardly be only considered as an output; it is also the main input of any process of knowledge generation. Cumulative forms of knowledge are those in which today's advances lay the basis for tomorrow's, which in turn lay the basis for the next round (Scotchmer, 1991). A synthetic knowledge is generated through convergence or co-lateral integration between (previously) independent pieces of knowledge. Thus, for many industries, advances take place in a generational sort of way – a new product or process is not a radical departure from what has gone before, but rather builds on and extends knowledge and technology that was used in the production of the product or process it supersedes.

Thanks to these properties, any process of knowledge generation is likely to produce positive learning externalities. In other words, the generation of a new piece of knowledge increases the probability of useful new products, processes and ideas arising from novel and unanticipated combinations: "the more is invented, the easier it becomes to invent still more" (Machlup, 1984).

These positive learning externalities are based on various knowledge interactions. Let us compare production of knowledge to the discovery of new mineral deposits. First, some knowledge is like surveying; it generates maps that raise the return to further investment in exploration and exploitation (David, Mowery and Steinmueller, 1992).[2] Second, it has been observed that minerals production in an area leads to localisation of exploration, so that, 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 others will undertake exploration in the neighbourhood, producing knowledge is likely to generate positive externalities for the explorers and each agent has an interest in diffusing the product of his discovery so as to profit from the results of others. At the very least, information about where others have failed to make a discovery will be valuable in guiding one's own search. The third aspect of positive externalities deals with the migration of young investigators into new fields – colonising new areas with tools and concepts developed elsewhere. This "frontier expansion" requires falling yields in colonised areas to generate breakthroughs into new territory (here again, the analogy works perfectly).

There has been a recent resurgence of the view that in the realm of knowledge production, positive externalities dominate. This is reflected in P. Romer's (1993) emphasis upon not only the so-called "non rival" character of ideas available for application in conventional production, and the consequent increasing returns to investment in R&D, but also on the notion that new knowledge promotes ever more product specialisation, and essentially unbounded growth of productivity and welfare improvement from that source. Scotchmer's (1991) work, in emphasizing the cumulative nature of inventive activity – the effect of raising the height of the shoulders of giants from which one can see further, rather that obscuring the view – is part of the same re-orientation of economic analysis away from insistence on diminishing margin returns in all directions of the convexified world. David's (1993*a*) attention to the impediments that intellectual property protection poses for innovation, based on the related notion that a major use of new knowledge is as an input into further production of knowledge, also has greatest force in situations in which the returns to increased round-aboutness of knowledge production are not diminishing at the margin, but instead increasing.[3]

Thus, we may conclude from this first paragraph that there is a particular, causal or conditional, relationship between the stock of knowledge and the flow of innovation during a given period of time. However, it is not a purely definitional relationship. In fact, the stock of knowledge can increase the amount of innovative opportunities only if the conditions of wider distribution, and timely inexpensive access to existing and new knowledge are fulfilled.

The conditions of access to knowledge

Indeed, an efficient system of distribution and access to knowledge is a *sine qua non* condition for increasing the amount of innovative opportunities. Knowledge distribution is the crucial issue of the relation between stock and flow.

In the case of knowledge, however, the condition of "efficient distribution and utilisation" is not something that can be expected to arise automatically from the interplay of market forces.

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, 1994*a*). The particular economy of knowledge distribution is based thus on two particular conditions: *i)* individual incentives to enter into co-operative games based on the exploitation of positive externalities (complementarities); and *ii)* 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 for at least four reasons:

- First, building up information structures generates access costs, which become higher as these stocks evolve and become more specialised, 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 localised; 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 organisations which developed it, see Section II, 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 organisations 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".

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 positive externalities being only partly enjoyed. This creates an unfortunate loss of energy in the system of innovation.

Summary

This section has identified a particular relationship between the stock of knowledge and the flow of innovation during a given period of time. However, it is not a purely definitional relationship as in most endogenous growth models.[4] This relation is shaped by the conditions of access to the stock and distribution of new knowledge. Thus, institutions mediate the relation between the knowledge stock and the flow of innovations. The shaping of this relationship should be seen to be an organisational and institutional problem, dealing with the optimum utilisation of a non-rival good.

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 co-ordination, 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. 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 specialising in basic research activities. Both tendencies warrant careful and sceptical 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: what are the institutional innovations allowing a system to improve its "distribution performance"? However, before addressing the institutional and organisational issues, it is important to ask: why is "knowledge distribution power" becoming a more critical attribute of innovation systems?

Distribution and the networked knowledge base

We have already studied one theoretical reason for the importance of distribution: openness of the information system is vital for efficient use of costly research resources in creating "reliable knowledge". Now a second reason seems to be more crucial in the "pleading" for an increase in distribution power.

The science and technology research paradigm is shifting towards greater collaborative use of existing knowledge stocks, and a higher degree of transdisciplinary complexity in research programmes, thereby raising critical issues concerning access and exploitation of the networked knowledge base. This important newly-emerging tendency is reflected by various features: *i)* the codification and formalisation of increased parts of the knowledge stock; *ii)* the growth of electronic traffic on digital research networks as tools for creativity and the development of collaboration technologies supporting distributed researchers with common access to dynamic digitised libraries; *iii)* the generation of novelty in important, recently emerging fields by recombination of components, such as biotechnology, software and new materials; and *iv)* the convergence of previously-distinct technological areas to form new technical systems, *e.g.* the convergence of artificial intelligence art, computing, telecommunications, optoelectronics, to create information systems based in machine organisations. Some of these features are documented in the following paragraphs.

The codification of an increased part of the knowledge stock

The digital revolution has continued and intensified the move towards codification (Cowan and Foray, 1995; David, 1993*a* ; Ergas, 1994; Arora and Gambardella, 1994). This is an area in which the revolution in information technology, including such advances as the substitution of graphic representation for natural language, the development of expert systems, etc., has made itself very strongly felt. In particular, the development of new algorithms, as one of the greatest achievements of modern mathematics, have very greatly increased the ability to formally represent or codify knowledge.[5] Engineering increasingly relies on computer-aided design, testing and experimentation, rather than on rules of thumb, as the primary tool for the development of new products and processes. According to Ergas (1994), this codification of increasing parts of the knowledge stock has significant consequences. First, it brings science into tighter and quicker interaction with technology. This closer coupling of science and technology allows each to draw fuller benefit from advances in the other. It also alters the institutional structure of the innovation process, as access to science – which has been largely based in universities – becomes more important in determining the ability to remain at the forefront of applied development efforts. Second, formalisation increases the pace of new product and process development. The ability to test through simulation rather than through practice, and to do so on the basis of an arbitrarily large range of assumed conditions, allows for more quickly focused and hence more productive search, thereby cutting the delay involved in going from the initial specification to the agreed-upon prototype. Moreover, by reducing the time and cost required for new product and process design, these tools encourage producers to experiment across a broad front – to develop and trial many variants of a new product rather than only one or a few. As a result, products and processes become more differentiated and are renewed more quickly – accelerating the rate of technical obsolescence.

The trend towards codification, however, does not reduce the strategic value of tacit knowledge – in particular in its "post-codification" forms – that retains its crucial position, as a source of efficiency, on the one hand, and as a source of rent for new expertise, on the other hand.

Re-use and recombination of knowledge: new styles of novelty

As an aspect of the emerging new paradigm, one may observe in a certain number of sectors the development of a new mode of science-based innovation based on the ability to exploit more intensively the enhanced information distribution capabilities of the system. In this new research mode, advances in technology are grounded more than ever before on the dynamics of mutual strengthening and reciprocal consolidation of (competing) innovation projects. This implies routine use of a technological base allowing innovation without the need for "leaps" in technology, and a corresponding new pattern of specialisation and "division of innovative labour" (Arora and Gambardella, 1994).

One should emphasize that the conceptualisation that has shaped intellectual property laws, and thus largely regulates much industry practice in regard to R&D, is based on notions of absolute novelty and priority of invention (or disclosure) that imply a view of knowledge as advancing in discrete steps, or "quanta of innovation". But it often has been pointed out that much innovation does not correspond to either of these principles, but, rather, involves adding only small elements of novelty, or novel rearrangements of known elements of design. One must, of course, recognise 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, however, is the recent movement towards the systematic exploration of the effects produced by new combinations, which has emerged as the new research mode in some industrial sectors. In biotechnology, innovation now proceeds through the concentration of all known characteristics plus a difference. Similar tendencies are manifested in the software industry, where re-utilisation of existing codes or algorithms (representing sub-processes) has now become an essential strategy 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, accordingly, the resulting innovation has a stronger collective character. This new innovation mode (or recombinant strategy, entailing the routine use of a knowledge base) requires efficient and rapid 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. But, that in turn calls for enhanced mechanisms of evaluation of additions being made to the dynamic database; and improved "search engines" to direct users to the relevant and reliable component within it.

The further development of 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. As has been pointed out, 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. Nevertheless, their effect upon the way in which knowledge is organised and presented, and on the resulting costs of access to it, make the structure of intellectual property rights a crucial consideration for the design of a "distribution-oriented" innovation system.

Information technologies and research networks

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, the number of interconnected networks and their functionality, began rising at dramatic exponential rates. Through the use of the T/IPC communication protocols this has now been extended 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 information (with and without access charge) and private information shared by collaborators, including digitised 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.

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 technologies" are being developed to support multi-media information exchange, multi-user editing, annotation and display. There is every reason, therefore, 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 specialised 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, analysing and displaying data has been amply demonstrated during the past two decades (Moutton, Young and Eberhardt, 1990). 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 co-operative research organisations will be best positioned to benefit from the information technology-intensive conduct of science and technology research.

What is a "distribution-oriented" innovation system?

Our analysis of the economics of knowledge in the following pages rests upon a particular conception of economically valuable knowledge, one which highlights the three characteristics of knowledge-products discussed in Sections II and III: degree of codification, completeness of disclosure, and ownership status. We have argued that these characteristics are not inherent in the knowledge itself but are, instead, the products of social organisation 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, the economically relevant characteristic of knowledge will depend on the identity of institution or organisation within which the knowledge was produced, the rules for disclosure that obtain within that organisation, and the external legal and administrative environment regulating transactions in information. The nature of the transferability of knowledge (for example between university and private firm) is therefore directly dependant upon the problems of social organisation and incentive structures which characterise those two different institutional forms.

Thus, one can suggest that the relative "distribution power" of a system can be defined by reference to a particular configuration of norms, institutions and incentive structures identified above: a system with a high distribution power would be characterised by the predominance of the norm of disclosure (*versus* secrecy and access restriction), strong incentives towards codification (*versus* keeping a great deal of tacitness in the knowledge stock), intellectual property rights systems enhancing the disclosure and co-ordination functions (such as systems maintaining free access to new findings for research use). Such a core of norms and institutions can reinforce the collective perception that it is pro-innovative to reduce the obstacles to information dissemination caused by property rights and appropriation by secrecy, replacing them with devices for promoting co-operation and co-ordination among the actions of innovative agents. As a result, distribution of knowledge as an institutional goal is enforced in such a system: universities act as opened nodes in global information networks; firms rapidly diffuse their new products and processes (through various possible market and non-market mechanisms); researchers from different organisations and sites are drawn easily into collaborative institutional activities (standardisation committees, co-operative research networks) that allow them to solve co-ordination problems posed by collective action.[6]

We have already argued, however, that in the case of knowledge, the norms of openness and free access are very fragile. The theoretical reason is that making the knowledge stock itself more socially useful will in many instances not call for the same policy measures as those designed to make it more economically-valuable to private parties. Indeed, in the short run, these two goals are likely to be in conflict. There is, therefore, a persistent, market-driven urge towards reducing the distribution power of the innovation system by altering the norms, incentive mechanisms and property rights systems in directions that encourage non co-operative modes of pursuing scientific and technological knowledge.

Thus, we take a "distribution-oriented" system to be one whose institutions, incentive mechanisms and co-ordination arrangements have the following three proximate objectives:

- limiting the extension of intellectual property rights that erode the public good nature of knowledge (and therefore impede distribution) into fields and sectors initially organised under the non-commercial norms of openness and co-operation, such as university research or even sectors of emerging science-based technologies;
- designing systems of property rights in ways that do not impede the pooling of knowledge – since intellectual property systems have disclosure features that can be developed in ways supporting co-ordination of the actions of innovative agents:
- improving the efficiency of information search and evaluation in view of the incipient increased costs of storing, retrieving and using knowledge caused by the exponential expansion of the science and technology knowledge base.

Coping with the extension of property

One crucial aspect of the extension of the system of private property into the realm of science and technological knowledge is the penetration of market-driven rivalry into domains of knowledge production where rivalry among researchers or among organisations previously was organised (and restrained) under the non-commercial norms of openness and co-operation (David and Foray, 1995). Thus, an essential goal of policy is to counterbalance this tendency by providing incentive mechanisms and creating institutions that allow the system to maintain its distribution power. There are two domains where this function is an issue of particular importance: university research and sectors of emerging technologies.

In a recent paper, David, Mowery and Steinmueller (1994) have analysed the sources of inherent conflict between university's and industry's research institutions. These involve the incompatibility of the distinctive reward systems that underlie the organisation of research in the two domains (see Section II). As a consequence, university participation in industrial research involves a series of restrictions aimed at balancing, regulating and containing these conflicts, including guarantees of (eventual) disclosure of research after predetermined delays, formulaic negotiation of intellectual property rights deriving from research outcomes, and scrutiny of potential personal conflicts of interest in faculty research activities.

Many empirical studies deal with particular facets of that problem, exploring for instance:

- the extension of university patenting and research contracts activities and its implications for the organisation of research and the quality of patented research results (Henderson, Jaffe and Tratjenberg, 1994);
- the increasing industrial influence and control on a research agenda of university laboratories through the extension of government-supported University-Industry Research Centres (Cohen, Florida and Goe, 1994);
- the adoption of access restriction practices at the level of "intermediary results", especially research-related information that cannot be published in journals, such as experimental materials and innovative instruments, locally-produced software and data sets (Hilgartner and Brandt-Rauf, 1994);
- the increasing frequency of scientific publications that do not fully disclose relevant findings that would permit replication by other scientists (*e.g.* reduced ratio of publications of molecular structures whose co-ordinates are disclosed to total published structures; reduced disclosure of algorithms used in mass spectographic analysis) (Dasgupta and David, 1994).

These variegated indicators, when taken together, are particularly worrying, since universities are logical candidates for an enhancement rather than a curtailment of their functionality as "open nodes" in global scientific and technological information networks. As observed by David, Mowery and Steinmueller (1994), the interactions between universities and industries that seem likely to turn out to have been most dysfunctional tend to be those arising when companies succeed in convincing universities to internalise the norms of highly-proprietary research, *i.e.* research that is closely linked to the strategic aims of the firm, or when universities adopt practices that cause them to act in a similar fashion for their own financial interest. Universities have historically been a strong element of the institutional infrastructures designed to improve the distribution power of the systems of innovation. In the history of the Western democracies, universities have been concerned with the preservation, interpretation and transmission of knowledge. Furthermore, the traditions of co-operative, disinterested scholarship that the academies support, along with the institutional norms of open science communities to which university regulations have been adapted, make these institutions (in their generic form) particularly well suited to the tasks of integrating internationally-distributed sources of knowledge, and, most importantly, of training people how to search, evaluate and utilise the evolving knowledge base.

The issue of increasing fragmentation of the knowledge base by market-induced restrictions on access may also arise within individual sectors where rivalry previously was organised (and restrained) under "information pooling" and openness. Some recent cases attest to the possibility of a "spontaneous diffusion" of a norm of secrecy and access restriction in such systems. Take, for example, the current migration of the software industry from one comparatively weak intellectual property regime to another that is much more restrictive. The initial protection of intellectual property in software industry was accomplished by resort to copyright law: a system which prohibits the users of a software program from making copies of it without the permission of the individual company that licences the program. It prevents one company from appropriating another company 's work and selling it as its own. But the existence of a copyright does not prevent other programmers from using algorithms or techniques contained in the program in their own work. A single software technique can be implemented in different ways to do totally different jobs. Thus, the institutional system of the software industry was relatively "diffusion-oriented", encouraging the information dissemination and facilitating the co-ordination among the innovative projects. Under this regime, it was normal for computer scientists in the commercial, as well as the academic world to publish their discoveries. Secrecy about techniques was not a significant problem and universities played a critical role by developing software and distributing it without charge.[7] The system was thus perceived as one rich in positive externalities, in which norms of co-operative behaviour in the "university/hacker culture" and the formal institution of copyright played the role of self-reinforcing institutional mechanisms to lock-in the system to a dominant convention of openness and disclosure. Within the last few years, however, software developers have been surprised to learn that hundreds, even thousands, of patents have been awarded for programming processes ranging from sequences of machine instructions to features of the user interface. Many of the patents cover processes that seem well-established elements of the "state of the art", or obvious to its skilled practitioners. Software developers now fear that any one of the thousands of individual processes in their programs may be subject to patent-infringement claims. There are two features in this "phase transition" of the intellectual property rights environment of the industry worth noting in the present connection: *i)* it is a process that exhibits the main characteristics of a spontaneous mode of diffusion; and *ii)* the process is one conducive to a dramatic disruption of the co-operative research networks that sustained the dissemination of information and the co-ordination of activities among innovators.

The spontaneity of the process is caused by the chains of reprisal that encourage the new form of behaviour, turning it into a new, emergent norm. (As suggested by David and Foray, 1995, this process can be analysed as a system of additively interdependent Markov chains.) Thus, although very few programmers and entrepreneurs believe that patents are necessary for improving the social organisation of R&D in the industry, there is a proliferation of patents. This paradox is due to the fact that most patenting by companies is undertaken as deferrence against others' patent-infringement suits, or to secure assets that could be used in cross-licensing negotiations. As a result, a new game, with new rules and new norms of behaviour, is emerging spontaneously and rapidly.

Second, this new game leads to a radical disruption of the pre-existing networks of co-operation: the expansion of software patents could mean the end of software developed at universities and distributed without charge; patents could also mean an end to public-domain software, which has played an important part in making computers affordable to public schools; software patents would pose a special danger to small companies, which often form the basic structure of software development, but cannot afford the cost of patent searches for litigation; and, last but not least, software patents introduce a major timing problem in a system where the product cycles are very short with respect to the application times for software patents which take an average of 32 months.

Thus a crucial question arising from this story is whether or not the industry is evolving towards a cross-licensing system where firms secure narrow patents to trade for the right to other patents, which might be capable of inducing the formation of new co-operative R&D strategies. Given the characteristics of the product (a modern software package may contain thousands of separately patentable processes, each of which adds to the risk of infringing patents that are already in the pipeline), it is hard to conjecture that the patent system will be able to become a co-ordinating factor in this industry.

Can one suggest any rationale for policies with respect to such a transition towards a convention of secrecy and access restriction? The most realistic policy option is certainly to allow firms to construct new forms of co-ordination in a system in which the norm of openness has been altered. The goal, thus, is to provide the industry with some institutional tools – such as the self-organising investment boards oriented towards collective support of basic research, training programmes, standardisation activities, specialised capital goods supply (see Romer, 1994), or such as any private institutions which can internalise externalities (see Weder and Grubel, 1993) – to allow firms to build new forms of collaboration and co-operation.

A new approach to the design of intellectual property rights

Intellectual property rights, in and of themselves, are not an obstacle to distribution of knowledge. Not only is disclosure required for registration of such "property", but the procedures involved can be designed so as to induce the agents seeking protection to disclose quickly and disseminate widely their innovations. Furthermore, the nature of the protection granted may be specified in ways that encourage patentees (and copyright-holders) to make their innovations available for use by others at reasonably modest costs. This latter goal can be approached by restricting the "breadth" or scope of the patent grant, and the "height" or degree of novelty required of the typical patentable innovation. Narrow patents, and patents involving low degrees of novelty tend to favour recombination because they promote "pooling" and cross-licensing of innovations (Ordover, 1991; van Dijk, 1994). Other means are available too, such as introducing *sui generis* legislation adapting property rights specifically to meet the needs of sectors (*e.g.* software) where the recombination model of innovation is particularly important and extending the principles of compulsory patent and copyright licensing at "a reasonable cost". To take another example, from biotechnology this time, the successful introduction of the system of prepaid, lump sum 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 approach maintains a free circulation of genetic resources among researchers by use of a system of dependency licenses in the case of dependent innovations (Joly and Hermitte, 1993).

Of course, such measures tend to diminish the private value of individual increments to the privately owned knowledge base even though they may raise its social value. At the other extreme, trade secrecy, like the various forms of access restriction within the firms and scientific institutions in the case of military research directly inhibits knowledge distribution; and strong trade secrecy laws reinforce the attractiveness of holding back R&D results until filing broad patent applications on largely novel systems. Two policy approaches exist other than weakening trade secrecy protection. One approach is to make the forms of intellectual property protection that require detailed disclosure more attractive than secrecy by providing some assistance, and expertise for the operations of patenting, and pursuing infringers; the second approach is to promote collective forms of "pre-competitive" R&D (high-tech consortia, industrial collective research), and inter-firm co-operation in development of anticipatory technical standards.

The dynamics of using intellectual property as a means of promoting innovation via co-operative knowledge sharing is characterised by positive feedbacks and multiple equilibria. The properties of the system can be considered in terms of the linkages illustrated in Figure 2*a*: 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 2*b* both slope upwards. The system is therefore characterised by the possibility of multiple equilibria. It may be trapped in a low-level equilibrium if one of the positive feedback effects is weak or not assured. 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).

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 and rapid "on-line" access to patent office databases, 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 Ordover, 1991; Foray, 1995, and further discussion below).

Distribution as an information search problem: ability to retrieve, evaluate, use and maintain knowledge

In a system characterised by a high distribution power, the proportion of public and private knowledge that is disclosed should increase strongly in relation to the restricted-access knowledge. If we follow the line of thought of Richardson (1960) and Simon (1982), the principal problem then will reside in the efficient storage of information, and its accessibility and the costs of compression and selection. How to design organisations for an information-rich world?

Simon (1982) provides an excellent illustration of the difficulty of retrieving specialised technological information. He studies the lag between the level of sophistication of the statistical techniques applied by data users, and the level of sophistication among experts in statistics. The more sophisticated programs are not retrieved when they would be appropriate because: *i)* the user is not aware of

Figure 2*a*. **Patenting, innovation and the growth of knowledge**

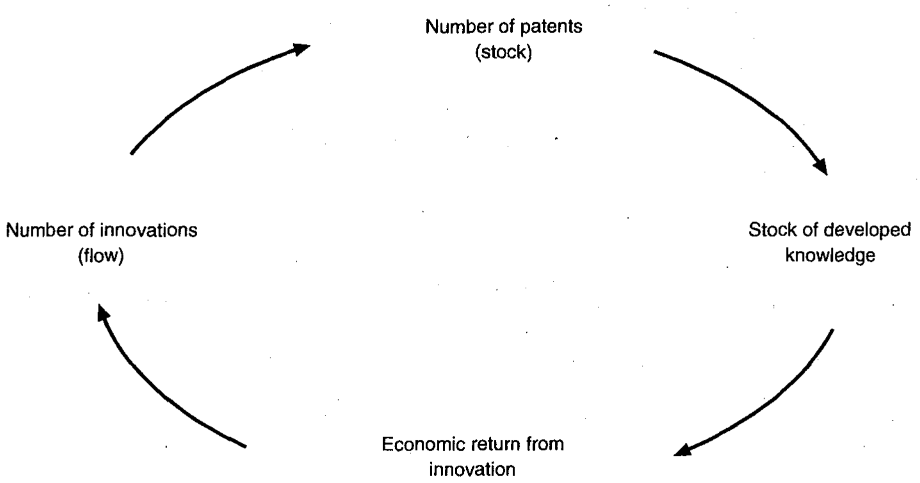
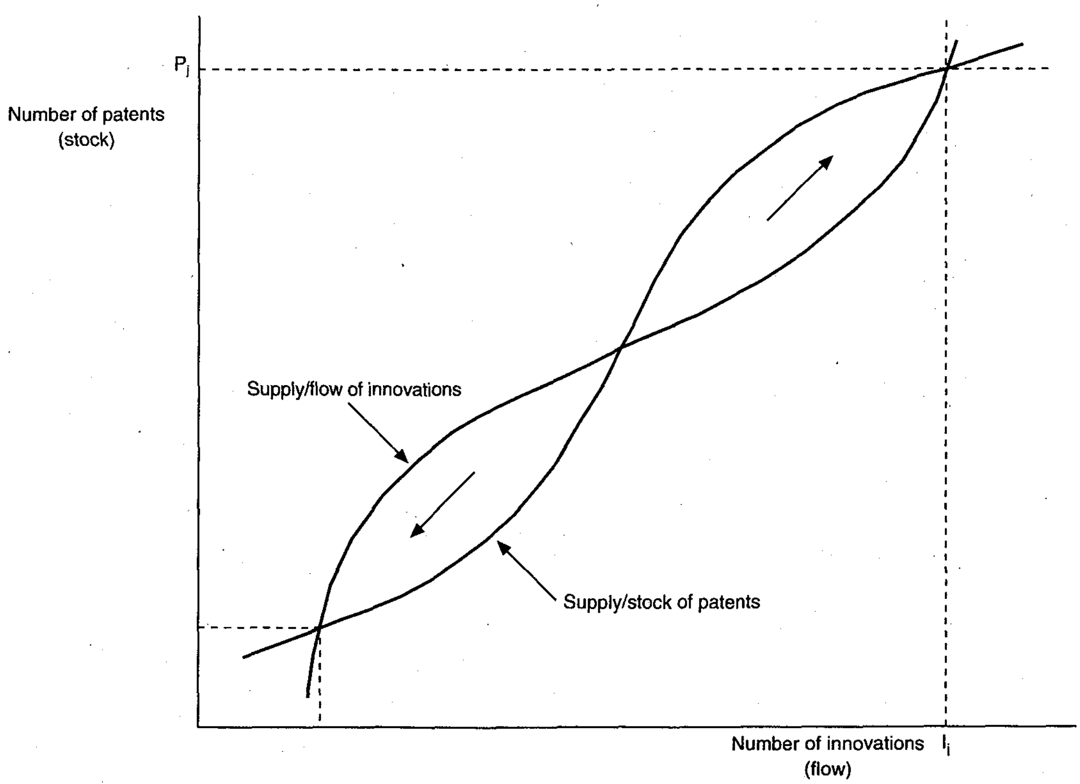


Figure 2*b*. **Positive feedback and multiple equilibrium in the supply of patents and innovations**



their potential advance; and *ii)* his access to the existing knowledge through appropriate inquiry procedures has not been institutionalised. Among other things, he may have no way to recompense the expert properly for his time and trouble on a problem that is only a matter of "application", hence not of direct professional interest to the technique-oriented expert.

What general lesson is to be drawn from this concrete example? Today, the search for pertinent information that is adapted to a particular project is most often localised, that is to say, limited to the relations of proximity between entities, and only rarely will be carried out within the totality of potential space for the existence of the sought-after information. It is therefore necessary to pass from the localised-knowledge distribution process, based on channels related to the physical proximity of firms, to a wider interaction, which would be more appropriate to the optimal allocation of new knowledge among innovative firms.

The challenge is twofold:

- Following the emphasis of Richardson (1960) on the availability of information for co-ordination of market action, it is necessary to increase the amount of available technological information to each agent. Consequently, significant policy orientations are: the enhancement of the intellectual property registration system to improve information disclosure features (above); the extension of information infrastructures to build a universally-accessible digital library; a more effective use of the standards-setting process, as an important forum for the exchange of technical information both within each industry and with users and suppliers.[8]
- The second challenge arises from the need identified by Simon (1982), namely to "buffer the agent from the over-rich environment of information in which it swims", because the scarce resource has become attention rather than information.
  - However, there is no necessary contradiction between these two constructions of the problematic, inasmuch as it is possible to seek to improve both the richness of the information environment and the capacity to economic agents to survive and prosper in it.
  - On the one hand, it is possible to reduce redundancy – at least a certain type of redundancy which is produced by the "lawful" property of the facts (facts are lawful if certain of them can be predicted from certain others). As suggested by Simon (1982), we need store only the fraction needed to predict the rest: "With each important advance in scientific theory, we can reduce the volume of explicitly stored knowledge without losing any information whatsoever". Thus, it can be efficient to reduce redundancy when retrieval costs may be as high as the costs of recreating information from new experiments or deriving it from theory. Codifi-

cation itself promotes this route to efficient "retrieval" of scientific and technical knowledge.

- On the other hand, it is possible to develop information processing systems as devices supporting attention-conserving factors. In particular the *consolidation of general discriminating capabilities* (Teubal, Yinnon and Zuscovitch, 1991) through the creation of reference standards and artificial agents will increase the productivity of the search processes of technological information (Steinmueller, 1992). Furthermore, technology centres and transfer sciences (see Blume, 1994) must be developed as modes of institutionalising access to the existing stock of knowledge, which will involve the creation of new professional incentives for the required expertise (as recommended in Simon's example).

However, the most important policy orientation in this perspective deals with personnel training to support access to, and utilisation of, digital libraries (Section III).

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

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

- 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 context 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 continuously integrating a flow of innovations in design and engineering. This requires, on the one hand, structures of horizontal co-ordination inside the firm, and, on the other hand, a capacity for making co-ordinated adjustments in the industrial departments to the successive technical improvements and engineering innovations. This capability of adjusting continuously to a flow of incremental innovations is based, according to Imai (1992), on the operation of "micro-macro information loops". These co-ordination 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 organisational norm), and they support collective learning of the necessary adjustments.
- The education and training problem has already been addressed. It includes two main points: on the one hand, education and training in the

domains of engineering and transfer sciences; on the other hand, education and training supporting the acquisition by economic agents of the capability to interpret, manipulate, locate and retrieve codified knowledge (above, Section III).

- 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* (OECD, 1995), shows very clearly that such changes are liable to destabilise institutions and rules designed for a different mode of technological advance. From the finance point of view, the movement towards a more strongly distribution-oriented system would tend to increase the uncertainty regarding the appropriability conditions of innovation and might result in the shortening of the life span of proprietary products. These tendencies, combined with the increased cost of R&D – due to the multidisciplinary character of research and to the high lumpiness (indivisibility) of research activities – may have major effects on the organisation and behaviour 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 by relating the methods of financial system surveillance to alternative innovation systems.

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

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 foundational 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?

On this set of issues we presently are able only to comment briefly and, for illustrative purposes, will restrict our remarks to the insights that may be drawn from studies of Japanese intellectual property institutions (see, *e.g.*, Doi, 1980; Ordover, 1991; Westney, 1994). There are a number of respects in which the Japanese implementation of a patent system diverges systematically from the US system: *i)* filing costs are low; *ii)* priority is given to the first to file; *iii)* patent applications are laid open immediately; *iv)* are subject to challenge by interested parties for a limited period; and *iv)* applicants may make changes during a limited period after filing. This regime, coupled with the absence of trade secrecy laws, encourages rapid disclosure and dissemination of information about patents filed on "narrow" innovations, particularly suited for cross-licensing. At the micro level, this regime, according to Ordover (1991), "rewards those who reverse engineer and modify, often in minor ways, the existing inventions and penalises 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". If the Japanese system is to be understood as a successful adaptation to a particular historical context that was inherently transitory, the implication might be drawn that the next evolution of the Japanese pattern of innovation would involve transforming the institutional infrastructure in a way that will degrade their "distribution power".

However, the thrust of science and technology policy in Japan today is towards the reinforcement of the institutions and mechanisms designed for distributing knowledge, the fact that the Japanese economy has "caught up" with the world's technologically-advanced countries notwithstanding. This renewed emphasis on knowledge distribution has a dual aspect (Imai, 1992): *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; the integration of R&D, marketing, and manufacturing; and connections between physical products, software and services – which generate rapidly changing streams of information and give insight for further R&D. 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".

How can we explain the apparent paradox that the increasing necessity of generating systemic innovations appears to be inducing an increasing emphasis in Japan on distribution-oriented institutions? The resolution resides in exposing a misconception of the nature of "radical" innovation, which leads to a mistaken view of the nature of innovative institutions best suited to the maintenance of technological leadership. In other words, the "paradox" arises from the supposition that there is a necessary contradiction between the production of radical innovations and a distribution-oriented institutional structure which promotes a collective mode of problem-solving. Rivalry is a spur to effort, as has been amply demonstrated. But rivalry in the pursuit of knowledge has also been shown to lead to many inefficiencies (see, *e.g.* Dasgupta and David, 1994).

What is a radical innovation if not the non-linear effects (architectural or revolutionary) resulting from the cumulative process of knowledge advances and from the convergence of technical structures that were not previously linked? Thus, the generation of radical innovations is may be quite dependent upon the knowledge distribution environment. There are no strict one-to-one correspondences between one mode of organisation and one style of innovation.

It does appear, nevertheless, that historically there has been 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 United Kingdom – in the situation Pavitt (1992) described to the British Science Council: "not too much science but too little technology!".

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

Distributive systems and the global economy

A system that qualified as "pro-distributive" from the point of view of its internal circulation of knowledge may or may not possess efficient absorptive capabilities from the point of view of the acquisition and appropriation of knowledge from outside. But it is most likely that these two characteristics will be coupled. The 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 will be amplified by the difficulties the others encounter in acquiring externally-generated scientific and technological knowledge. These asymmetries can invite protectionist and neo-mercantilist reactions, in which countries whose industries appear to have difficulty identifying and implementing new concepts and technologies arising at the research frontiers that its own scientists and engineers are exploring, seek to prevent such knowledge from "leaking out". Retaliation in these policies of information-restriction (including reciprocal tightening of trade secrecy laws and intellectual property protection measures) will engender a "negative-sum" game. Yet a destruction of that kind is by no means necessary. The most pernicious policy responses arise not from the logic of the economics of science and technology, but rather, from the misguided application of techno-mercantilist arguments, and from 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 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. Piecemeal importation of other nations' solutions are likely to fail, and attempts at wide-ranging unilateral shifts away from national policies geared to private "appropriation" of knowledge are far more vulnerable to domestic political opposition than are policies that can be premised on multilateral reciprocity among trading partners.

V. POLICY IMPLICATIONS AND AN AGENDA FOR FURTHER RESEARCH

National policy implications

In terms of national policy implications, the challenge can be formulated as that of moving towards the "disclosure" region of the knowledge product space (Figure 1). Among the lines of action that could be pursued in this connection, we note the following seven:

- intellectual property protection for widespread licensing of commercial exploitation, fixed access charges for research use;
- IP registration system enhancements to improve information disclosure features;
- information infrastructures, intelligent software, and personnel training to support access to, and utilisation of, digital libraries;
- university-industry-government R&D collaborations under rules preserving universities' role as nodes in "open knowledge networks";
- support of educational programmes in the "transfer sciences";
- increased emphasis on diffusion-oriented rather than "mission-oriented" science and technology projects;
- encouragement of new financial instruments, institutions and accounting standards to facilitate investment in intangible knowledge products, and the financing of collaborative R&D enterprises.

International policy implications

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 co-operation and co-ordination 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 an example of the first policy, it seems desirable, as argued recently by David, Mowery and Steinmueller (1994) that greater 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.

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

- *Intellectual property rights harmonisation.* Harmonisation can benefit informational aspects of patents and copyrights; it does not imply anything about the necessity or desirability of providing a high level of protection for intellectual property.
- *Standardisation 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 co-operation 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 co-operation 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 a specialised function of some countries creates basis for continuing connections which can link countries of origin with S&T activities in training centres.

A new research agenda for assessing and comparing systems of innovation

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. Instead innovation systems must be assessed by reference to some measures of the use of that 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.

According to the usual indicators (R&D expenses, patents and bibliometrics, high-tech products), it is difficult to know: *i)* what is the proportion of scientific knowledge discoveries that are accessible to industrial innovators; *ii)* what is the proportion of current additions to engineering knowledge rapidly transferred to researchers in basic science; *iii)* what is the extent and rate of diffusion of specific new technologies in particular branches of industry; *iv)* what is the importance of the transfer of knowledge between military and civilian domains; *v)* 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; *vi)* 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 characterised 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 (see also Smith, this volume).

The development of new quantitative and qualitative indicators (or the creative use of existing ones) is an urgent need in the formation of more effective science and technology policies. It is therefore a promising development that, under the auspices of the OECD's Working Group on Innovation and Technology Policy in the Directorate for Science, Technology and Industry, a programme of exploratory studies for the creation of a new indicator framework is currently underway involving experts from a number of national statistical offices.

NOTES

1. Similarly, if it is true that "scientific reseach is 'research dependent' while engineering research often operates beyond the bounds illuminated by prevailing theory and the accumulation of understanding takes place in localised experiments of a trial and error kind" (Metcalfe, 1991), the degree of theoretical dependence is no more than a social norm, a product of the competition between scientific communities. Ferguson (1992), Chapters 6-7, discusses the changes in the norms of academic engineering training in the present century in regard to dependence on formal mathematical modelling. There are, as with technical standards, degrees of incompatibility (of freedom) in the accumulation of scientific knowledge (Loasby, 1986).

2. The extent of spillovers from certain kinds of knowledge may be dependent also on the structure of the phenomena to which the knowledge pertains. For example, in David, Mowery and Steinmueller (1992), the applicability of "homotopy", "metanymy", and the absence of "lumpyness" (*i.e.* indivisibility) suggest that there will be substantial spillover effects from knowledge acquisition. But these are not universal characteristics of every branch of science and technology.

3. Knowledge interactions can also produce "bounded learning" phenomena, reducing the magnitude of the positive learning externalities: what can be learned at any one point in time is strictly bounded. Scientific and technological advances are interdependent and the fact that a "key" knowledge process may be missing may diminish the returns to further advances in other areas. This consideration has been spelled ou by David (1975) as an argument for the localisation of technical progress in a core around the existing technique: one cannot advance except in a "balanced way", which means that a constraint on advance in one element of a system will block all advance, rapidly diminishing the R&D effort.

4. In most endogeneous growth models dealing with the accumulation of knowledge, the flow of innovation is the time derivative of the stock of knowledge (Romer, 1990, 1993), but this is regarded as a purely definitional relationship.

5. A characteristic that these new algorithms share is that while the analytical complexity of the problems being solved increases exponentially in the number of variables, the computational requirements of the algorithm increase by some linear function of the problem's size.

6. See David and Foray (1995) for an analytical exploration of the question of how a system can get locked-in to such a dominant convention of openess, disclosure and knowledge distribution.
7. The place where trade secrecy is used extensively in software is the "source code" for programs.
8. The system of industrial standardisation, in other words, functions as a means of placing ongoing pressures on firms to upgrade their products, while providing them with the technical information required to do so (Ergas, 1987).

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INTERACTIONS IN KNOWLEDGE SYSTEMS: FOUNDATIONS, POLICY IMPLICATIONS AND EMPIRICAL METHODS

CONTENTS

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I. INTRODUCTION

Recent years have seen fundamental changes in the ways we conceptualise innovation processes. The purpose of this paper is to discuss the basis and policy implications of "systems" approaches to innovation, and then the extent to which policy-relevant empirical descriptions of systems are possible. What kinds of indicators and empirical methods can we use to characterise the profile and interactions of an innovation system?

Although this article is aimed at operational policy tasks there is nevertheless a discussion of underlying conceptual issues. These are related to the nature and characteristics of technological knowledge. The reasons for this discussion are that, firstly, these conceptual approaches have a powerful impact on the rationale for public policy, sometimes by explicit argument and sometimes because they form the "conventional wisdom" about policy. Secondly, they affect the development of indicators. Statistics are not neutral "bits" of data; they always have a conceptual foundation. This implies that statistics and indicators are conceptually specific, and therefore useful for some tasks and not for others. A particular problem in mapping systems is that for the most part we are constrained to use indicators which are derived from very different explicit or implicit concepts of innovation and knowledge.

In turn, this suggests that there are no straightforward routes to empirical system mapping: we have neither purpose-designed data sources, nor any obvious methodological approach. The challenge, therefore, is to use existing indicators and methods which give an appreciative understanding of system structures, profiles and dynamics. The good news however is that there are new data sources which permit advances in this area.

The article therefore has the following specific objectives:

- first, to contrast the concepts of knowledge which characterise neo-classical production theory and modern innovation theory, and to clarify the implications for policy and for indicator systems;
- second, to outline some key public policy tasks in a knowledge-systems approach, and some of the indicator needs which they imply;

– third, to discuss the types of statistics, indicators and empirical methods which can be used in mapping 'knowledge profiles' and which are available for analysis of policy measures *vis-à-vis* knowledge systems.

Systems approaches to scientific and technological change are part of a wide-ranging reappraisal within the analysis of economic performance. In general, the past two decades have seen major changes in thinking about the foundations and scope of policies for innovation. These changes have been driven by persistent macroeconomic problems and instabilities since the early 1970s; by scientific and technological revolutions, which are to some extent co-evolving and producing major generic technology change; and by changes in our understanding of the nature and characteristics of innovation processes, and their economic effects.

These developments are inter-related. As early as 1980, OECD analysts were arguing that the crisis of the 1970s was both long-run and technology-based, and it has since become widely accepted that structural change, changing trade shares, and inter-country growth differences have strong technology components, in two senses. First, inter-country differences in performance reflect differences in relevant science and technology resources and activities (Fagerberg, 1988). Secondly, such divergences appear to reflect less tangible differences in how technological knowledge is created and distributed within particular national contexts. In other words, industrial success reflects a new model of knowledge-sharing and co-ordination processes, as illustrated by the Japanese example (Freeman 1987; Fransman 1990).

These developments have been associated with a much increased volume of research, theoretical and applied, on the nature, characteristics and effects of innovation processes. Such research has been based primarily on case studies of firms and industries, although there have also been a range of statistical studies based on official data sources and innovation indicators of various types. The best overall survey of this research programme is Dosi (1988). One of the key results of such work has been a rather fundamental rejection of some of the tenets of production theory and theories of invention (within economics), and of the primary innovation model which has been used for policy analysis. These basic approaches are fundamental both to the rationale for policy, and for the relevance and practical use of different types of indicators. For that reason it is also useful to discuss some of the underlying foundations both of the neo-classical mainstream and the newer alternatives, since they give rise to quite different assessments of policy objectives and indicator needs.

II. TYPES OF SYSTEM CONCEPTS IN INNOVATION PERFORMANCE

Systems approaches vary in emphasis and level, but they share a common core idea: the overall innovation performance of an economy depends not so much on how specific formal institutions (firms, research institutes, universities, etc.) perform, but on how they interact with each other as elements of a collective system of knowledge creation and use, and on their interplay with social institutions (such as values, norms, legal frameworks, and so on).

The argument of this paper is that the systems approach has significant implications for the rationale, objectives and methods of public policies for science, technology and innovation. However it is important to note that there are a number of somewhat different systems approaches available from economic and social studies of innovation. Very broadly these are of three types:

Technological system approaches: analyses of technology which conceptualise technologies not as artefacts but as integrated systems of components, and supporting managerial or social arrangements. In this work the problem of understanding technologies has three dimensions:

- an *engineering* level at which techniques are inter-operative or complementary;
- a *cognitive* level on which technologists and engineers form a consensus on problem-solving heuristics, key lines of advance and so on; and
- a *managerial and social* level, at which developmental and selection decisions are made.

These approaches tend to operate either with respect to particular complex technologies, or particular industries. Examples from the history of technology might include the long-run historical work of Gille (Gille, 1978), Hughes's work on electricity production and distribution systems (Hughes, 1983), or – in economic theory – Dosi's work on technological paradigms (Dosi, 1982); plus a closely relevant sociological literature (see for example, Bijker *et al.*, 1992); for a general view on technological systems, see Rosenberg (1982).

Industrial cluster approaches: these are analyses which explore the performance of industrial sectors in terms of the integration of different types of firms and industries, sometimes around key technologies, and which emphasize environmental conditions and inter-industry interactions in creating dynamic clusters or blocks of industry characterised by high growth of output, productivity and – sometimes – trade shares. The best-known example of this approach in recent years is Michael Porter's *The Competitive Advantage of Nations* (Porter, 1990), but this approach actually has many antecedents; in particular the work of Dahmén (1950) on "development blocks" and Hirschman (1958) on linkage effects. Although such work is strongly systemic in character, it is not necessarily focused on the specific dynamics of innovation and technology creation (even in Schumpeter, where the emphasis is on the effects of technological change rather than its characteristics and sources).

National systems of innovation: these are essentially analyses of innovative environments which focus on processes of learning and knowledge accumulation, particularly emphasizing institutional aspects, and various forms of interaction among innovators. There is a significant literature in economic geography and regional studies on this subject, springing out of the work of F. Perroux, and mainly focusing on factors shaping the emergence of high-technology regions. More relevant for overall policy discussion are analyses at national level, such as the work of the "regulation" school (for a brief overview, see Boyer, 1988). But, drawing on this work, and linking it with innovation theory, is more recent research on the "national innovation systems" concept. The main authors are Lundvall (1992) and Nelson (1993). In turn, related to this, is the "knowledge systems" concept first systematically proposed in Soete and Arundel (1993), and developed in David and Foray (1995). In these approaches, economic dynamics and economic performance are primarily shaped by innovation activities, and the focus is on the processes of learning through which technologies are created and used; the argument is that learning is a collective process, shaped by formal institutions (such as universities, corporations, regulatory systems, etc.) and by social institutions; such knowledge-creating systems are central to economic performance issues.

These system concepts overlap, but if we are using indicators it is nevertheless necessary to be clear about what type of approach we are using. This paper focuses on the concept of a knowledge system and its "distribution power", developed by David and Foray (1995, see this volume), particularly its implications for public support and management of institutions for scientific and technological learning. What is different about the David-Foray approach is that is based on an explicit taxonomy of types of knowledge, and their forms of interaction. This issue is present in the more traditional "national systems" approaches (see especially Johnson, 1992), though not always in an explicit form. But an approach *via* a more elaborated concept of "knowledge for innovation" is clearly central to any system theory of innovation, and it has obvious relevance to policy-makers who are dealing primarily with knowledge-creating institutions; in addition, the David and Foray approach is amenable to empirical analysis.

III. FOUNDATIONS OF THE "KNOWLEDGE SYSTEM" APPROACH TO INNOVATION POLICY

There is a fundamental contrast between system approaches to knowledge creation and diffusion, and the approaches which have underpinned much thinking on microeconomic policy and general economic performance.

Neo-classical production theory and its concept of technological knowledge

Insofar as innovation policies have had a theoretical rationale in the past, it derives from ideas within neo-classical production theory concerning the nature of technological knowledge; these ideas have been powerfully influential in structuring views about the appropriate scope, objectives and instruments of policy. Although neo-classical ideas have been frequently criticised in the modern innovation literature, especially where it comes to policy discussion, it is worth considering the approach here, since it has important implications, both for the foundations of policy, as well as for indicators and the empirical operations of policy-makers.

Neo-classical production theory is built on the idea that firms face a dual production decision. Firstly, they must decide what to produce. This decision is based on rates of return: potential product lines are known, and firms will allocate and reallocate capital among them in search of the highest returns. Then the problem is the choice of production technique: firms within an industry face a given and known array of production technologies and are assumed to have the competence to operate all available production methods. Armed with this knowledge, and with a knowledge also of present and future factor and product prices, firms can make a profit-maximising choice of technique. In this context technology is seen as knowledge, and firms are able to access knowledge in a relatively rapid and costless way. With these types of underlying assumptions, the technological dimensions of production are clearly relatively unproblematic.

The problem of technological change is also unproblematic, both with respect to adaptation to already-existing technologies, and to (exogenously-given) new technologies. This type of competitive theory rests on the ideas of rapid substitution possibilities across well-defined choice sets in production. Firms move smoothly to new production configurations in response to changed environmental conditions, adjusting their technologies (that is, adjusting the capital-labour ratio) in response to changed factor or input prices. But the environment also includes technology itself. This implies that firms are adjusting instantaneously and optimally to changes in the choice set itself, although these changes are seen as exogenous to the system; new technologies simply change the long-run equilibria of the system. In this type of approach, economic efficiency rests on flexibility, both at the economy-wide level (where free entry and exit to activities are central) and at the firm level (where the ability to change the technical configuration of production is central to profit maximisation). These notions have had rather powerful policy effects. Both allocative and technological efficiency rest on freeing markets, removing barriers to entry (and not being too concerned about exit), removing barriers to change within the firm, and increasing competitive pressures as a form of generating incentives to optimise.

However both these types of adjustment, and hence the policies which are built on them, rest on an implied form of technological knowledge with very particular characteristics. What exactly are the underlying assumptions about the characteristics of technological knowledge?

Neo-classical theory does not contain any elaborated concept of production-relevant knowledge. But it is possible to describe the characteristics that knowledge must possess in the neo-classical approach, even though the characteristics are implicit within the analysis. We could argue that in a neo-classical world, technological knowledge must have the following attributes in order for the production theory to hold:

- *It is generic.* That is to say, an item of knowledge, or a particular advance in knowledge, can be applied widely among firms and perhaps among industries.
- *It is codified.* Transmitability implies that knowledge is written or otherwise recorded in fairly complete usable form.
- *It is costlessly accessible.* This can involve the idea that transmission costs are negligible, but it can also mean that firms do not face differential cost barriers in accessing knowledge or bringing it into production.
- *It is context independent.* That is, firms have equal capabilities in transforming such knowledge into production capability.

It is only with these kinds of tacit assumptions about knowledge that firms can readily make optimal profit-maximising choices. If knowledge has the above features, then the production problem of the firm is essentially a problem of calculation, rather than a problem of technological capability and organisation; note also that the production decision of any firm is independent of decisions made by others; interdependence or interaction between firms is not an issue.

However if these kinds of assumptions make the acquisition and operation of technologies unproblematic within equilibrium theory, they raise acute difficulties when it comes to the development of technology, and in particular to the invention of new technological principles.

Neo-classical technological knowledge and the scope of policy

Perhaps the most influential approach to business-sector R&D, and hence to policy, derives from two classic papers by Richard Nelson and Kenneth Arrow respectively (Nelson, 1959; Arrow, 1962). Although the papers have close analytical similarities, Nelson's deals with basic science, while Arrow's is much more an analysis of knowledge creation in the business firm in a neo-classical framework.

Arrow begins by identifying technology with knowledge: technology in the most general sense is "know-how", and therefore the process of invention "is interpreted broadly as the production of knowledge". The question then is, what are the technical and economic characteristics of knowledge, and how do these characteristics affect the amount of new productive knowledge which firms might seek to produce?

The first problem is that of uncertainty, which in this case means that knowledge outputs are not predictable from inputs: producers must commit resources to a knowledge production process without knowing the results with any accuracy. Arrow's first point is that although market economies have a number of mechanisms for sharing risks – such as insurance, contingent markets, or equities – these rarely apply to research activities. Insurance, for example, would be impractical because it would weaken incentives to succeed; only the existence of large companies, with sizeable portfolios of relatively small projects, resolves this problem (because the companies act, in effect, as their own insurance bodies).

Then there is the problem of appropriability: it is difficult or even impossible to create a market for knowledge once it is produced, so it is difficult for producers of knowledge to appropriate the benefits which flow from it. Firstly, "there is a fundamental paradox in the determination of demand for information; its value for the purchaser is not known until he has the information, but then he has in effect acquired it without cost". Secondly, any purchaser of the knowledge can in effect destroy the market, since he can reproduce the knowledge at very low, perhaps even zero, cost. If producers cannot appropriate the benefits of knowledge, then they have no incentive to produce it, and market economies will therefore underproduce that which would be socially beneficial if it were produced.

A final characteristic of technological information is indivisibility. That is, the underlying knowledge must exist on a certain minimum scale before any production at all can take place, and this necessary minimum is independent of the rate of production. A familiar example of such indivisibility would be a railway, which must be constructed in its entirety before any trains can use it; and it must be constructed whether it is used by one train per day or fifty. The latter point means that there are scale economies in the use of indivisible capital goods, and this applies to technological information.

These problems of risk, indivisibility and inappropriability all suggest that market economies will systematically under-invest in R&D, and this will, argues Arrow, "lead to the conclusion that ... it would be necessary for the government or some other agency not governed by profit-and-loss criteria to finance research and invention".

But what kinds of knowledge really have the characteristics which have been sketched, and which appear to be central to the Arrow analysis? The first two characteristics clearly apply to the knowledge which results from fundamental scientific research; indeed the other classic statement of the externality problem (Nelson's 1959 paper) speaks specifically of basic science. Implicit in the Arrow approach is the idea that technological knowledge is the same kind of knowledge as basic science, indeed perhaps that it is a form of applied science.

This "market failure" approach to knowledge production leads to a relatively simple set of policy proposals. In this set-up the basic policy task is to encourage discovery-oriented activities, and then to protect the use of the results. The problems of risk and indivisibility lead to straightforward under-provision of knowledge, and suggest that the public sector should either produce knowledge directly, or provide subsidies to knowledge-producing institutions. The appropriability problem implies the existence of a major positive externality, and suggests policies either of subsidy, or the creation of property rights (*via* patents or other intellectual property protection). The basic problem with the approach is that it does not give any secure guide to how to identify areas of market failure, or the appropriate levels of public support which might follow from it. There appears to be a rationale for public provision, but where, and how much? (Metcalfe, 1994)

The "linear model" in research policy

It is worth noticing that this type of approach to innovation policy accords very well with what is sometimes called the "linear model" of innovation. This is the view that the process of innovation is especially a process of discovery, in which new knowledge is transformed into new products *via* a set of fixed (linear) sequence of phases. There is some debate about whether the term "linear model" is really appropriate for characterising S&T policies within OECD countries over the long term, but we can outline the broad characteristics of a "linear" approach, and this accords with many ideas and practices in post-war research policy. These characteristics are:

- first, the technological capabilities of a society are essentially defined by the knowledge frontier; hence, technological advance depends on the expansion of the frontier by a knowledge creation process based on discovery;

- second, the knowledge which is relevant for industrial production is defined by principles which are essentially scientific, and which have in some sense been transferred, translated, or concretised from a more abstract realm;
- third, the "translation" process is basically sequential; there are temporally and institutionally discrete phases in the translation process, and these have to occur in sequence;
- fourth, the approach is technocratic, in the sense that it views technological change broadly in terms of engineering development processes and hardware creation.

The most powerful element of this approach is the idea that innovation is based on discovery processes within science. If this is true, then clearly policymakers have to focus on the discovery phase and its characteristics. This "scientific discovery" model of innovation, which was implicit in Arrow's work, leads fairly directly to policies of block funding for universities, R&D subsidies, tax credits for R&D, etc.: the main instruments of post-war science and technology policy in the OECD area, in fact. Policies are not, of course, developed simply out of some kind of theoretical rationale, but we ought to note that what has here been called the "linear model" approach accords well with the notions of technological knowledge and discovery which are implicit in the neo-classical framework outlined above. These linear notions remain powerfully present in policy thinking, even in the new innovatory context.

Recent theory and applied research suggests that the knowledge characteristics described above are not a good guide to the nature of technological knowledge, and must therefore have limitations as a guide to the rationale and content of S&T policies. What are the alternative views, and what are their implications?

Technological knowledge in modern innovation theory

Modern innovation theory tends to emphasize quite different aspects of technological knowledge, and hence provides a different angle on the question of technological knowledge. There is no single source for this new view of technological knowledge, and the outline which follows draws on a wide range of sources.

Clearly all firms operate with some kind of technological knowledge base. However this is not a unitary knowledge base, and it seems reasonable to distinguish between three areas of production-relevant knowledge, with different levels of specificity. This kind of differentiation in fact goes back quite a long way in economics, but has been significantly developed in recent years (see, for example, for an early account, Salter, 1969).

First, there is the general scientific knowledge base. This is itself highly differentiated internally and of widely varying relevance for industrial production; but some fields – such as molecular biology, solid-state physics, genetics or inorganic chemistry – have close connections with major industrial sectors. Although it is important not to over-emphasize the role of scientific knowledge in modern industrial development, or to presume that there is a one-way connection between science and technology, the connections of course exist and are very important. In large part this is because organised science does not evolve simply according to some internal dynamic, but is in fact shaped by policy or funding decisions which usually have economic, industrial or military objectives.

Secondly there are knowledge-bases at the level of the industry or product-field. At this level, modern innovation analysis emphasizes the fact that industries often share particular scientific and technological parameters; there are shared intellectual understandings concerning the technical functions, performance characteristics, use of materials and so on of products. Richard Nelson calls this the "generic" level of a technology:

> "On the one hand a technology consists of a body of knowledge, which I shall call generic, in the form of a number of generalisations about how things work, key variables influencing performance, the nature of the currently binding constraints and approaches to pushing these back, widely applicable problem-solving heuristics, etc. I have called this the 'logy' of technology ... Generic knowledge tends to be codified in applied scientific fields like electrical engineering, or materials science, or pharmacology, which are 'about' technology." (Nelson, 1987, pp. 75-76.)

This notion tends also to underpin the important system concepts of "technological paradigm" or "technological regime": generic knowledge bases are highly structured, and tend to evolve along structured trajectories (Dosi, 1982). This part of the industrial knowledge base is public (in the sense that it is in principle available to all firms): it is a body of knowledge and practice which shapes the performance of all firms in an industry. Of course this knowledge base does not exist in a vacuum. It is developed, maintained and disseminated by institutions of various kinds, and it requires resources (often on a large scale). Gregory Tassey has defined the combination of knowledge and institutional base as the "technology infrastructure", in the following way:

> "The *technology infrastructure* consists of science, engineering and technological knowledge available to private industry. Such knowledge can be embodied in human, institutional or facility forms. More specifically, technology infrastructure includes generic technologies, infratechnologies, technical information, and research and test facilities, as well as less technically-explicit areas including information relevant for strategic planning and market

development, fora for joint industry-government planning and collaboration, and assignment of intellectual property rights." (Tassey, 1991.)

Thirdly, within these technological parameters, the knowledge bases of particular firms are highly localised. Firms tend to have one or a few technologies which they understand well and which form the basis of their competitive position. The highly specific character of this knowledge is not simply technical: it is also social, concerning the way in which technical processes can be integrated with skills, production routines, use of equipment, explicit or tacit training, management systems and so on. At this level, the relevant technological knowledge base may be informal and uncodified, taking the form of skills specific to individuals or to groups of cooperating individuals. The tacit and localised character of firm-level knowledge means that although individual firms may be highly competent in specific area, their competence has definite limits. This means, firstly, that they may easily run into problems in innovation which lie outside their area of competence, and secondly that their ability to carry out search processes relevant to problems can also be limited; thus they must be able to access and use knowledge from outside the area of the firm when creating technologies.

These different types of knowledge base are not separate but integrated with one another, often in complex ways. Moreover they evolve over time: that is to say, technological knowledge tends not to result from generalised processes of search, but rather builds on past achievements. This gives an evolutionary character both to artefacts and knowledge, but it also implies that knowledge is both structured and cumulative over time. The capabilities of any knowledge-producing institution, at a point in time, tends therefore to be a product of its past history. This introduces both into institutions and to the system as a whole a process of path dependence.

All of this suggests that knowledge bases of industrial firms have characteristics which are very different than those within the neo-classical approach. Such knowledge bases:

- Are *differentiated and multi-layered,* consisting of articulated forms of quite different knowledges. The creation of technological knowledge at the level of the firm is a multi-faceted process, involving the complementary development of very different types of knowledge: codified scientific results, tacit knowledge (embodied in the skills of engineers, R&D staff, workers and managers) and so on.
- Are *highly specific, organised* around a relatively limited set of functions which firms understand well.
- Are developed through costly processes of search, through processes of learning and adaptation, and *are therefore cumulative,* developing through time as firms build up experience with particular technologies; this in turn implies that technological knowledge is path dependant.

- Are *internally systemic* in the sense of being part of an overall production and marketing system which has many components. In addition to multifaceted technological knowledge, innovation usually involves a heterogeneous range of activities, which must be integrated and co-ordinated by the innovating firm. These include identifying and integrating technological and market opportunities, financing new product and process development, training, design, engineering and prototype developments, and so on.
- Are *interactive and externally systemic:* innovation usually involves, either explicitly or implicitly, structured interactions between institutions, involving processes of mutual learning and knowledge exchange.

Foundations of the system model

What is it about the view of technological knowledge presented above which leads to the necessity to think in terms of systems? Two important dimensions of this are mentioned here:

Firstly, the technological level itself. Advanced-economy technologies do not exist as individual artefacts: they usually take the form of integrated technological systems, in which component elements are incorporated into overall systems. Thomas Hughes, in his study of the development of electricity as a dominant technology emphasized that this type of technology consists of "systems, built by system builders" (Hughes, 1983). For such key technologies as cars, computers, and aircraft, but also for a host of less spectacular products, there is in a sense no unified knowledge base at all: product producers are in effect system managers, whose competence relies primarily on the ability to specify and integrate diverse inputs (see Mowery and Rosenberg, 1982, for examples of this in the aircraft industry, and Rosenberg, 1982, for a wider overview).

Secondly, because firms are bounded or constrained in their knowledge horizons, their areas of actual or technological skill and knowledge are limited by experience and by the resources which they devote to search; this is always constrained. First, firms are often highly constrained in their ability to identify and access scientific or technological information from outside their (relatively restricted) technological environments. Second, even if they do so, there is a great gulf between having an item of technological information or knowledge, and being able to integrate it into a complex production system. But the "boundedness" of the technological horizon of firms has another dimension, of some importance for the system approach. This is that, because of constrained technological capabilities, firms attempting to innovate are always likely to run into problems which lie outside their existing capabilities and knowledge base. So although firms do not have general costless access to a generic knowledge base, or to any other form of technology-relevant knowledge, they still need to import externally-developed technological knowledge to solve innovative difficulties. This is particularly the case with emerging technologies (Fransman, 1990). Of course this can and often does take the form of a market transaction: buying contract research, or consultancy services, or licensing a patent, for example. However because the need to extend or renew the knowledge base from outside is a relatively continuous activity in many innovating firms, there is always the possibility that this acquisition of external knowledge can occur through relatively routine activities which in practice lead to the evolution of systemic relationships.

The David-Foray concept of knowledge systems

The David-Foray concept of knowledge system is narrower than the "national systems approach". The latter begins from a wide understanding of technological knowledge. Lundvall's definition is as follows:

> "... a system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful, knowledge... a national system encompasses elements and relationships, either located within or rooted inside the borders of a national state." (Lundvall, 1992.)

Nelson (1993) define innovation as "rather broadly... the processes by which firms master and get into practice product designs and manufacturing processes that are new to them". The system is "a set of institutions whose interactions determine the innovative performance... of national firms".

The David and Foray approach is in one way much narrower than this, but on another level more complex, since it seeks to produce a descriptive account of the multi-dimensional character of scientific and technological knowledge. David and Foray do not look at all forms of knowledge, or related interactions, which are relevant to firm-level economic performance: they abstract from such issues as finance, marketing, design etc., which are elsewhere seen as part of the internal and external knowledge functions of firms relevant to innovation. Within the Aalborg work, financial systems, organisation and so on played an important role (*e.g.* Christensen, 1992). The David and Foray approach focuses explicitly on "learning systems for scientific and technological knowledge", but such knowledge is seen in a highly differentiated way, both in terms of its characteristics and functions, and its institutional features.

Firstly, relevant knowledge is classified in terms of its objects, and related actions, distinguishing between: knowledge of factual propositions; knowledge which constitutes explanations and understanding; operative knowledge for performance of tasks; and knowledge of relevant actors (see Johnson, 1992 and

Lundvall, 1992). Analogous to the scheme above, technological knowledge bases are seen as either generic, infratechnological (meaning primarily methodological), applied, and product-process relevant. All of these types of knowledge can be either codified or tacit, and are produced under different modes of organisation which shape different disclosure regimes.

These considerations lead to a concept of "knowledge-product space", which is essentially a way of categorising different forms of knowledge by placing them with respect to three different dimensions (see article by David and Foray in this volume): from completely tacit to fully codifiable; from fully disclosed to fully restricted; from privately-owned to publicly-available.

The argument is that within this complex structure of differentiated knowledges, what determines performance is not so much knowledge creation as the "distribution power" of the system: the system's "capability to ensure timely access by innovators to the relevant stocks of knowledge". The distribution power of the system affects risks in knowledge creation and use, speed of access to knowledge, the amount of socially-wasteful duplication and so on.

For the purposes of this paper, what matters are the concrete mechanisms through which such distribution occurs. David and Foray identify five processes of distribution: *i)* the distribution of knowledge among universities, research institutions and industry; *ii)* the distribution of knowledge within a market, and between suppliers and users; *iii)* the re-use and combination of knowledge; *iv)* the distribution of knowledge among decentralised R&D projects; and *v)* dual technological developments.

In Section V of this paper we explore ways of characterising and quantifying these system elements. But before doing so, it is worth considering what we want to use such mapping for: what are the main policy challenges in a system approach of the David-Foray type?

IV. CENTRAL POLICY ISSUES IN THE "KNOWLEDGE SYSTEM"

System co-ordination

A key policy issue arising from systems approaches is the need to identify and perhaps support nodal points in the creation and distribution system; these are likely to be changing over time: the innovation system is not a structure, but a dynamic process. At the simplest level, the task would be to identify key points or functions within the system where public support would improve the overall distribution capability. Since knowledge systems are complex in practice (even in small societies), and usually managed by quite separate institutions, there is a need for policy co-ordination and for adequate information systems to ensure that such co-ordination is possible. Actually, this problem is present even when a linear approach to policy is adopted. Although such policies are fundamentally discovery-oriented, they tend in practice also to involve other elements: to combine basic research policies with policies aimed at developing commercial applications, at diffusion, at training, and so on. Even in the most simple linear approaches, however, systemic interactions are present: increasing resources in invention processes will slow down diffusion rates, for example, and education and training measures will always affect the ability to emphasize or de-emphasize components of the linear sequence. Most policy systems at the present time over-emphasize knowledge creation, *via* instruments such as R&D subsidies, intellectual property rights, and so on; even within a linear approach, there is reason to suggest that the systemic effects of this will be undesirable (David and Foray, see this volume).

Externalities

The basic rational for public policy is that there are necessary activities and functions which are insufficiently fulfilled by private initiative; this usually implies an externality, and much public policy is concerned with externalities. These characteristics of knowledge which were described above have a number of implications for the externality question. On the one hand they imply that the externality effects emphasized by Arrow are *not* a significant obstacle to the production of knowledge. This means that the idea of low-cost transmission and straightforward appropriability of knowledge – as outlined in the previous section – can be misleading as a source of external benefits (Carlsson and Jacobsson, 1993). On the other hand, the knowledge system approach is one which emphasizes a wide range of interactions, some of which will take the form of non-traded flows of economically-useful knowledge. There are potentially large externalities, the identification of which might be central to policy formation and operation. What forms can such externalities take? Given the general characteristics of industry-specific and firm-specific knowledge bases sketched above, we can suggest a range of forms of external knowledge. These certainly include generic "public domain" sources of scientific technological information. But they could also include: knowledge from other firms in an industry (through marketing relationships, co-operative knowledge exchange, trade literature, etc.); acquisition of skilled personnel; acquisition of process technologies; regulations and standards, and so on. Any identification of this must require some form of overall system mapping, with particular reference to "intangible" forms of knowledge flow.

International access policies

A third important policy issue concerns the interface between national efforts and international activities. On the whole, replication is something to be avoided although, given the complexity of learning processes (especially where learning by doing is important), this is by no means an absolute. But in the context of increasingly globalised scientific and technological activities, decision problems here become very important; once again, the relevant information is system-wide.

V. EMPIRICAL IDENTIFICATION AND ANALYSIS OF KNOWLEDGE SYSTEMS

This section deals with the empirical problem of mapping and analysing knowledge systems. It attempts to describe analytical techniques which can throw light on national system profiles. The section looks first at methods for *identifying system interactions*, and secondly at methods for *identifying system specificities and characteristics*. Each of them is intended to throw some light on the distributional modes identified by David and Foray, noted above.

It must be said that previous systems approaches have been notable more for their conceptual innovations, and the novelty of their approaches, rather than for quantification or empirical description. Lundvall (1992) is primarily a qualitative study, with the exception of two sections on trade performance; the study gives no real guide to how we might empirically define and monitor the structure and dynamics of a system. Nelson (1993) is explicitly descriptive, but with some exceptions this turned out to involve rather conventional data use on industrial structures, R&D flows, and foreign patenting. Somewhat surprisingly there was no attempt to apply a systematic set of indicators across countries, with the idea of identifying system specificities, let alone identify and map interactions. By far the most comprehensive quantitative work is Archibugi and Pianta (1992) which develops a range of indicators for identifying specialisation patterns in science and technology in OECD countries.

The focus here is more on interactions than on structures. We explore currently existing data and methods, which are widely available in existing data sets, or which can be used in individual studies which are amenable to wider implementation. However understanding knowledge profiles is not something which can be achieved simply *via* statistical analysis; there are central qualitative dimensions which require various forms of case study (which may in fact generate quantitative data), and relevant case study methods are also indicated below.

Available data sources

It is necessary at the outset to acknowledge some basic data and source difficulties. A general problem in this field is that many of the objects of analysis which we are interested in – knowledge creation and distribution, innovation activity or capability, knowledge systems, etc. – are intangible activities which are difficult to define. They are certainly not measurable in terms of what we normally think of as statistical variables (Grupp, 1990).

However this is not necessarily an insuperable obstacle to empirical analysis. There are three broad dimensions of this problem. Firstly, even when a concept is intrinsically unmeasurable, there may exist related indicators which provide more or less adequate proxies. Within economic theory, for example, the concept of "welfare" is in principle unmeasurable, but we are still able to construct real income indices. Large parts of the service sector (especially public services) do not produce a measurable product, but we can nevertheless construct output variables. Such problems are very much found in knowledge-creation and use activities: we are able to construct measures which grasp particular dimensions of the process, and which can be used as overall indicators, but there remain many measurement obstacles. Secondly, it is important to recognise that some of the central data sources in this field were not designed at all for the analysis of science, technology and innovation. That is, there are certain systematic data sources which exist for other purposes, but which can be adapted for analytical purposes. This is particularly the case with patent series, which are an off-spin of a legal process (the nature of which has, moreover, changed over time), and bibliometric and citation data, which exist primarily because of priority conventions in science.

A much more substantial problem is that most existing indicators tend to be relevant to "phase" or linear models of innovation; they are not necessarily amenable to system analyses. Three primary data sources are very well known in analysis of science and technology statistics. They are research and development (R&D) statistics, various patent series, and bibliometric data (publication counts and citations).

The general strengths and weakness of these sources are well-known, but they continue to have unexploited possibilities in analysis, which will be discussed below. Related data, not generally comparable between countries, is higher education data related to the training and employment of qualified scientists and engineers. These types of data tend to dominate the analysis of national systems.

However there are two major data sources, as yet not fully exploited, which are highly relevant for this area.

The first of these is the STAN (Structural Analysis) and ANBERD (Analytical Business Expenditure on R&D) datasets (for a description of both databases see

OECD, 1994). A fundamental problem with many international data sets, including from the OECD, is lack of comparability. These difficulties arise from different collection periods, and from a wide range of errors and omissions in data. This has led DSTI to develop the STAN and ANBERD databases, which integrate – in a consistent way – R&D data with data on industrial output (gross output and value added), labour costs, employment, exports and imports, and investment. STAN and ANBERD are in turn linked with an increasing amount of *i)* input-output data, and *ii)* bilateral trade data. The input-output database at the present time covers seven countries: Australia, Canada, France, Germany, Japan, the United Kingdom and the United States.

The second source is the firm-level innovation data sets which have emerged from the joint EC-OECD efforts in innovation data collection. The project is known as the *Community Innovation Survey* (CIS), and is being jointly supported and implemented by Eurostat and DG-XIII-D (SPRINT programme, European Innovation Monitoring System). The primary aim of CIS is to develop and use data on the following topics:

- expenditure on activities related to the innovation of new products (R&D, training, design, market exploration, equipment acquisition and tooling-up, etc.);
- outputs of incrementally- and radically-changed products, and sales flowing from these products;
- sources of information relevant to innovation;
- R&D performance and technological collaboration;
- perceptions of obstacles to innovation, and factors promoting innovation.

CIS was implemented in 1993 in all EU member States, and a preliminary European database on approximately 40 000 firms is now running. The data on information sources and collaboration is particularly relevant to the topic here.

Other potentially useful sources are the data on:

- intangible investment;
- technological balance of payments;
- mobility of researchers;
- inter-firm technology co-operation agreements.

Analysing system interactions

The basic problem in mapping knowledge systems is to identify the structure of economic and technological interactions. This section deals with the identification of types of interactions. In each case, techniques and sources are identified, with a brief discussion of how they contribute to an understanding of interactions, and of their general strengths and weaknesses. The intention here is to look at a range of quantitative measures for exploring four basic types of interactions:

- inter-industry transactions embodying flows of technological knowledge;
- methods for describing patterns of use of formal scientific knowledges;
- patterns of technological collaboration between firms, universities and research institutions;
- measures of personnel mobility and related interactions.

These types of interactions have both domestic and transnational components, and in each case the potential for transnational mapping is described.

Inter-industry interactions and embodied R&D flows

This section deals with some relatively well-known techniques for identification of interactions between industries; these relate to producer-user interactions in process technologies, and to the market distribution of patented knowledge.

Firms compete in large part through technological competition which improves the price-performance ratio of their product(s). They do this by improving their process technologies, and through improvements in the technological characteristics and performance of their products. By far the most important element of this is product innovation: in practice a significant part of industrial R&D is devoted to product innovation. But many of these new products are themselves input technologies, and they therefore enter as capital or intermediate inputs into the production processes of other firms and industries. Performance improvements generated in one firm or industry therefore show up as productivity or quality improvements in another, "a special kind of external economy" (Rosenberg, 1982). A familiar example is computing, where large decreases in price-performance ratios (apart from producing big statistical headaches) have their major impact not on the computer industry itself but on computer-using industries (see Bresnaham, 1986, for an assessment of the economic impact of this). The point here is that technological competition leads fairly directly to the intra- and inter-industry diffusion of technologies, and therefore to the intra- and inter-industry use of the knowledge which is "embodied" in these technologies.

These inter-industry flows are a very significant element in understanding the technological level or intensity of an industry, and its general innovative performance. As a recent OECD report remarks:

> "Particularly for the 'low technology' industries, omission of this 'indirect' technology is likely to lead to misleading policy interpretations and perhaps to an overemphasis of technology policy on the 'high technology' industries where 'direct' technology is more visibly and easily measured." (OECD, 1990*a*)

Two core methods have been used for tracking these inter-industry technology flows. The first relies on the use of patents by industries other than the innovating industry. The idea here is that a patent is not simply a technique or a piece of equipment but a "carrier" of the R&D performed in the originating industry. Perhaps the best known study is by Scherer: he first established a concordance between US industrial patent classes, and the industrial R&D directed towards the technological fields covered by those patent classes, then examined the extent to which user industries used the technologies covered by these patents (Scherer, 1989*a*; Scherer, 1989*b*). On this basis he constructed a kind of input-output matrix for US industry with the rows being the generating industry, and the columns the user industries; each cell contained the R&D used by a particular industry. The rows summed to the R&D performed by an industry, and the columns to the R&D used; the diagonal elements covered intramural use of process technology. Scherer showed that about 75 per cent of industrial R&D flowed to users outside the originating industry, and that the inter-industry flow was positively correlated with productivity growth in the receiving industry (Scherer, 1989*b*).

A second approach uses standard input-output techniques which map transactions between sectors and hence the flows of capital and intermediate goods. The total R&D use of an industry is then calculated on the basis of intramural R&D plus the R&D embodied in its capital and intermediate purchases. On the assumption that R&D is a private good, there are two methods to measuring the embodied R&D. The first is as follows:

> "... the fraction of sector *i* 's R&D that flows to sector *j* is determined by the proportion of *i* 's sales of intermediate and investment flows to *j* in sector *i* 's total production of such goods." (OECD, 1990*a*)

The second method is to multiply sector *j* 's purchases from sector *i* by sector *i* 's R&D/sales ratio. In either case the inter-industry use of R&D, plus that used in exports and final consumption, sums to the value of sector *i* 's intramural R&D.

More interesting from the perspective here is the public good case: the assumption then is that one firm or industry's use of embodied R&D does not diminish its use by other firms or industries. At its most extreme, this implies that all users of the products of sector *i* have access to all the R&D performed in sector *i*. Scherer's solution to this problem was to assume that the largest user sector reaped all the benefits of sector *i* 's R&D, and that smaller users reaped a share of sector *i* 's R&D equal to their output as a proportion of the largest user sector's output. Either way, insofar as the productivity-enhancing product innovations of sector *i* are not appropriated through rises in its product prices, then there is an externality, the scale of which is determined by specific or generic characteristics of the technology.

What we get from all this is not some exact absolute measure of the benefits of knowledge embodied in products. Rather, we get a set of indicators of the relative intensity of embodied-knowledge interactions between various types of industries (for a comparative study, see OECD, 1994).

There are a number of possibilities which remain relatively unexploited with such techniques. One is straightforwardly to assess a debated issue in systems approaches, namely the extent and significance of internationalisation. It is possible to use such data sets as STAN and ANBERD, combined with appropriate bilateral trade datasets, to open up the imports vector in an input-output table into a matrix which indicates the industrial structure of imports, and the consequent extent of transnational embodied knowledge flows (Wyckoff, 1993).

However a familiar problem in input-output approaches is their rather static character; an input-output table generates a set of input-output coefficients which are a snapshot of inter-industry relationships at a point in time, but which give no real insight into the dynamic process of structural and technological change (Andersen, 1992). For this reason it is important to analyse changes in input-output structures over time, and this has recently been undertaken within the OECD. It should be noted that most OECD countries have the relevant data sources for this type of exercise although, apart from those within the STAN project, there would probably be significant problems of data management. Nonetheless this approach offers important insights both into interactions in the industrial structure, and to international components of technology flows; this or a related approach has been implemented not only for the countries in the STAN dataset but for such countries as Finland and Norway (Virtaharju and Åkerblom, 1993).

Inter-sectoral use of scientific/generic knowledge

Perhaps the most difficult area in analysing knowledge interactions is the question of links between basic science and technology creation, and specifically to the role of universities.

Although technological knowledge is not itself generic, the solution of some kind of technological problems, or the development of some kinds of technological knowledge or products, may require access to generic knowledge. Two cases should be distinguished. Firstly, various technological activities may rest on the implicit use of more or less long-standing scientific results which are in some sense the basis of a technological paradigm. This raises complex questions about what the long-run economic value of science actually is. These questions will not be addressed here. Rather we look to a second – much narrower – use of science, namely the use of general results in innovation and problem-solving. In practice such knowledge often consists of results from fundamental research conducted, for the most part, within university systems. Market transactions can occur in the use of such knowledge, but this is relatively rare: with non-market uses a technological externality exists. Two types of question are relevant here: firstly, how often do firms use publicly-accessible literature or research results in the course of innovation activity, and secondly, how significant are such results in the development of industrial innovations?

Three basic methods have been used:

- interview methods for analysing interactions in innovative problem-solving;
- the use of bibliometric analysis, specifically the analysis of citations in patents;
- a direct interview method for analysing use of university research.

The classic discussion of the first of these issues is Gibbons and Johnston's 1974 paper on the "mechanisms by which scientific research and education contribute to industrial innovation". Their point of departure was, in effect, rejection of the linear model of innovation – in which innovation results from prior processes of research discovery – in favour of an approach which saw the function of research as problem solving within ongoing innovation activities. Gibbons and Johnston examined 30 industrial innovations in the United Kingdom, all involving significant technological change. The basic method was in-depth interviewing, focusing on the types of information which were used to resolve technical problems in the development of each innovation, the number of "units" of information involved, and the source and content of the "information units". (A "unit" was defined in terms of the coherence of its content and source and involved, for example, information about the properties of materials, or relevant general laws, or appropriate test procedures). About one-third of the information used came from sources external to the firm, and of this about one-third came from what might be called generic sources: universities, scientific literature, conferences, research associations, and so on. The only traded element in the external sources of information was consultants, who supplied only 4 per cent of the information units. Generic sources of information were not limited to these external sources: among what Gibbons and Johnston called "personal" sources of information, the second-largest element was education. They concluded that:

> "In this study, 36 per cent of the information which contributed to the development of an innovation and which was obtained outside the company during the innovation had its origin in basic scientific research. Of *all* the information obtained by 'problem solvers' during an innovation, approximately one-fifth could be similarly classified." (Gibbons and Johnston, 1974)

The Gibbons and Johnston approach has never been systematically followed up, although a number of similar case studies exist (see, for example, Georghiou *et al.*, 1986). There is no obvious reason why such methods cannot be developed into a more systematic and comparable approach to university-industry links and other interactions.

A second body of research which relates generic knowledge to specific applications derives from bibliographic analysis of citations in patents. The fundamental claim of a patent is to novelty in some technical process which is also practically useful; a patent is therefore a description of the technical workability of something which is, at least potentially, an industrial innovation. The applicant for a patent must describe previous technique ("prior art") in the relevant field, and show the innovativeness of his or her invention; he or she therefore cites relevant literature (in many cases other patents), and the patent examiner – in testing the claims for originality and usefulness – also cites relevant work. There is now a fairly considerable body of bibliometric work analysing the extent and structure of citations to basic scientific literature in US patents, and it seems clear that in a significant number of technological fields, such citations are increasing in importance (*e.g.* Narin and Frame, 1989; Narin and Noma, 1985; Narin, 1988). In science-based fields such as genetics, approximately 80 per cent of citations are to journals publishing basic research (Collins and Wyatt, 1988). In chemistry, a recent study concluded that "there is little distance between chemical technology patents and basic chemical science. In other words, chemical technology draws its information directly from basic chemical science" (van Vianen, Moed and van Raan, 1990).

Finally, there is survey evidence on the direct use of generic information in the form of direct use of academic science by firms. In the course of a recent attempt to estimate a general rate of return to academic research, Edwin Mansfield interviewed R&D directors of a sample of 76 US manufacturing firms, asking them to identify product and process innovations that *i)* "could not have been developed (without substantial delay) in the absence of recent academic research", or *ii)* "were developed with substantial aid from recent academic research". Estimates were then made of the sales flowing from such innovations; a total of US$41.1 billion of sales in 1985 derived from such products commercialised in the period 1982-85. This was 5.1 per cent of the total sales of major firms in information processing, electrical, chemical, instruments, drugs, metals and oil industries in the United States. Process innovations relying on academic research simultaneously reduced the total costs of these industries by 2.6 per cent (Mansfield, 1991). Whatever view we take of the specific rates of return calculated by Mansfield, this kind of interview technique can be extended to other institutions, and thus to general interactions.

Co-operative relationships of innovating firms

A key insight of systems analyses is the role of user-producer interactions, and the more general process of co-operation between firms. These may involve either vertical relationships between firms in a production *filière*, or horizontal relationships between firms within a industry, in which case they may be either competitors or producers of heterogeneous products deploying a common knowledge base. There are three basic ways in which it appears possible to explore these interactions: case studies of innovating firms and emerging industries, the analysis of data from innovation surveys, and the analysis of formal co-operation agreements.

There is now an expanding, though arguably still inadequate literature (in terms of quantity not quality), of case studies on innovation processes. These case studies tend to follow either specific firms or specific innovations through a general knowledge creation process. Three broad examples will be mentioned here: the seven case studies of the Minnesota Innovation Research Programme (van der Ven *et al.*, 1989); various case studies by Erik von Hippel and Morris Teubal, who map a wide range of forms of user-producer interactions and formal and informal exchange of know-how; and the network analyses of Håkon Håkonssen (von Hippel, 1989, Teubal, 1987, Håkonssen, 1989). For the understanding of systemic flows, there is a strong case for simply expanding the quantity of this type of work.

An important new data source relevant to inter-institutional interaction is the output of the co-ordinated innovation surveys developed *via* the OECD, the European Commission and individual researchers in the early 1990s. There are two such initiatives which relate directly to the topic here: they are the Community Innovation Survey (CIS), described above, and the PACE project, which is an internationally co-ordinated follow-up to the Yale surveys of the 1980s.

The CIS project developed out of a heterogeneous set of more or less independent surveys carried out by private researchers in the 1980s (see OECD, 1990*a*; Smith, 1992 for descriptions); in 1992 the experience of the surveys was synthesised into an OECD manual, which aimed at improving the conceptual and statistical coherence of future surveys (OECD, 1992*a*). The OECD approach was subsequently developed by Eurostat and DG-XIII (European Innovation Monitoring System) within the European Commission, and implemented on an EU-wide basis; this survey was known as the Community Innovation Survey (CIS) (the data will henceforth be referred to as "CIS data"). Eurostat is now building a comprehensive firm-level database with the CIS data, which will when completed contain data on approximately 40 000 European firms (see European Commission, 1994 for an overall description). A closely similar approach has been adopted and has been or is being implemented in Canada, the United States, Norway, Finland and Australia.

The CIS survey primarily collects data on activities related to new product innovation in manufacturing, and on outputs of new or improved products within the sales profiles of firms. But it also contains several questions on technological co-operation and information flows, and it therefore makes it possible to link up the general innovation performance of firms with their patterns of technological collaboration and information use. There are two sets of relevant data from the survey, on information sources, and collaboration. The PACE project asks a closely similar set of questions, but to a very different population of firms: the CIS survey is aimed at the manufacturing sector as a whole, *via* a stratified sample with generally low cut-off points; it is not specifically aimed at R&D-performing firms. The PACE survey is aimed at large R&D-performing firms, invariably with more than 500 employees. The surveys are therefore complementary.

First, the questionnaire asks firms to rank, on a 5-point ordinal scale, the importance of the following "types of information required in the development and introduction of technological change":

INTERNAL SOURCES

- within the enterprise;
- within the group of enterprises.

EXTERNAL/MARKET SOURCES

- suppliers;
- clients and customers;
- competitors;
- joint ventures;
- consultancy firms.

EDUCATIONAL/RESEARCH ESTABLISHMENTS

- universities/higher education;
- government laboratories;
- technical institutes.

GENERALLY AVAILABLE INFORMATION

- patents;
- professional conferences/fairs/exhibitions/meetings;
- professional journals.

Secondly, the questionnaire asks about the acquisition and transfer of technology. This is simply a binary (yes/no) question, in which firms are asked whether they use a particular channel of transfer or acquisition, and where the source is located geographically. This covers a number of key forms of knowledge flow, including licences, contracted R&D, consultancy services, mergers and acquisitions, communications with other enterprises, or hiring policies. One of the interesting possibilities with the overall data set is actually to explore the effects of co-operation: for example to test links between co-operation channels and other innovation activities and outputs of firms. This data set has only recently been established, so it is too early to suggest results, but a preliminary result from the Norwegian survey suggests that firms active in co-operation arrangements with other institutions have significantly higher levels of new product sales than those not engaged in co-operation; this result seems to be rather robust, applying across all industries and size-classes of firms.

The PACE questionnaire is far more wide-ranging, as well as more specific, than the CIS survey: it asks firms for 5-point ordinal rankings of the importance of three broad types of knowledge flow or support: technological knowledge, research outputs and methods of access to these outputs, and public sector policies. The main dimensions of the information generated by the project are as follows:

SOURCES OF INFORMATION

- parent firms or subsidiaries
- joint ventures
- suppliers
- customers
- universities
- public conferences

OUTPUTS OF RESEARCH

- use of basic research results
- specialised knowledge
- instrumentation
- prototypes
- trained researchers or scientists

METHODS OF ACCESS

- publications
- conferences
- hiring
- personal contacts
- funding R&D
- joint R&D

PUBLIC POLICIES

- procurement policies
- subsidies
- R&D support
- information programmes
- co-operation programmes
- agencies for accessing international information

It is clear that these types of new data offer major opportunities in system mapping. There are, of course, many potential pitfalls with them, and the general quality of this data will need serious evaluation. But the prospects for policy-relevant system mapping look very promising.

Finally, there exist methods for mapping specific co-operation agreements by firms: here an extremely wide literature already exists, although there has been no real discussion of whether there might be benefits to come from standardised approaches, and if so, how they might be developed. In a comprehensive survey, Chesnais (1988) described six main categories of such studies:

- studies on joint ventures between firms;
- industry case studies, reporting incidentally on co-operation;
- studies of inter-firm co-operation agreements in general;
- technological collaboration in specific industries;
- business management studies (on co-operation and corporate strategies);
- institutional studies of co-operative R&D in different national environments.

The literature on these topics is particularly large, but has not – apart from Chesnais's work – been explored from a policy perspective; there appears to be considerable scope for using such literature in national policy contexts. It should be noted that it is possible to build quite substantial and consistent data sources on this issue: the MERIT-CATI databank in particular collected data on over 7 000 co-operation agreements, and has generated interesting analyses of knowledge interactions (for an example, see Hagedoorn and Schakenraad, 1990).

Personnel mobility

An important element in system interactions is occupational mobility. Data on stocks of researchers and qualified scientists and engineers is quite widely available. Flows are more problematic. However, a number of studies in various countries have shown that mapping such mobility with survey techniques is practicable, and a number of OECD countries have mobility data which throws some light on interactions between major research-performing sectors. At the simplest level there is simply data on mobility rates from universities and research institutes, combined with patterns of recruitment and destinations when leaving. This data is available, in more or less partial form, for most European research institute systems (see Ekeland and Wiig, 1994). Their study of the Norwegian system showed that the substantial sector of technological research institutes recruited researchers primarily from the university sector after postgraduate study, and sent personnel to the business sector; annual turnover rates average about 7 per cent, and most of those moving do so within six years. The general picture which emerges is one of a stable interaction pattern, in which publicly supported research institutes play a key role in supplying skilled personnel to business. For some countries such data is supplemented with data on "partial" mobility, meaning periods on sabbatical, loan, contract research, and so on. In general, this is an underdeveloped research area, but one where data exists and is relevant to knowledge system interactions.

System specificities

Thus far, this paper has explored methods for identifying interactions within systems. But such interactions should be placed within a view of system structures and specificities. There are a number of relatively straightforward indicators which are relevant for policy analysis, but which could be more widely used. These include, for example, the Revealed Comparative Advantage (RCA) and Revealed Technological Advantage (RTA) indicators, various patent indicators indicating degrees of self-sufficiency or external dependency, and so on. There exists one systematic attempt to use all of the available science and technology indicators to identify such specificities, namely Archibugi and Pianta (1992); further analysis of system approaches could involve a development of their work.

There is one particular indicator, widely used, where system specifities ought to be taken into account, and ought to modify the policy use of the indicator. This is the use of R&D intensities for international comparisons. In comparing the R&D performance of companies, industries or countries, we clearly cannot use absolute amounts of R&D expenditure or employment, if only because there are large size differences between countries. To overcome this, there is one overwhelmingly popular indicator, namely "R&D Intensity". For an economic sector, such as manufacturing or services, or an individual industry, this is usually defined as the ratio of R&D expenditure to value added or gross output. For an entire economy the equivalent measure is R&D/GDP. These ratios are widely used and are the usual basis for distinguishing between high-technology, medium-technology and low-technology industries. The R&D Intensity indicator can be extremely useful, but it can also be misleading. This is particularly the case if we simply compare the overall R&D Intensity numbers for manufacturing sectors as a whole. It is not uncommon for rather sweeping policy conclusions to be based on such comparisons. This kind of policy conclusion is oversimplified and unjustified. The reason for this is that the overall R&D Intensity for any country is strongly affected by what kind of industries the country possesses. The overall R&D intensity is an effect of two separate things – on the one hand, how much R&D is performed in the various industries, and on the other, the mix of low and high-R&D industries which the country possesses. The OECD has proposed a structure-adjusted indicator, called STIBERD, which attempts to take account of these structural impacts (see OECD, 1994); use of such indicators is central to reasonable structure analyses.

"Institutional mapping"

What has been presented above is a kind of portfolio of mapping techniques which, taken together, can give us some first approximations of system interactions and characteristics. However it is important to note a significant limitation in such statistical exercises, which is that they tend to erase one of the most important insights of the knowledge system approach, namely institutional differences. It therefore seems important to link any quantitative approach in this field with qualitative approaches which map institutional differences – for an example of this in the "national systems" context, see Mjøset (1992).

Knowledge systems are characterised by institutional complexity. On the private level, technology infrastructure institutions include industry associations and conferences, training centres, trade publications, collectively-established technical standards (such as architecture and operating systems in computing), branch research institutes, and so on. Public sector institutions include research councils, standards-setting organisations, patent offices, universities, research institute systems, libraries and databases. Public sector instruments include R&D programmes, legal or administrative regulations, subsidies to capital stocks (especially structures and scientific equipment), and public procurement. We could define the public science and technology infrastructure as consisting of a combination of these institutions and the flow of resources through them.

However the nature of these institutions may vary considerably between countries. Consider, for example, universities. Of course all OECD countries have university systems. But there is no definitive form for universities: they can have many different organisational structures, many different links with society, many different approaches to how knowledge is generated, and how teaching should be undertaken, and so on. Even within national boundaries there can be surprising diversity of forms: the United States is simply the most striking example of this. The potential diversity is even greater in an international context.

These rather elementary points raise wider questions about the nature of institutions: how do they evolve, what is the scope for policy intervention in their evolution? These issues are at least as central to comparative analyses as the quantitative procedures described above.

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CHARACTERISTICS OF INNOVATION POLICIES, NAMELY FOR SMEs

CONTENTS

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I. INTRODUCTION

Innovation policy first emerged as a concept towards the end of the 1970s, but it was not until recently that it was refined and that innovation ceased to be confused with research, invention and high-tech. Innovation is now defined as "that process by which a new product or process is successfully brought from the concept stage to market".[1] This definition warrants the following comments:

- the innovation may be radical, but may be limited to simple modernisation of the status quo;
- the idea which sets this process in motion is almost always a result of market analysis and only rarely the result of research;
- but the success of the innovation process is determined to a large extent by the accompanying technology.

This article addresses the system of measures designed to stimulate this process. Unlike a paper on technology, it does not address issues such as the acquisition of new knowledge or knowledge diffusion; its central topic will be the innovating firm.

In practice, innovation policy is aimed primarily at SMEs, since larger firms are considered as being well-equipped for innovation (they expect government aid only for their research programmes). Innovation policy for SMEs is therefore the first issue that this paper addresses, although many of the initiatives it outlines could benefit firms in general.

II. INNOVATION POLICY AS DISTINCT FROM RESEARCH POLICY

From the outset we should state that innovation policy is not the same as research policy, nor is it an adjunct to research policy. They are each policies in their own right and, while they certainly complement each other, the two should never be confused:

- *research policy* is aimed at advancing scientific knowledge, by supporting public laboratories and, more indirectly, industrial laboratories;

- *innovation policy* is aimed at helping companies innovate successfully, *i.e.* helping them get new products and processes onto the market. It thus contributes directly to the competitiveness of the industrial fabric.

The mistake was to confuse these two aims: of all the factors which affect the market success of a new product or process, the application of new scientific knowledge is seldom the crucial factor, even if the product or process is strongly technology-based. In practice, a good third of all innovations are by firms which have no formal research teams. Conversely, improving the competitive position of companies is seldom the sole aim in advancing scientific knowledge. It is therefore important to draw a distinction between the two aims and, consequently, between the two policies (Aubert and Dubarle, 1978).

The confusion between the two policies, which still lingers, stemmed from the "linear" model of innovation that was employed. This model pictured the innovation system as a "pipeline": the results of basic research went in one end and commercial products came out the other. A direct and incontrovertible link was asserted between economic competitiveness and intensive research. However, the cumulative experience of the past 20 years demonstrates that this direct link applies only in certain very specific cases; at best there may be a statistical correlation, but studies on the ground have not confirmed this (Heraud and Laval, 1994).

European countries repeatedly complain that their performance (and successes) in the science and technology field do not result in industrial and commercial success (Soete and Arundel, 1993). There is nothing mysterious in this: the *innovation capacity* of European companies is trailing behind that of other countries (in the high-tech field in the United States, in all sectors in Japan). A vigorous innovation policy carried out by the public authorities and within the major companies could certainly remedy this shortcoming. However, we should be aware that such a policy will take a long time since there can be no technological change without social change, the propensity to innovate being primarily a cultural phenomenon (Porter, 1990; OECD, 1991, p. 99).

In fact, the linear model, which still persists, tends to see everything in terms of the creation of new scientific knowledge and, in some cases, technology diffusion. However, *innovation is something else*: *it is a creative act motivated by an economic objective*, which mobilises financial as well as human resources in a purely market context, far from the academic system. The actors involved are engineers, financial backers, various experts and, of course, entrepreneurs, but seldom research scientists. At both firm and government level, the innovation process requires a much broader perspective than that of research.

This said, one must not go to the other extreme either: in this day and age, services and processes stand no chance of success in the international market unless they incorporate vast amounts of knowledge of all types;[2] the actors in an innovation project must be totally immersed in a culture which not only possesses this knowledge but also promotes it forcefully. An environment that is "ill-informed", indifferent to advances in knowledge, is a barren environment. It so happens that the best way to ensure that knowledge with universal application thrives in a firm or its environment is to conduct research.

In short, innovation policy for SMEs and research policy need to be conducted in tandem, giving the same priority to both. The two must, needless to say, be interactive and mutually supportive (see Section VII).

III. WHAT WILL AN INNOVATION POLICY CONSIST OF?

The overall objective of any public innovation policy is, it will be recalled, to strengthen the long-term competitiveness of a given country's companies by creating a climate conducive to innovation. It achieves two things. First, in traditional sectors, innovation ensures a company's survival by giving it a firmer foothold in the market, edging it towards the top end of the market, and by increasing its export capacity; in emerging (growth) sectors, such as high-tech services and manufacturing, innovation enables new and healthy companies to take the place of ailing companies in traditional sectors and shifts production to job-creating sectors.

In saying that an innovation policy is a policy which assists firms, we touch upon the essential difficulty: it can act only in an indirect way, because it is firms, not government, which deliver innovative products, processes and services. Government, obviously, cannot do their job for them, but there are three things it can do to provide the right conditions:

- create a climate conducive to innovation;
- foster a corporate innovation culture;
- ensure that firms have all the necessary resources by providing an extensive and efficient innovation services system.

Creating a climate conducive to innovation

When entrepreneurs wish to launch a new product or to embark on any other change (modernisation, quality, reorganisation, etc.) they must feel that they are being given every support. Instead it is frequently claimed that obstacles are put in their way and that everything is made difficult for them, although it is often impossible to pinpoint the source of the obstacles. It is this sort of inertia which innovation policy will have to change.

- An innovation policy must promote *international competition* and technological development.
- Equally, it must encourage *co-operation*, since innovation will only flourish within a highly interactive system. One could say that whereas research and training policies, etc., fund or influence "resource generators" directly, innovation policy acts on the interfaces which these policies cement and build up.
- It will be easiest to promote an innovation climate on a *regional scale* (Landabaso, 1995). Interaction between actors from different spheres of activity, relationships of *trust* between industry, financial backers and government, and concerted action by administrations develop more easily at regional than at national level. It can build a competitive advantage, defined as "the innovative capacity of the region" (Nauwelaers, 1995).
- Consumers (the public in the case of consumer goods, firms in the case of capital goods) *should welcome the launch of new products* and be encouraged to develop *a taste for new high-performance products* (Muldur and Caracostas, 1993). The products themselves should, in addition, be marketable in large *integrated markets*: even today barriers within Europe all too often leave the United States as the only large market for new product launches.
- Generally speaking, an innovation policy will aim to eliminate anything in legislation or regulations which could constitute a *barrier to innovation.*

Developing a corporate innovation culture

Not every firm wants to innovate or, indeed, is capable of innovating, far from it. The *capacity to innovate* requires four essential qualities:

- imagination concerning new products, services or processes;
- absorption capacity, or the capacity to make maximum use of the external environment and to take on board new knowledge and skills;
- the ability to manage a project successfully through to market;
- a taste for risk-taking.

Fostering these qualities in SMEs means getting them to change their behaviour which is certainly a difficult, and perhaps a questionable, undertaking. But governments, after all, have a duty to educate their citizens – don't they also therefore have the right to drag firms into the new, knowledge-based economy, by fostering an innovation culture?

This second approach can be summed up in three words: *risk-taking, learning, culture*:

- One by one, firms should be encouraged to *learn* new behaviour and new skills: they must learn how to get the best out of all the expertise that their environment offers and to develop their *absorption capacity* (Cohen and Levinthal, 1989), which we could equally call *learning* or *innovation capacity*. They must be able to manage an innovation project, particularly in the design/feasibility stages.
- To begin innovating, firms must be prepared take *risks* (back to culture again); to be successful at innovation, they must know how to *manage* those risks (Kessler *et al.*, 1995). Risk management is an art, but is fast becoming a technique, to the extent that analysis is taking the place of some vague notion of risk (sometimes confused with uncertainty or even speculation), breaking it down into its component parts, with different specialists handling each type of risk. These techniques have made great strides in both the financial (securitisation, derivatives, guarantees, etc.) and commercial fields (for instance, a high degree of specialisation was developed for the NASDAQ system in the United States).
- As in any "advanced market", the demand for the factors of innovation (technologies, equity capital, project management, etc.) follows in the wake of supply. Innovation policies must therefore set out to *stimulate that demand* (Chabbal *et al.*, 1994*a*) by making firms aware of new technologies, letting them know the existence of new issues and new dangers.

Although the objective of this second approach is clear, as with all policies which seek to change behaviour, it is difficult and slow to implement.

Ensuring that firms which wish to innovate have the resources and the expertise to do so

Innovation by a firm is a creative act which goes beyond the simple acquisition of knowledge and other resources. Nevertheless, the success of an innovation process demands the mobilisation, where and when required, of such resources as finance, technology, all sorts of information on markets, on the competition, etc. This is the area in which governments feel most at home, as they think that they can influence supply both upstream (resources) and downstream (*distribution system*).

- The first objective is to target those actors who feed the resource pool (chiefly financial and technological resources) so that SMEs or their partners will be able to draw what they really need from it (once *the needs of the SME* (whether expressed or not) have been *identified*.
- The second is to ensure that SMEs will find all of the professionally-qualified partners they need within their immediate environment (Chabbal

et al., 1994*a*): because innovation in SMEs in particular is a very new phenomenon, most "intermediaries" have had, at best, "on-the-job" training, or, more seriously, have had only minimal involvement with SMEs since the bulk of their work is for major companies or large government programmes. They find it difficult to adapt to the very specific needs and working methods of SMEs. These intermediaries will have to be trained and a code of professional practice established if we are to have service companies that are fully conscious of their clients' needs.

- Knowing how to *disseminate technology* through three main vectors is particularly important (*cf.* Freeman, 1987, Chapter 2): *equipment*-embodied technology; *mobile personnel* – or close co-operation on projects or participation in networks – who can pass on knowledge (including tacit knowledge); *data banks* and other means of communicating explicit knowledge. At a more general level, it is necessary to increase their "*distribution power*", a concept recently expounded by David and Foray (1995, see this volume).

This second package of measures is primarily targetted at the SME's partners, the "intermediaries". Such measures have a multiplier effect in that setting up one first class intermediary (sometimes public sector, but more often private sector) improves the innovation capacity his many client SMEs.

An essentially local policy

To conclude, we would emphasise, once again, that an innovation policy for SMEs is above all a local policy: it is, therefore, essentially the domain of regional policies, which is also the level at which most of the initiatives that will be described were implemented (Landabaso, 1995). This is not to say that national governments (and Europe) have no role to play; it simply means that their role should be demarcated by the "subsidiarity principle".

It is hardly necessary to repeat here that these measures would serve no purpose if people were not creative and if firms were not prepared to innovate. Government policies can do only so much.

IV. THE ACTORS IN INNOVATION POLICIES FOR SMES

Innovation policy takes many forms and can seem complex. It aims to improve the innovation system by ensuring that it is comprehensive, consistent and interactive. The merit of this (somewhat tautological) definition is that it introduces the systemic dimension of innovation policy. This network can be described as a network of actors, identifying particularly those who act as interfaces. For this description, we will use the modelisation and the vocabulary of the *Centre de sociologie de l'innovation* (CSI) (*cf.* Callon *et al.*, 1995, p. 415).

Along the innovative process, the SME brings together a small network of experts, represented by the diagram below (Figure 1) (*cf.* Chabbal, 1994):

The firm itself, at the centre of the diagram, is the ultimate target of innovation policy. Greatly simplifying the situation, there are two main types of SME.

- First, RICs (research-intensive companies) (Chabbal *et al.*, 1994*b*, Chapter 9), some of which will grow very rapidly (top of the pyramid in Figure 2) while others are technology suppliers (mid-section of the pyramid). These companies constitute 90 per cent of the "SME clientele" of the research programmes.
- Second, "standard" SMEs (base of the pyramid), which are far more numerous. They innovate, but carry out little or no research and are not directly affected by research policy.

Of course a more detailed classification – region by region and sector by sector – can be useful, and many have been made, especially for research-intensive companies.

Each side of the hexagon in Figure 1 represents one of the SME's principal partners in the innovation process. The need for *innovation-related services (public and private)* is one of the premises on which an SME-geared innovation policy is based: too small to have all the requisite skills normally available in a large company, SMEs have to call on external services (where the best known example is that of software consultancy companies. As innovation is a fundamentally interactive process, external service providers will only be effective if they behave like real partners.

Although these "intermediary services", as they are often known, go by different names and are differently structured in different countries, there are some *core functions* which, to be effective, need qualified professionals with very specific profiles.

Some of these professionals are what one might call *"mediators"*. Even when a pool of necessary resources, scientific, financial and market knowledge, etc., is available, that knowledge still has to be adapted or converted into a form usable by SMEs and channelled in their direction. This is the job of "mediators", whom we might also call transfer agents, provided that we keep in mind that their role is essentially one of transformation rather than of distribution. Let's take a look at who these partners are.

- Some are the *"technology suppliers"* [contract research companies, high-tech SMEs, Technology Resource Centres, etc. (Chabbal *et al.*, 1994*a* and

Figure 1

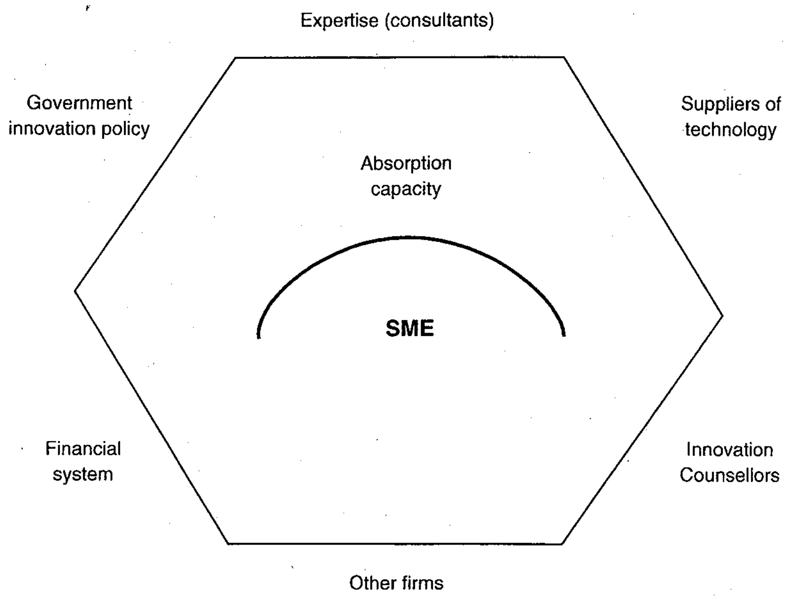
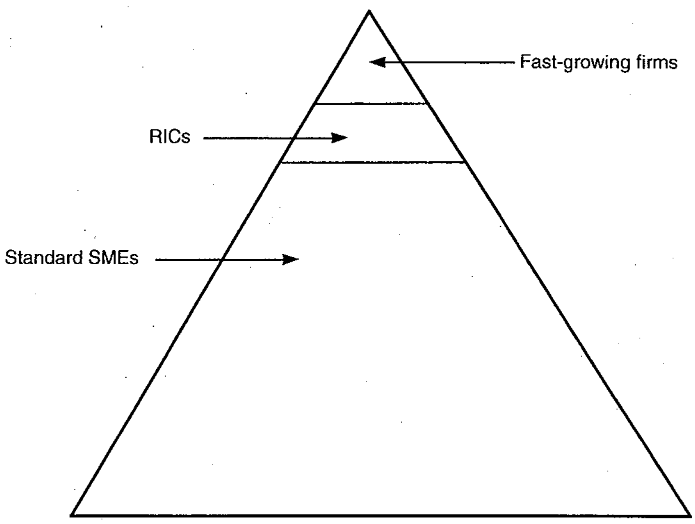


Figure 2



1994*b*)]; and must not be confused with laboratories whose function it is to fill up the knowledge reservoir but not to pump the knowledge towards the innovation projects of SMEs.

- Others, *consultants* of one kind or another, are *experts in various areas*: in marketing, patenting, value engineering, other forms of management, data banks, not forgetting trainers.
- Last but not least are *financial intermediaries*, which we will return to later. These are mainly banks and venture capital investors plus all the other actors in a NASDAQ-type financial market (analysts, known variously in the United States as "researchers", "market makers", "underwriters", etc.).

Other partners, who are relative newcomers on the scene, act as project *architects*, providing back-up (Germany's *"projekt gestalter"* for example) particularly in the *design stage*.

Another important function of such professionals is that they are the *first port of call* for SMEs. As such, their main role is *diagnosing* the SME's needs, whether it wishes to innovate or simply to modernise, and *directing* it to the experts who can best meet those needs. A major part of their job involves canvassing local SMEs. These professionals, often known as Technology and Innovation Counsellors, usually belong to Regional Technology Advisory Centres (RTACs) (examples are the United Kingdom's "Business Links", France's "Points d'appui technologiques" (PAT) and "Réseaux de diffusion technologiques" (RDT) or Denmark's TICs. Between them, these Counsellors are able to offer the degree of specialisation that the job may require, although, in the main, their remit is fairly general.

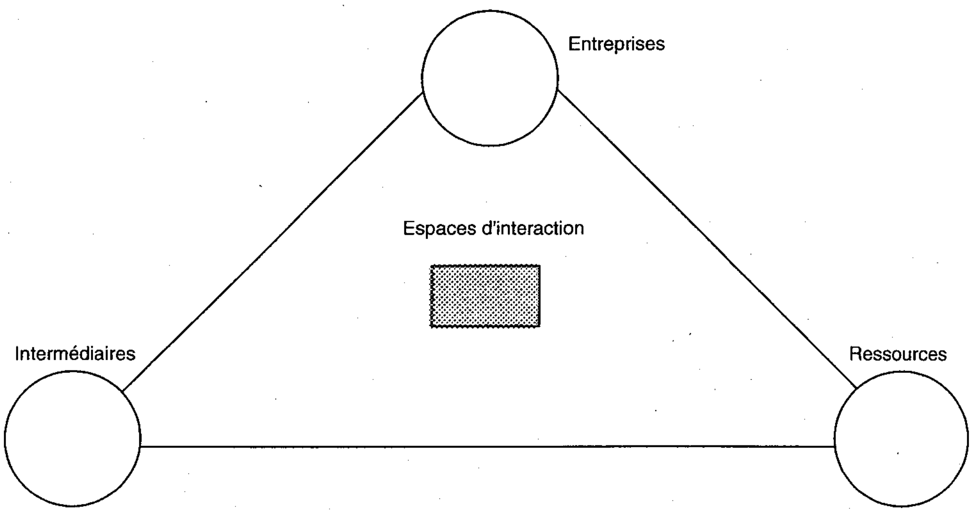
One of the tasks of these initial contact points is "first generation technology transfer", as opposed to the more in-depth transfer involved in a real partnership. This entails alerting SMEs to the new opportunities that technology offers, through publications, seminars, visits, demonstrations, tests and other initiatives to make SMEs more confident in their environment.

Last, but not least, in this list of partners, are *other firms*, which are actually the best partners from the standpoint of the SME. Partnerships between firms can take any number of forms: the majority of the actors outlined above are private-sector service companies (to the extent that those which are directly involved with public research are generally set up as private companies). Others, SME clients and suppliers, are those which generally provide the impetus for innovation. Finally, companies are forming more and more *networks* (Jakobsen and Martinussen, 1990), for joint research work, export and other purposes.

The two groups directly targeted by innovation policy are firms, on the one hand, and their partners (or "intermediaries", as they are now known), on the other. It is also interested, although indirectly, in a *third group*: "resource generators", who add to the pool of knowledge that innovating companies dip into, either directly or through partners. In the case of technology, they are basic research laboratories; in the case of capital, they are primarily pension funds and other "patient" investors: both belong to systems (research, financial, etc.) whose socio-economic role is by no means confined to innovation but whose long-term policies should take into account its needs.

These three target groups – firms, intermediaries and resource generators can be represented as a triangle (see Figure 3) which we will refer to frequently.[3]

Figure 3



V. THE TOOLS OF INNOVATION POLICY

Now that we have answered the first two questions (what to do, who to target) we will address the third question – how do we go about it? What tools can innovation policy use?

A major problem is co-ordinating and striking the right balance between government initiatives and those that are more properly the domain of the private sector. As a general rule, government intervention should be limited to running pilot projects which are designed to encourage a new type of demand until it is strong enough and well enough defined to make private-sector supply profitable. However, experience has shown that there are areas, such as SME awareness initiatives, forecasting, etc., which warrant longer-term government aid. It is essential to ensure good co-ordination all the way down the line between government and private initiatives, not forgetting joint initiatives.

As we have already pointed out, innovation policy is complex but consistent. Figure 3, which shows the three target groups referred to above, will help us classify the wide variety of tools available.

- transfer and interaction areas between the actors and institutions, the nerve centre of any innovation system, is shown in the centre of the triangle;
- incentives designed to steer more general measures (fiscal, regulatory, research programmes, etc.) in a direction conducive to innovation are aimed at the "resources" target group;
- direct measures (subsidies of various kinds) and "qualitative initiatives" (assessment, quality certification, etc.) are aimed at the "firms" and "intermediaries" target groups.

The "REED" cycle (Reflection, Experimentation, Evaluation, Dissemination)

Since it is faced with a complex system, public innovation policy has to adopt a diversified and systems-based approach. To ensure that it is nonetheless consistent and clear it must be underpinned by a *reference framework* which should, among other things, enable it to forecast what the effects of policy tools will be on each of the actors and on the system as a whole.

Such a framework was established by trial and error, using a process which involves successive stages of reflection, experimental development, evaluation and dissemination (of best practice), sometimes called the REED cycle (Chabbal *et al.*, 1995). This is a pragmatic, considered approach that makes it possible to build up in-depth knowledge of what has every apparance of a "black-box". Briefly, the stages of this cycle are:

- *Reflection*: in order to construct a conceptual framework, public authorities can prompt research, undertake analyses, compile statistics, set up forums for comparative analysis of the knowledge thus acquired (*e.g.* EIMS under the SPRINT programme) (Miege, 1995).
- *Experimental development*: as a follow-up to such analyses, governments can set up pilot schemes, with the co-operation of industry, to test hypotheses and gain on-the-ground experience (SPRINT programmes, UK schemes, etc.)

- *Evaluation*: the conceptual framework, which has been thus gradually built up, serves as a frame of reference for evaluating either specific projects or innovation policy proper.
- *Dissemination* of "best practices": public authorities obviously have a duty to communicate what they learn from the above stages to all the players in the innovation system.

The REED procedure has a number of advantages: as well as showing the way, it allows those actors who have participated in the process to put together a *common* analytical framework which does much to ensure the consistency of the programmes set in motion.

Outline of the interaction and transfer mechanisms which firms can use

We have stressed the importance of interaction and transfer in innovation systems. These can develop through a wide variety of mechanisms and public or private organisations:

- *Networks*: currently the most widespread of such mechanisms, networks involve all the actors in the innovation system (Callon *et al.*, 1995*a*); although networks of firms are the most difficult to set up, they are the most effective once in place. Such networks may be regional, national, Europe-wide.
- *Co-operative projects*: already widely used in the research field, they have become as well an effective way of developing products (EUREKA) and validating or disseminating technologies (VALUE and SPRINT, respectively). Project management methods have improved considerably in recent years (EC, 1995).
- *Financial markets*: NASDAQ is a typical example of an interactive marketplace and plays a major role in the expansion of innovating SMEs in the United States (Fassin and Lewis, 1992; EVCA, 1993; Chabbal, 1995).
- Other "interactive environments": include forums, trade fairs, *technology parks, science parks*, and other incubators (Bruhat, 1993), all of which are increasingly used to stimulate the local industrial fabric, either by encouraging high-tech firm start-ups or by forging links between the latter and traditional industry.
- *Demonstration*: now a much more widespread practice in transfer centres (TRCs, etc.), especially for transferring embodied technology (equipment, software, materials, etc.).
- *Personnel mobility*: long-term training courses, aid for recruiting laboratory research staff and technicians and for other means of disseminating tech-

nology while at the same time expanding the technology absorption capacity of SMEs.
- *Patents and licences*: patent policy has an enormous influence on the rate at which technologies spread: for example, Japan's policy, geared to incremental innovation, is considered to be more in tune with the realities of the innovation process than the European concept, which is geared to "invention" (David and Foray, 1995).

The above list should also include services which act as "mediators", as defined in Section IV above, chiefly:

- Technology Resource Centres (TRCs), *i.e.* specialist teams whose job it is to adapt and "feed" the results of laboratory research to SMEs (see below);
- various types of advisory services;
- *"valorisation" consultancy services*: whereas technology is disseminated primarily by using the expertise of researchers, a firm may sometimes be able to incorporate an entire process into its activities. In such cases it procures a licence from another company or public agency. This is where licensing agents have a part to play. They may receive government aid under what is known as "research results exploitation policy".
- *training services* which provide support when new equipment is installed or which are aimed at the different categories of intermediary mentioned in Section IV.
- financial intermediaries in the innovation funding business, primarily *venture capital companies*.

An innovation policy will have as its aim:

- on the one hand, to multiply its interface contacts, its innovation service firms and its interactive environment;
- on the other hand, to create institutions (networks, one-stop-shops, pilot committees, etc.) which put these different interfaces in contact with one another and which co-ordinate the different sources of expertise and finance.[4]

Government action to channel resources in the right direction (first target group)

Innovation policy is not directly responsible for supporting research nor for financial or environmental policy, etc. However, it can and should serve as a spokesman to companies, and SMEs in particular, to steer these policies in directions conducive to innovation.

The "resource reservoir" analogy serves to illustrate this point. Innovating firms should be able to find the resources they need in this reservoir: longer-term financial resources, technological know-how, information on international markets, etc.

The role of innovation policy will be to counteract natural trends of resource creators such as the "technology push", for technology resources, the preference for "liquid" investments, the shortsightedness and regionalism of entrepreneurs.

The following are some of the initiatives governments have taken in this direction.

Technology and demand forecasting

- *Forecasting*: while there is nothing new about forecasting exercises, they now tend to be more focussed on practical goals. Some focus on trends in consumer needs: for services, consumer and capital goods (the Delphi technique) (Grupp, 1993; Office of Science and Technology, 1995). Others, modelled on the former to a greater or lesser extent, attempt to predict what the key technologies of tomorrow will be (surveys, etc.).
- *SME demand forecasting*: SMEs do not demand leading-edge technologies, but existing mainstream technologies which can be tailored to their own needs. Although technologies have to be adapted for each individual firm and each individual product, it is instructive to identify problems for which a collective solution could benefit an entire sector. This exercise differs from the former in that it must be undertaken by the people on the ground who are in constant touch with SMEs and are able to "visualise" the knowledge that has to be made available to meet any of a wide variety of needs which, more often than not, are not clearly articulated by the firms themselves. This will be one of the tasks of Technology and Innovation Counsellors and of sectoral Technical Centres.

The hope is, of course, that the outcome of such exercises will be taken into account in defining research programmes, particularly European Commission programmes.

Fiscal measures

When well-targeted, fiscal measures can provide a powerful incentive. Those that induce businesses to increase their research effort will be dealt with later. Fiscal measures aimed at encouraging longer-term savings (in compensation for the reduction of liquidity in their investments), or at encouraging companies to increase their equity capital rather than to borrow, should also be included under this heading.

Standards

Standards for new products should be preceded by research and be performance-oriented (since this will stimulate innovation) rather than essentially descriptive (O'Connor, 1992).

Regulatory measures

The aim, here, is not to introduce new measures, but to influence and reformulate general regulatory measures so that they will stimulate innovation rather than fetter it. For example:

- *protection regulations* (environment, safety, investors, etc.) should also take into account the effect they will have on innovation, which should be viewed as a way of resolving problems in need of solutions rather than as a threat (one only has to consider the very positive impact of the Clean Air Act in the United States);
- regulations applicable to government *procurement contracts* and anti-trust legislation should promote *creative competition*. While ensuring the total transparency of procedures, care should be taken to ensure that innovative projects can often be selected in preference to "cheaper" projects (Miege, 1995).

Subsidies (and other aid) for intermediaries (second target group)

It is usually firms which have to pay for innovation-related services and consulting; the resources of such services should therefore come from firms. One might well ask what part the government should play with regard to "intermediaries": how can government innovation policy help services which will ultimately be the responsibility of the private sector?

This is an area in which the REED process could prove useful since it can identify the optimum operating conditions for these interfaces (it has made it possible to clarify the role of TRCs as distinct from research laboratories, for example). By using this approach to define *"best practice"* in new professions, the government could accelerate the take-up by SMEs of services which they are not familiar with, possibly involving certification to ISO 9000 (DTI, 1995) or other quality standards. Again we would stress that the development of a conceptual framework would also enable us to set up evaluation schemes for innovation policies on a comparable basis (for example, evaluation of national policies by the OECD and regional policies by SPRINT).

The European Commission's efforts to promote the development of the European NASDAQ by fixing the rules of the game and therefore helping the private operators responsible for setting up this securities market – comes into this category of non-quantitative aid.

Beyond the government's role as a think-tank and in standardisation, experience shows that there are a few other niches in which government intervention is useful.

- First, the *launch* of services which meet new needs and for which demand only becomes apparent once there is already a structured supply. Public authorities can then supply basic equipment and ensure operations until turnover is high enough to ensure viability.
  - One example is the United Kingdom's "Enterprise Initiative Consultancy Scheme" which allows SMEs to claim a percentage of the costs incurred when they use outside consultancy services; the training and selection of consultants is based on SMEs' assessments of the services provided. After 10 years' sustained effort, the United Kingdom now has more than 10 000 high-calibre consultants covering the full range of areas (DTI, 1995).
  - This category would also include assistance for "spin-off" companies (Mustar, 1993), to allow industry or public research staff to set up companies specialising in the supply of technology of all descriptions (tests, analysis, software, customised instruments or materials, assistance with innovation projects, contract research). Assistance could take a number of forms, including a guarantee that a researcher could return to his job with his original employer should the venture fail.
  - The same rationale is behind aid for the demonstration initiatives described elsewhere in this paper.
- Second, *incentives for working with SMEs*. The transaction costs for working with SMEs are currently very high in relative terms (Chabbal *et al.*, 1994*b*, Chapter 11). In fact the costs involved in contracts with SMEs, often considered "small contracts" (short-term, modest sums, etc.) are almost as high as for major contracts secured with large firms. As a result, commercial interface services have almost entirely neglected services to SMEs. This is why the public authorities are increasingly offering a "bonus for working with SMEs" in the form of a "top-up"; the sum paid by the SME is "topped up" by a prorated subsidy (say, 40 per cent of the amount paid by the SMEs) to offset the higher costs involved in working with SMEs. In the long run, the subsidy should cease once SMEs have learned how to work in partnership with innovation services. Studies and initiatives in this area should be considered a priority.
- Third, *sharing the risks* taken on by those who invest in radical innovation, for example, the guarantees extended to banks and venture capital companies (SOFARIS in France, BJTU in Germany, etc.)

- Fourth, *aid for setting up interactive environments*: financial markets, networks, technology parks, etc.

Government support can go as far as permanently financing some categories of intermediaires which until now have only been able to operate thanks to public funds or collective support. This is especially the case of Technology and Innovation Counsellors in their tasks of prospection and guiding SMEs.

Economic logic requires that such aids and subsidies be withdrawn once SMEs and their partners have learned to control their transaction costs.

Direct measures for firms (third target group)

Let us now turn to the most classic of all public policy tools: direct subsidies for firms.

Most economists are, it goes without saying, opposed to the principle of subsidies since they consider the results counter-productive, causing intersectoral and international distortion, shielding companies from the realities of competition and delaying restructuring and adjustment. They should only ever be used as a temporary measure and should be reviewed thoroughly at regular intervals.

This said, in an economic climate in which SMEs have not yet really adapted to the changes resulting from unrestricted international competition and to the pace of technological change, every country now operates some form of direct subsidy for innovation.

Subsidies can be used to serve a variety of purposes.

- The first of these is to *increase the absorption capacity of firms*: the aim is to enable an SME to employ staff who will strengthen its absorption capacity, *i.e.* its ability to use the outside environment to its best advantage and to add new knowledge and skills to its assets. Without the right staff, experience has shown that it is virtually impossible to establish a dialogue between the SME and its partners.
  - When the size and nature of the SME is such that it can build up a research team, this team will be the interface that will do the "absorbing" (if it has been clearly designated to play this role and is prepared to do so). There are various programmes and instruments which encourage firms to set up such teams: the most neutral of these is the "R&D tax credit" (increased expenditure on research is tax-deductible).
  - Even when an SME cannot reasonably expect to set up a research department, it is to its advantage to employ staff who have research qualifications (Berkaloff *et al.*, 1971) or professional experience which would equip them for the interface role. Incentives to employ such staff

include a number of programmes which will pay all or part of their salary for a certain period (TCS in England, CORTECHS, CIFRE, ANVAR-embauche and long-term training courses in France, etc.).

- The second is to *help SMEs improve project design*: the ultimate success of an innovation project hinges on the design stage; this is when technical feasibility studies are conducted, the exact nature of the product and the characteristics of its potential market are defined, partners are arranged and patents are filed. Subsidies can be useful at this stage since they allow firms to have all such studies conducted in depth and to call in top expertise – all of which entails expenses, the importance of which SMEs with insufficient experience of innovation might well underestimate.
- The third is to *share the entrepreneur's risk*: through the now quite common "advance refundable if successful" formula (*e.g.* ANVAR aid for innovation in France, SENTER in the Netherlands).
- The fourth is to *provide incentives for modernisation and innovation* by contributing to investment costs and the costs of calling in outside partners (consultants, TRCs, etc.).

The wide availability of subsidies, which, it is worth repeating, should be assessed and reviewed frequently, should not be allowed to overshadow the importance of the information initiatives already mentioned, which are intended to change the behaviour of the SME.

Examples

The foregoing concepts can be illustrated with reference to two important particular cases: innovation funding and technology transfer.

Innovation funding

The following is based on an analysis by a French working group of bankers, venture capitalists, entrepreneurs and civil servants, which met from April to July 1994, and submitted a report to the Minister for Business (Chabbal, 1995).

What type of resources?

Experience has shown that the external part of innovation funding must be provided mostly in the form of *equity*: a capital increase allows an SME to cope with the *risks* attached to a project, and to get through the phases during which the project has not yet started to show a return. Moreover, even if the backer is only looking for a limited-term investment, he will not pull out until the project has matured sufficiently to yield him a substantial capital gain. Also, the injection of new capital increases the SME's borrowing capacity and allows it to overcome cashflow difficulties. There is a whole range of new financial instruments that can be labelled as quasi-equity, which enable the external funding to be tailored to the SME's exact requirements (OECD, 1995).

This is in no way to minimise the importance of public funding, which can play a crucial role – by providing seed money – during the design phases of a project. But such funding will represent only a fraction of the total financing.

Origin of resources

The necessary funds have to be raised from savers who are willing to accept a relatively long-term return on their investment – although they hope that it will be high ("patient" investors). While investment in innovation is, as a rule, profitable (and even more so than other kinds of investment), it is long-term and uncertain. Short-term money, from which depositors require total liquidity and a predetermined return, should not therefore be invested in innovation. The bulk of the savings invested in innovation is collected by institutional investors – primarily *pension funds and life insurance companies.* However, individual investors ("business angels") may also invest directly in innovation projects; they are particularly common in Anglo-Saxon countries.

Innovating SMEs

As regards the target of such investment, *i.e.*innovating SMEs, it is appropriate to distinguish between two categories of firms: on the one hand, companies set up on the basis of a product, service or process with a large technology content (new technology-based firms) and, on the other hand, mature SMEs that decide to develop an innovation. If the innovation constitutes a real breakthrough aimed at a new market, a frequent intermediate solution is to set up a new company within the adult SME (internal spin-off).

The financial intermediaries

These are obviously essential, since an SME cannot have direct recourse to pension funds (or other institutional investors).

- The intermediary with which SMEs are most familiar is their *local bank* branch. However, banks normally play only a secondary role in the funding of innovation projects (Larrera de Morel, 1987), the bank loan merely topping up the equity injection. Furthermore, bankers are traditionally ill-equipped to appraise projects that are essentially investments in intangibles, the appraisal of which requires long experience of the innovation process. Lastly, a bank loan is asymmetrical, since a banker does not have a financial stake in the success of the firm but is the first to suffer if it fails.

- The main intermediaries are *venture capital agencies*, whose role consists in investing the money of institutional investors and private savers in companies for a fixed term. The fixed-term nature of the investment is essential, since this kind of money is meant to be reinvested in other projects. The art of the venture capitalist therefore consists as much in knowing when to exit a company as in selecting projects that will show a return on the capital that has been entrusted to him by "patient" investors. Experience also shows that venture capitalists have an important role to play in monitoring projects; the quality of this monitoring will be an important factor in whether the project is an eventual success (and thus in the capital gain made by the venture capitalist when he takes his capital out of the company).

Interfaces

Financial markets: in the United States there is a financial market called NASDAQ which specialises in the funding of growth companies, *i.e.* companies which regularly need to increase their capital. A public share offering, provided that it is warranted by the size, and especially the potential, of the company, is by far the best method of financing. Of course, the functioning of this market entails the intervention of a wide range of other intermediaries (Fassin and Lewis, 1992) (market-makers, analysts, investment banks, brokers, etc.); the global expertise provided by these markets will prove essential at every stage of the innovation process, especially during the years which precede its introduction onto the financial market, when the amounts invested reach high levels.

Local funder networks: during the initial phases of innovation, when the sums required are still small and the firm is looking for a local funder, public and private local funders can be useful in setting up a network to forge relations of trust and to facilitate interaction.

"Short-circuits" in the system: individual investors (business angels) "short-circuit" the system

Government measures

Among possible measures contained in the report submitted to the Minister for Business (Chabbal, 1995), we can cite:

- Promote *patient investment*: introduce policies to foster the creation of pension funds.

- Implement tax measures to encourage *long-term saving*: provide incentives for firms to prefer a capital increase to borrowing.
- Provide liquidity guarantees for direct *investors* (business angels).
- Assist venture capital: top up funds raised from private investors with public funds.
- Increase the attractiveness of small investments (under FF 1 000 000) by bearing part of the design and management costs.
- Share part of the funder's risks by the use of guarantee funds (SOFARIS).
- *Provide direct support to firms*: share part of the entrepreneur's risks by providing aids which are repayable if the project is a success (ANVAR), and by injecting public seed money.
- *Create interfaces*: exert political pressure on the banking sector to create a NASDAQ-type European market. Provide assistance with setting up local networks of innovation-funders. Give SME shareholders an incentive to increase equity in the middle of the innovation process.

In short, these measures aim to strengthen patient investment, to encourage development capital agencies to fund innovation by SMEs, to foster the emergence of local saving, to create a financial market specialised in growth companies and, by the same token, a body of experts familiar with innovation.

Technology transfer

The classic problem arises when technology transfer involves numerous actors. The breakdown given below and the accompanying profiles follow the same outline as the previous example (funding).

Needs

Generally, technological knowledge and competence are integrated into the development of a product or process through a range of vectors which, as we have already pointed out, is extremely wide (equipment, personnel mobility, joint ventures, licences, data banks, etc.). There is always a need for adaptation to some extent and, consequently, for a fair degree of interaction between the SME and the supplier as well as for SME staff training.

Resources

Basic technology laboratories are the reservoirs of knowledge and competence to be transferred, but these must be available (*i.e.* research policy will have to have channelled research towards the appropriate disciplines) and accessible (*i.e.* the intermediaries responsible for transfer must be in close contact with the laboratories).

SMEs

In the present economic climate, we can safely say that technology transfer is something that all SMEs need or will need. However, given the wide disparity in the level of their technological expertise and the specific nature of their needs, a highly diversified supply and great flexibility are required. The action to be taken and the actors needed will vary widely depending on whether or not the SME has a research team.

Intermediaries

Intermediaries, always useful, are indispensable if the SME does not have a research team. We have already discussed the role of TICs (Technology and Innovation Counsellors) in first generation transfer. *Technology brokers* and applications development companies can step in to establish co-operation between patent-holders and firms which wish to exploit a patent. The numerous *high-tech firms* which are springing up as technology diversifies supply equipment, specialised machinery, software, testing services, etc. Sectoral *technical centres* cater to modernisation and quality needs.

One formula which is particularly suited to the needs of SMEs is the Technology Resource Centre (TRC) and we will describe it in more detail here (Chabbal *et al.*, 1994*a* and 1994*b*, Chapter 6). A TRC is a team of engineers and technical staff, usually small (five to fifteen people), working full time for firms – on innovation projects or supplying short-term services (analyses, testing, rapid prototyping, troubleshooting, etc.) – and always to guaranteed deadlines and performance standards. They do not conduct research themselves, but have close links with one or more of the laboratories which generate the knowledge that the centres will transfer. Centres of this type exist in Germany (Steinbeis Centres, some Fraunhofer Centre teams), England (the Wolfson Centres in some universities, for example), France (CRITTs, CRTs of institutions like the CEA and the CNRS). More of these centres are needed since the role and priorities of conventional laboratories make it extremely difficult for them to release any research staff to work on SME projects which, rather than aiming at developing new knowledge, are geared to product or process development and are far downstream of research initiatives.

When the technology to be transferred is equipment-embodied (instrumentation, software, materials) the demonstration function assumes greater importance. It has expanded over the last few years because SMEs, which are transfer centres' main clients, are more wary of new technologies than are large firms. When they want to modernise or are looking for technological solutions that can be easily integrated into an innovation project, they want to see that they actually work before they buy. After initial contact is made at an *exhibition*, *organised visits* to businesses which already use the new technology can give it credibility and also alert potential users to the training and organisational requirements that it will entail. Lastly, TRCs have given SMEs *access to their equipment* to familiarise them quickly with the services that they can offer. Demonstrations of this type have a lot to offer: firms can check whether the technology they try out is really the answer to their problems. They also serve to establish a relationship of trust between the TRC and the SME as the latter comes to realise that the TRC can really offer it practical, on-going and all-round help.

Interfaces

We have already reviewed the mechanisms that can be used to develop the necessary interfaces. Of these, Technology Advisory Centres (TACs) and networks of all kinds (France's technology diffusion networks, for instance) deserve special mention.

"Short-circuits"

Given the very different roles of laboratories and SMEs, short-circuits in the system are rare. The exception (direct researcher involvement in an SME project) arises when a researcher is allowed to follow through an idea that is his own brainchild and is either temporarily assigned to the developer's project team or decides to set up his own company. The second alternative, the "spin-off" formula, as it is known, seems to be the most efficient and most common (Mustar, 1993).

Government assistance

At the resources level, there is the conventional panoply of tools used for any technology policy, *i.e.* forecasting and financial incentives, not forgetting indirect measures such as standards, government procurement contracts, demonstrations and other ways of stimulating the supply of embodied technology.

At the intermediaries level, there are experimentation and evaluation, training and accreditation schemes, incentives to work with SMEs, networks: in short, all the watchwords of the type of policy that we have been describing obviously apply here. Here again, it is not easy to draw a line between what should properly be government measures (wholly government-financed because intrinsically non-profitable) and commercial initiatives which nonetheless qualify for government subsidies, or purely commercial initiatives. The "Business Links" scheme, and others like it, will probably remain in the first category for a long time to come, while TRCs designed to work primarily with SMEs belong to the second.

At enterprise level, some kinds of aid to firms encourage them to adopt technologies that government considers they need to stay competitive (automation, quality, etc.). However, it would seem that the subsidies with the most leverage are those which tend to increase the absorption capacity of SMEs. Various schemes, which promote the temporary employment of people with experience in a research environment, either at technician or researcher level, have been introduced in Europe. Examples are the CORTECHS, CIFRE and ANVAR programmes, and the TCS (Teaching Companies Scheme).

VI. THE CASE OF LARGE COMPANIES

Although this article is primarily concerned with SMEs, it is also necessary to consider large firms, first, because it is they that produce most R&D-based innovations, and second, because both large firms and SMEs co-operate closely in most innovation processes and are linked to one another by successive innovations in a technological trajectory.

Innovation in large companies

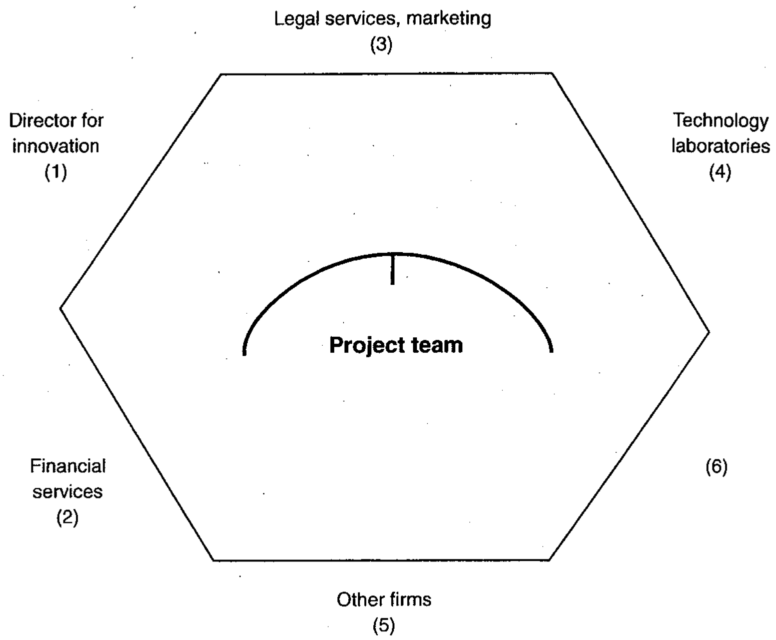
The innovation mechanisms in a large company (LC) are not really different from those that have been described for SMEs. Indeed, the differences among SMEs or among large companies can be greater than those between an LC and an SME.

The extreme case, from the standpoint of innovation policy, is that of the major company which is wholly self-sufficient, *i.e.* a company which has its own complete system of innovation; the various actors, objectives and tools are those that have been described earlier, but they are located in different parts of the company and the barriers between them can be as high as those between an SME and its environment.

To foster innovation within the company will then require an *internal innovation policy* that in many respects is similar to public policies for SMEs. This policy would consist essentially in: promoting an innovation culture throughout the firm, and particularly in fostering incremental innovations; setting up project teams to speed up and optimise product design and the marketing of new products and processes (Benghozi, 1990); nurturing radical innovations (if necessary by promoting spin-offs, *i.e.* the creation of a new company by the researcher who had the idea for a product, if its manufacture would fall outside the firm's normal strategy, etc.).

It would be possible to list the various facets of this internal innovation policy – the actors, objectives and tools. Instead, to bring out the similarities, and the differences, between that policy and public innovation policies for SMEs, we shall adapt the hexagon in Figure 1 (Figure 4).

Figure 4



In the middle of the hexagon, in the place of the SME, is the project team (Benghozi, 1990; Midler, 1994) set up by the innovation policy manager to mobilise all the skills, both inside and outside the firm, needed for an innovation project.

(1) The person responsible for innovation policy in a large company is usually the industrial director or director of strategy, less often the research director. He seldom has the title of *Director of innovation*, although it would have the advantage of showing the importance attached to internal innovation policy.

(2) and (3) Financial services are on one side of the hexagon, and legal services, marketing, design, cost analysis, value analysis, etc., are on another side.

(4) The project team's contact with the laboratories that are reservoirs of technological knowledge will be effective only if there is an interface composed on the one hand of in-house manpower within the project team (in general, research engineers on secondment to the team) and, on the other, of engineers within the development laboratory. The latter obviously work in symbiosis with the firm's laboratories (which themselves liaise where necessary with outside laboratories).

Frequently, however, a project team's technological partner is an external technology resource centre which is sometimes public but more often private.

(5) The new division of labour between large firms and sub-contractors leads to a systematisation of "co-innovation". Very often, to launch and carry out innovation projects, a firm will have large recourse to its suppliers and customers.

(6) Stimulation of demand: many large firms have a systematic policy of promoting communication between factories and R&D teams.

To a large extent, therefore, these innovation services, which are usually internal but may be external, play the same role *vis-à-vis* the project team as the local environment plays to the SME.

Corporate research

The real value, from the economic standpoint, of research and development can be appraised by examining its role in a large firm. It may be considered that international competition obliges firms to carry out R&D, but only that which is necessary.

- *Development* is, by definition, the part of R&D involving the development of products, services and processes. It is carried out mainly within the framework of the *innovation projects* described above, and is an integral part of the innovation process as defined earlier. Development expenditure is therefore, by definition, expenditure on innovation.
- *Research*, in contrast (Pavitt, 1992), is a long-term investment whose ultimate objective is the acquisition and exploitation of leading-edge skills that will spearhead the firm's innovation activities. *Since it is a rapidly-evolving area, such competence can be acquired only by participating in research.*

Research staff can be mobilised to the following tasks:

i) Obviously, to develop original knowledge that will give the firm a lead in its strategic niches. The part of such knowledge that can be communicated constitutes the entrance ticket to the network of researchers in the sector.

ii) But also to adapt and absorb the knowledge developed world-wide that the firm may need now and in the future. To a large extent, it is by participating in the aforementioned networks that researchers can quickly acquire knowledge that can really be turned to effective use (unlike the traditional "technology watch", which is slow and poor at filtering knowledge).

iii) To validate knowledge that constitutes a "technological package", *i.e.* adapt components or sub-systems with a view to incorporating them in future programmes (advanced engineering).

iv) To reach out to the firm's external environment (suppliers, public sector, customers, etc.), and tap it for the knowledge that the firm will inevitably lack. Every innovation is multidisciplinary and no firm, no matter how big it is, will have all the necessary skills. This is particularly true of SMEs, which often do not have any research teams. We have all already stressed the importance, even in these cases, of having an "outreach and innovation function" that enables the firm to find the right partners and derive the maximum benefit from them.

v) To meet the needs of the company's factories, which want solutions to their manufacturing problems (troubleshooting, tests, etc.).

vi) To incorporate the necessary knowledge (either created or absorbed) in innovation projects (sometimes by assigning research staff to project teams).

All these functions fit into an industrial development strategy which, in principle, makes it possible to pinpoint the skills that should be maintained or acquired in the long or medium term. It goes without saying that this strategy will take account, especially in high-tech sectors, of the competencies acquired by the company's laboratories.

In short, the firm will find in its research laboratories the people possessing the knowledge and competence which are (or will be) necessary to it in order to carry out its innovation projects (Pavitt, 1992).

Separate status, however, has to be given to *radical innovation, i.e.* the manufacture of a product or process conceived or designed entirely by the research laboratory (for example, a molecule or electronic component). Although the most spectacular type of innovation, it should not overshadow the other roles of the research laboratory, since ultimately it is they that justify the laboratory's existence.

VII. OVERVIEW OF PUBLIC POLICIES ON RESEARCH, TECHNOLOGY AND INNOVATION

The role of public research *vis-à-vis* companies

In a firm which has its own laboratories there is a direct link between innovation and research. However, the link is more blurred and more difficult to establish at a general level.

It is first of all necessary to rectify the common misapprehension that countries can acquire the knowledge it needs solely through its own public research efforts. The type of knowledge produced by laboratories and diffused throughout firms is primarily a *public, and thus international, good*. However, some countries take this argument too far, and draw upon the international reservoir of public knowledge without really adding to it. Hence the recommendation formulated in 1989 by the OECD Council that all countries should carry out fundamental research in proportion to their GDP.

If it is considered absolutely necessary to justify public research on the grounds of competitiveness (fortunately there are others!), it is necessary to go back to the problems of enterprises and to ask how the public research laboratories located in their vicinity can be of service to them. Once again, the answer lies in the need for people who are abreast of the latest knowledge, *i.e.* knowledge that is being continually updated world-wide by research recognised by the international scientific community.

These people can be useful to firms in various ways. They can:

- help company managers to identify the skills that will be the strategic skills of tomorrow and, from there, plan the contents of future technology programmes;
- advance knowledge (often interdisciplinary) in strategic areas, often in consultation with corporate laboratories, within the framework of technology programmes;
- make their expertise available to Technology Resource Centres specialised in working with SMEs, or production and development centres of large companies (testing, participation in project teams, etc.);
- set up firms that exploit directly ideas than can be patented, help to exploit the patent through an existing firm, or they can be hired by contract research companies or other high-tech firms.

Such people constitute a *pool of expertise*, which, experience shows, is *not very mobile geographically*. From this standpoint, therefore, research done in a given country or even region will be directly profitable to the firms in that country or region (Pavitt, 1992).

In contrast, if there were no public research in the country in question, such people would not exist and the above-mentioned functions would not be performed. It is, however, necessary that the research effort be carried out in fields where knowledge is useful to firms and that conditions of mobility and co-operation between firms (including SMEs) are satisfactory. Such is the purpose of the technology programmes described below.

Technology programmes: bridging the gap between research and innovation policies

Technology programmes expanded rapidly in the 1980s, at the instigation of governments and businesses which wished to bring together industrialists (able to spot future products) and researchers whose job it is to acquire the knowledge that will make those products possible. To clarify the role of the programmes, we will refer to a pertinent study conducted by the CSI (*Centre de sociologie de l'innovation*) which identifies three different poles in public research-technology-innovation initiatives (Callon *et al.*, 1995*b*).

Research policy involves creating the appropriate set of laboratories and researchers and running them as efficiently as possible. The goal is to have a national scientific community that can compete and communicate with the best laboratories in the world in any field that a country considers useful. This enables it to keep abreast of and benefit from every development in science and technology in these fields, anywhere in the world.

The task of research decision-makers is to strike the right balance between disciplines, foster cross-disciplinary links and allow new disciplines to emerge. Although they are responsible for substantial sums of money (about 1 pour cent of GNP), they have little room for manoeuvre, given their fixed overheads such as wage bills and laboratory maintenance. Little, if any, of their budget is spent on anything other than public research.

Innovation policy, which we defined earlier, consists in creating optimum conditions for the successful marketing of new products, services and processes. Because the innovation process is entirely up to firms, governments can only act as facilitators, but their initiatives can exert a lot of leverage, for what, when all is said and done, amounts to little money. The measures we have outlined all account for rarely more than 1/1 000 of GNP (in France, some FF 4 billion). In contrast, expenditure by firms on innovation is high – approximately 2 per cent of GNP on the development component of industrial R&D and on other innovation expenditure listed in the Oslo Manual (OECD, 1992*b*).

Midway between the two policies just mentioned, a third has sprung up – *Technology programmes policy*. An innovation project has little chance of success if it cannot be developed in as short a time as possible. This will only be possible if the principles of the technological know-how are already established. Of course, adapting existing knowledge and incorporating it into the new product still requires an effort, sometimes a great deal of effort, but the essential thing is that the basics must be available and accessible. Inevitably, therefore, research will have been conducted at an earlier stage, if possible with the active participation of future innovators.

- The above analysis is the basis for defining technology programmes as programmes "which encourage non homogeneous actors (scientific research laboratories, technical research laboratories, industry), often competing actors (two firms or two laboratories), to work together in specific geopolitical areas (at regional, national, or European level) to identify the strategic skills of the future, and to promote initiatives which will enable the acquisition and development of those skills" (Callon *et al.*, 1995*b*). Moreover, "the main strength of this approach is that it makes it possible simultaneously to determine the type of knowledge that will be needed and the nature of future products, services and processes".
- It also determines the contents of the programmes: most of the work in this context falls into what is often referred to as basic technology research (Callon *et al.*, 1995*a*).
- Lastly, it points to one practical outcome of technology programmes, *i.e.* the creation of the techno-economic networks which make the indispensable interaction between researchers and innovators possible and immediately effective.

Among these programmes, some are geared to the development of high-tech products (satellites, rocket-launchers, nuclear plants, weapons, etc.). Often the state is the customer and sets performance targets: BETA has studied the direct and indirect implications of this scenario (Cohendet, 1995).

It is not hard to see why technology programmes have become an indispensable bridge between research policy and innovation policy.

VIII. SUMMARY AND CONCLUSION

One must never confuse research policy and innovation policy. Their objectives, actors and instruments are quite different. So, what is innovation policy, then? We should preface our answer by saying that widely differing regional and national contexts make for innovation initiatives that can sometimes appear to be very dissimilar. We are a far cry from the straightforward uniformity of research policies which set the same priorities and apply the same recipes all over the world.

What can governments do to help? They certainly cannot take the place of firms, since only they are capable of carrying out innovation. What they can do, is to create a climate conducive to innovation, encourage firms and ensure that the necessary resources are delivered at the right time and to the right standards.

Some aspects of innovation policy are aimed at all firms, whether large or small, and are concerned essentially with training competent people in areas where they will one day become necessary. This can be done by various means – forecasting, pre-competitive research contracts, other aspects of technological programmes, government contracts for advanced products, etc.

However, the bulk of innovation policy is directed at SMEs; after 15 years of experimenting and careful consideration, we now have well-proven policy tools with which to strike a balance between stimulating demand and organising supply, and between direct support for firms and assistance through intermediaries.

In the two examples we have given here, technology transfer and private-sector finance for innovation, four main problems arise:

- SMEs, whatever the type, are usually not very good at getting the most out of their environment and are not always inclined to do so.
- The resources they need for innovation are, in the last analysis, too scarce, since the vast amounts of capital, scientific knowledge and information which are available, in theory, are directed at targets which are perceived to be less of a risk.
- Innovation-related consultancy services whose job it is to channel resources in the direction of SMEs do not always have the necessary professional skills.
- There is a big shortage of interfaces and interactive mechanisms.

This paper outlines the ways in which these problems have been solved. Many countries have developed one aspect as opposed to another. Very few of them, however, have a global view of the policy to be implemented. But the will is there, and even the means, since the amounts that are required are relatively modest, especially compared with the funding that research policies require.

The following aspects of innovation policy should be stressed:

- Innovation policy forges the initiatives taken in numerous areas by very different and sometimes competing actors into a coherent whole.
- It must be developed on a regional basis.
- It is a multifacetted, global and systemic policy which is not always properly understood. It only needs to be made more transparent.
- Regular evaluation should permit its schemes to be periodically modified.

At the beginning of this paper, it was stated that research and innovation policies are complementary but distinct. The objectives, actors and tools do in fact appear to be different. There remains technology, which is, in principle, as much the province of research as of innovation. In practice, this brings us to a third type of policy, the "technology programme" policy outlined above, which uses very specific tools.

Experience has shown that to develop these three policies successfully each must be implemented in its own right and not as an adjunct to the others. This is how the EU Commission came to develop a major technology programme policy to which it has devoted a great deal of effort and resources, since it was allowed to set up and run laboratories only in exceptional circumstances. It is also how regional authorities which had no brief either to implement research policy or to launch major programmes instead successfully concentrated on innovation policies. The time now appears ripe to develop innovation policies simultaneously at regional, national and European level, there being less risk that they will be crowded out by research and technology programme policies.

NOTES

1. The concept of innovation has gradually evolved into a concept quite distinct from that of research. It was first introduced in 1967(Charpie, 1967) and defined in 1971(OECD, 1971) in the context of the linear model as "the first application of science and technology in a new way, with commercial success". Later (Aubert and Dubarle, 1978; Freeman, 1987; OECD, 1992*a*), innovation was characterised as a highly interactive process stretching right from the beginning of the design stage through to successful market launch, with the initial idea now generally coming from market analysis rather than from research. More precise definitions – of innovation in general, technical innovation, product innovation (radical or incremental) and process innovation – are given in the Oslo Manual, published by the OECD (OECD, 1992*b*). These enable us to differentiate between "innovation" and "technological breakthroughs" (which are more to do with basic technology research, although many people, unfortunately, persist in calling this "technological innovation") and between innovation and "technology trajectory" (which relates to a range of new products or processes developed from a basic technology which is constantly being refined).
2. This knowledge – whether codified or tacit, proprietary or in the public domain – is much more wide-ranging than the scientific or technological advances issuing from research (Lundvall and Johnson, 1994). Managerial, financial, commercial and legal knowledge are equally important in innovation policy: the excellent team of financial analysts put together for NASDAQ (Fassin and Lewis, 1992) who have built up a close knowledge of international high-tech markets, or the expertise of Japanese patent bodies, say, are as crucial for successful innovation as high-level research.
3. The system of actors described above is taken from the CSI's technico-economic network model (Callon *et al.,* 1995, p.415). A "polarised" mini-network is formed around the SME for the duration of the project. This network is part of a much larger one, membership of which ranges from the laboratories (sources of knowledge) to the consumer (the market) and of which the key elements are the SME network and the network of "interfaces". The CSI model supplies a methodology for implementing government policies based on technological policies (Callon *et al.,*1994, p. 430); but it can also be used by bodies responsible for implementing innovation policies, who will be able to detect the deficiencies in the network (which can be technological or financial, or result from lack of expertise), act selectively to remedy the deficiencies and measure the progress made, and end the programme as soon as the network begins to function

on its own. This method, which is both supple and workable could, for instance, serve to guide the bodies responsible for a regional innovation system.

4. It should be recalled that the technico-economic networks method allows the priorities of such action to be determined.

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AN INNOVATION SURVEY IN SERVICES: THE EXPERIENCE WITH THE CIS QUESTIONNAIRE IN THE NETHERLANDS

CONTENTS

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I. INTRODUCTION

In 1993-94 we carried out a survey of innovation in all sectors of services, using (a version of) the Community Innovation Survey questionnaire (Brouwer and Kleinknecht, 1994). In a brief summary of our experience, we deal with three points. First, we mention some (minor) modifications of the contents of the service sector questionnaire; second, we give a comparison of item non response between manufacturing and services; and third, we compare some key outcomes for services as compared to manufacturing. We argue that the problems encountered in a survey of the service sector are quite similar to the problems which arise in a survey of "supplier-dominated sectors" (Pavitt, 1984) in manufacturing – and these problems can be solved, or, at least, we can live with them. Moreover, we argue that innovation patterns in "supplier-dominated sectors" appear to be quite similar to those in large parts of the service sector. In the Netherlands, the service sector innovation survey has provided rich information both for policy advice and for economic analysis, and we recommend that a similar exercise be undertaken in other countries.

II. MODIFICATIONS TO THE QUESTIONNAIRE AND ITEM NON-RESPONSE

Given the importance of the service sector in the Netherlands, the Dutch government financed in 1988 a large-scale innovation survey of all sectors of the Dutch manufacturing and service industry which was very satisfactory. When applying the Community Innovation Survey (CIS) in 1992, it was evident that the service sector should be covered again. In doing so, the research team took advantage of the experience gained from the 1988 survey. Nonetheless, we will concentrate in this paper on the experience from the 1992 CIS survey.

When drafting a questionnaire for services, some critical choices have to be made. In order to ensure a maximum of comparability, we wanted the service sector questionnaire to be, in as many points as possible, identical to the harmonised CIS questionnaire for the manufacturing sector. On the other hand, it was obvious that the harmonised CIS questionnaire was fine-tuned to manufacturing, and some (minor) modifications appeared desirable.

One modification related to the question about innovation activities during the last three years (1990-92). The manufacturing questionnaire asked whether the firm was involved in the "development or introduction of technologically new or improved products or services". In our service sector questionnaire, we omitted the word "technological" from this definition since service innovations do not always need to be "technological" innovations, at least not in the narrow sense of the word. In order to avoid an inflation of the notion of "new or improved" services, we emphasized in a separate definition that "an innovation is characterised by a clear element of originality and investment in new knowledge by your firm". At the same time, we noted that an innovation can consist of:

- "the use of a *new or improved technology* (developed by yourself or by others); or
- an *original application* of an existing technology."

We also gave some examples of innovations:

"Examples of process innovations are the automatisation of your stocks handling, systems for electronic data exchange, CAD/CAM systems, tracking and tracing systems, or voice response systems. Examples of service innovations are tele-information systems, teleshopping, 06-clients phone numbers or clients cards."

Moreover, a brief note was made about what is *not* to be understood as an innovation:

"Please do *not* count as innovations mere routine variations of products, services or processes such as the routine acquisition of new machinery, of software or a change of design, decoration or colour or a change of your organisational structure."

Finally, in order to secure a reasonable response rate, we decided to omit several of the less significant questions of the harmonised "core" questionnaire. Omitted questions relate to:

- sales of technological knowledge;
- the importance of patents and other protection mechanisms;
- the importance of certain sources of information for the innovation process;
- motives and objectives behind the innovation process;
- bottlenecks of the innovation process.

This resulted in a questionnaire of about 10 pages in length, whereas the full manufacturing questionnaire covered about 15 pages. It seems that the shortening of the questionnaire has indeed helped to ensure a reasonable response rate in services. In general, we observe that service firms have higher rates of item non-response than manufacturing firms (see Table 1) which might indicate that they have more difficulties filling in the questionnaire. This would lead one to

Table 1. **Some examples of item non-response in the Dutch CIS**

Manufacturing compared to services

Per cent

Item non-response by variable	Manufacturing	Services
Total sales in 1992	9.5	13.4
Export sales in 1992	9.3	13.1
Size of R&D effort (man years and/or budget)	4.6	10.2
Share of R&D related to products or services (other than processes)	2.0	5.5
Sales by phase of the life cycle	21.0	33.5
What is the average length of the life cycle of the firm's most important products?	30.7	51.2
What is the share in 1992 sales of products or services which remained unchanged, were incrementally improved or introduced totally new during 1990-92?		
– products or services new to the firm	6.7	15.3
– among the products "new to the firm", were there also products "new to the industry"?		
– yes/no	4.8	9.6
– if yes, what was their share in total sales?	6.2	7.7
Did your firm during 1992 apply for national, European, US or other patents?		
– yes/no	1.2	2.6
– if yes, how many?	4.7	9.3
Total innovation expenditures in 1992	33.9	50.6
Composition of innovation expenditures	33.5	51.9
Percentage of innovation expenditures due to contracting out of innovation activities	61.3	65.5
Investments in fixed assets related to product or service innovation	48.6	65.2

expect that – *ceteris paribus* – the overall response rate in services should be lower than in manufacturing. The opposite was the case: the response rate in services (54.4 per cent) was even higher than in manufacturing (50.8 per cent). We ascribe this mainly to the shorter questionnaire.

Generally, in terms of economic statistics, the service sector is much less perfectly covered than manufacturing. Not only innovation but many other standard economic indicators (such as value added, productivity, etc.) are poorly (if at all) measured in services. It is therefore not surprising that item non-response is generally higher in services than in manufacturing. Table 1 covers some examples.

III. SOME KEY FINDINGS: MANUFACTURING COMPARED TO SERVICES

When thinking about the difficulties of measuring innovation and innovation-related activities in services, some basic findings behind the "taxonomy" of sectors developed by Pavitt (1984) may be useful. While not dealing with services, Pavitt sub-divided manufacturing into four types of sectors:

- science-based sectors (*e.g.* pharmaceuticals, electronics);
- scale-intensive sectors (*e.g.* the automobile industry);
- specialised suppliers (*e.g.* components, instruments); and
- supplier-dominated sectors.

While the first three types of sectors are quite R&D-intensive, firms in the supplier-dominated sectors tend to have only a weak R&D potential (often performing only occasional R&D) and they mainly rely on the adoption and implementation of technology developed elsewhere in the economy.

It is our impression that large parts of the service sector can be described in analogy to the supplier-dominated sectors in manufacturing. Supplier-dominated sectors include typical traditional industries such as wood and furniture, paper making, food and beverages, textiles, clothing and shoes, printing and publishing, basic metals and metal goods, or construction materials. In these supplier-dominated sectors, investments in new machinery and equipment, acquisition of software and computers, and manpower training may often be more meaningful indicators of technological innovation than the firm's own R&D efforts. Nevertheless, we do observe some R&D in these sectors.

It seems that this holds for many parts of the service industry as well. Indeed, the separation between supplier-dominated sectors in the manufacturing and service sectors appears to be somewhat artificial. What is the basic difference between a printing firm (a manufacturer), producing large numbers of a journal, and a bank, processing millions of bank transfers (a service firm)?

Both have in common that they concentrate on process rather than on product development, and the critical success factor may be the mastering by qualified people of machinery, equipment and software often developed by specialised suppliers outside their branch.

Tables 2 and 3 summarise outcomes of some key variables for manufacturing and service sectors. The first four groups of sectors within manufacturing can be characterised as supplier-dominated sectors. Their innovation performance is often weaker than those of the other three groups of high technological opportunity sectors (*i.e.* "science-based" sectors, "scale intensive" sectors and "specialised suppliers"). At least some of the figures of Tables 2 and 3 suggest that the supplier-dominated sectors show some similarity to services. This similarity can be seen not only from R&D intensities, but also in the composition of R&D. For

Table 2. **Percentage of firms in a sector which have certain innovation activities**[1]

Sector	Some R&D (intramural or contracted out) in 1992	Product innovation activities during 1990-92	R&D collaboration in 1992	Firm has an R&D department	Firm contracted out R&D in 1992
Food and beverages	32.5	40.0	45	22.8	13.3
Textiles and leather	17.7	28.5	25	8.9	7.6
Wood and construction mat.	17.9	33.4	35	10.6	6.6
Paper, printing and publishg.	9.1	27.9	60	4.3	2.6
Chemical, plastics	40.7	61.5	54	30.9	17.1
Metals, electronics, mechanical engineering, etc.	27.6	40.6	39	16.2	10.8
Other industries	43.7	49.8	55	33.4	12.5
Total of manufacturing	**25.1**	**39.0**	**43**	**15.8**	**9.7**
Public utility (gas, water, electricity supplies)	37.8	37.6	97	21.6	23.9
Construction and install.	5.9	14.0	45	2.7	1.8
Trade	6.7	22.2	45	3.7	2.3
Hotels, restaurants, repair	2.5	18.8	n.a.[2]	1.1	1.3
Transport and communication	3.2	16.7	66	0.6	1.1
Banks and insurance	5.2	31.7	51	1.6	1.7
Other commercial services	17.5	33.3	53	9.0	5.2
Other non-commercial services[3]	14.4	29.9	52	7.6	6.2
Total of services	**8.1**	**22.3**	**50**	**4.1**	**2.7**

1. All figures are raised to national totals.
2. Not documented because of a too limited number of observations.
3. Figures for non-commercial services are sometimes high since they include R&D laboratories.

example, the share in total R&D of informal R&D (*i.e.* R&D performed in departments other than an R&D department) is relatively high in services and in the supplier-dominated sectors in manufacturing; also the share in total R&D of R&D contracted out tends to be much higher in services and in the supplier-dominated sectors than in the high-technological opportunity sectors. Such findings indicate that R&D in the former two types of sectors tends to be a side activity rather than a core activity. It is therefore useful to have, in addition to R&D as a traditional input measure of the innovation process, indicators of the output side of the innovation process which may capture other (non-R&D) elements of the innovation process. Given the fact that the output indicators of the CIS survey (share in sales of innovative products) work quite well in the service sector, we can say that we have now a much far suitable measure compared to traditional R&D figures.

Table 3. **Innovation performance in manufacturing and service industries in the Netherlands in 1992 (various indicators)**[1]

Per cent

Sector	Average R&D intensity of all firms[2]	Share of informal R&D[3] in total R&D	Share of R&D contracted out in total R&D	Share in sales of products new to the firm	Share in sales of products new to sector
Food and beverages	1.07	32.3	11.3	37.5	5.8
Textiles and leather	0.50	42.4	10.2	49.0	8.4
Wood and construction mat.	0.54	28.8	19.1	34.0	13.1
Paper, printing and publishg.	0.67	28.8	19.1	34.1	12.8
Chemical, plastics	7.40	7.3	5.7	37.0	6.8
Metals, electronics, mechanical engineering, etc.	4.93	6.0	4.0	42.0	20.5
Other industries	3.93	12.8	12.4	46.6	10.3
Total of manufacturing	**3.33**	**9.2**	**5.7**	**39.8**	**14.7**
Public utility (gas, water, electricity supplies)	0.92	9.5	36.8	20.6	4.5
Construction and installation	0.16	41.5	5.5	52.8	4.9
Trade	0.56	20.2	13.1	37.3	11.5
Hotels, restaurants, repair	0.02	28.5	39.4	44.2	7.7
Transport and communication	0.51	51.3	10.7	37.2	6.3
Banks and insurance	0.24	37.6	18.2	45.8	11.2
Other commercial services	1.22	51.3	24.9	37.7	16.4
Other non-commercial services[4]	3.28	6.5	7.0	46.9	17.5
Total of services	**0.67**	**36.2**	**18.3**	**40.5**	**12.5**

1. All figures are raised to national totals.
2. Man years of R&D (intramural and contracted out) as a percentage of the total personnel of all firms (including non-R&D performers) in a sector.
3. R&D performed by departments other than an R&D department.
4. Figures for non-commercial services are sometimes high since this sector includes R&D laboratories.

IV. CONCLUSION

In conclusion, if it is possible to develop a meaningful questionnaire for "supplier-dominated sectors" in manufacturing, it should also be possible to cover, with similar indicators, the service sector. In the Netherlands we have done so, and, in general, the results are encouraging. While Table 1 shows that services generally have higher rates of item non-response, the deviations are not excessive. Questions which failed in manufacturing, failed even more strongly in services and, for questions which worked quite well in manufacturing we observe no excessive item non-response in services. In general, we feel that we obtained a rich set of data from our service sector survey of innovation.

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THE PUBLIC SECTOR AND INFORMATION TECHNOLOGY STANDARDS

CONTENTS

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I. INTRODUCTION

The contemporary emphasis upon the "globalisation" of the commercial and industrial base is raising the level of awareness of standardisation issues in national governments. The increasing complementarity and interconnectedness of world-wide financial, trading and industrial structures highlight the increasing importance to national economies of developing specific standards policies. In strategic terms, however, this awareness differs in intensity, and responses to it take many forms.

For governments, approaching the subject of standards is like approaching a serpent – it invites a judicious mixture of determination and caution. Determination is required because technical standards are an especially critical element in any national strategy for information technology (IT) development and implementation. Caution is required because, in policy contexts, standardisation still ranks among the least understood industrial phenomena.

A growing body of studies is drawing attention to the role of technical standards in mediating market relationships, facilitating international trade, and aiding in the development of technical infrastructures. Standards have been examined in terms of their functions in the reduction of redundant duplication in production and distribution systems, their relationship to R&D, and their role in the transfer of information about product characteristics between suppliers and purchasers.[1] It is clear that standardisation is a very important production and marketing tool with many potential economic and social benefits. At the same time, however, the use of idiosyncratic standards and certification requirements as protective devices in national markets remains prevalent. So too does the use of proprietary standards to "capture" a customer base – to "lock in" users to the products of specific suppliers.

The spectacular increase in the development and use of computer and telecommunication technologies (collectively referred to in this paper as "IT") has focused special attention on standards. The successful deployment of communication networks is dependent upon reasonable levels of technical interconnectivity and interoperability, although the administrative regimes surrounding these networks are often harmonised to a much lesser extent. As there is now often a choice between proprietary and non-proprietary ("open") standards, the questions concern how the required levels of compatibility are best achieved.

Concomitant with the growth in non-proprietary IT standards has been an increase in the scale and scope of involvement by national governments. As the potential range of IT applications is vast, the policy issues raised intersect a panoply of concerns – industrial efficiency, production quality, technical education requirements, national sovereignty implications, and so forth. It is not surprising, therefore, that in discussions about national standardisation strategies, IT is usually the sector with the highest profile.

Incorporating standards issues into the formulation of national IT strategies, however, is a highly complex undertaking. This paper assesses briefly the institutional structure for the development of IT standards, explores some of the rationales for public sector involvement, illustrates some of the pitfalls, and suggests some guidelines for developing an appropriate role for public sector bodies in the standardisation process.

II. THE INSTITUTIONAL STRUCTURE OF IT STANDARDISATION

The simplest way for a standard to become established is through *common convention*. Convention usually applies in cases where the existence of a standard matters more than its content – as in defining "left" and "right". On the other hand, legislative, regulatory, and professional institutions may set technical standards by *fiat*. Another way is through *common use*. In this case, the ubiquitous deployment of particular objects, systems, or processes establishes them as "standard". Standards may be established also by formal *negotiation*.

The frequent assumption is that non-negotiated, or *de facto*, standards are established by user and/or producer choice from among alternatives in the market. However, the initial range of available choices may have been limited sharply by any number of factors, ranging from the state of development of the technology to the prevailing conditions of its production and distribution.[2] Indeed, the whole question of "path dependency" – the tendency for choices to be influenced by historical events – is highly germane to the discussion of how standards of all types are established and deployed.[3]

Governments may become involved in all of the above standardisation mechanisms. They can codify pre-existing conventions. They can also set standards directly and enforce them by law. Most importantly in the context of this paper, governments can influence standardisation through several forms of intervention in standardisation processes, and they can use standards as policy instruments in their own right. Before these forms of intervention can be illustrated, however, it is important to understand what lies behind a number of significant recent changes in the institutional standardisation structure, and to examine these changes with respect to the role of governments.

Voluntary standards

The 20th century has seen the rise of national, regional, and international standards development organisations (SDO) formed for the specific purpose of mediating between the interests of the various parties likely to be affected by the establishment of standards. The basic characteristics of most SDOs are that: *i)* they operate in hierarchical committee structures in which decisions are made by consensus; *ii)* subject to certain guidelines for "balanced" representation, the committees are made up of volunteers; *iii)* promulgation of the standards is subject to a formal process of public enquiry; and *iv)* the promulgated standards are nominally implemented by industry on a "voluntary" basis.

The rubric "*voluntary-consensus*" is often applied to this process and to the standards it produces. "Consensus" however, should never be confused with "unanimity". In SDOs, the definition of consensus is normally the lack of sustained opposition. Where votes are taken, the requirement is normally for a majority substantially greater than 50 per cent-plus-one. Voting procedures in the International Organisation for Standardisation (ISO), for example, require a positive response of 71 per cent before a standard can be adopted.

More recently, the voluntary/consensus system has come under increasing attack from both public and private sector interests. The "volunteer" aspect has led many to question the efficiency of the methodology. Others have misgivings about the "consensus" element in that the power of a participating body to influence decisions under a consensus system is not always commensurate with the resources it has invested in preparing the standard. The system is often accused of being unrepresentative, and incapable of matching its production of standards to the rapid pace of technical change which has become characteristic of developed contemporary economies.

Governments and standards institutions

The voluntary-consensus system is the prime institutional focus of most private sector standardisation activity. The starting place for most public policies and strategies involving standards is an assessment of the relationship between government and the national SDOs, followed by an assessment of the position of national standardisation programmes as they relate to international activities.

A national SDO can have a variety of relationships with government, and only a small minority of national SDOs have no formal relationship with the public sector.[4] Most SDOs have their operating budgets subsidised by their national governments to some degree. Many are private organisations operating under legislative or contractual agreements with governments. However, under the voluntary consensus system, even if some of the operational expenses of an SDO are met by government, the most substantial costs – those incurred by participation in the working committees – are borne by the committee members and/or their sponsors.[5]

In the OECD countries, it is rare for the public sector to subsidise directly the costs of private sector participation in standards committees.[6] However, it is now a widespread practice for national governments to sponsor the participation of civil servants and/or independent consultants in national and international standards committees. It is also possible for governments to initiate and support standardisation programmes in national and international SDOs. State-owned corporations may also interact with the process in this way.

Traditionally, governments have been involved in standards in four ways. As already discussed, the first two are:

- direct establishment of technical regulations in laws and/or regulations;
- direct funding of voluntary consensus standards initiatives through operational subsidies and sponsorship of projects and committee delegates.

However, governments frequently become involved in two additional ways:

- referencing of industry developed standards in legislation and regulation;
- referencing of industry developed standards in public procurement specifications.

In laws and regulations, reference can be made to standards developed by private industrial and professional groups. The national electrical-wiring codes of many countries are ubiquitous examples of this practice.[7] At other times, however, government bodies specifically request or even commission technical specifications from industry standards-making bodies.

As governments are very high-volume purchasers of a vast range of goods and services, public procurement considerations are often of special importance in determining the implementation success of a voluntary standard. In procurement specifications, governments can refer to voluntary standards as promulgated by the national SDOs. However, once these standards are deployed on a significant scale, and supported by legislation and government bureaucracies, they can become *virtually mandatory*. This can have the effect of freezing a technology at the state of development referenced in the standard. A way to circumvent this problem is to link the legislative or regulatory reference to whatever the current version of the standard in question happens to be.[8] This practice allows the SDO to revise the standard as required. However, it also assumes that the SDO has the resources or inclination to do so.

"Upstream" and "downstream" standardisation for IT

In most industrial sectors, standardisation has been viewed primarily as a *reactive* process – as a consolidation of the experience gained from the implementation of a technology. In the early 1970s, Verman proposed a linear paradigm for the evolution of standards in which, typically, the impetus to standardise begins within individual firms, and moves eventually into the orbit of a national SDO.[9] In selected instances, national standards then might become accepted outright as international standards, or otherwise harmonised with other national standards by an international standardisation body. Although this model is highly mechanistic, and although it relates more to the administration of standards development than to its execution, it remains widely reflected in the procedures, structures, and policy statements of national and international SDOs.

In actual practice, however, it is not always the case that standards result from an *ex post* consolidation exercise. In the telecommunication industry, for example, it has long been recognised that standards and the development of the technology and service environments go hand-in-hand.[10] Standardisation programmes for computer systems now follow largely the same philosophy.[11] The process of standardisation should be perceived relative to two closely interrelated aspects, each with the potential for "upstream" and "downstream" action.

- *Relative to the technology.* "Upstream" refers to a standardisation programme undertaken during or before the actual development and implementation of the technology. "Downstream" refers to a consolidation process based upon implementation experience.
- Relative to the standards development institutions. "Upstream" refers to the international levels and "downstream" refers to the national and firm levels.

These "upstream" and "downstream" elements can be seen very clearly in the development of "open" technical standards for computer networks. This activity began some 30 years ago, largely in response to both public and private sector fears that a small number of dominant US computer vendors would impose proprietary interconnection standards upon the growing market for distributed information processing systems. These fears were by no means confined to non-US interests. The prospect that computer networking would be dominated by one or two very large companies was seen as inimical to many US interests as well.

International standardisation activity for computer networking was begun in Technical Committee 97 (office technologies) of the International Organisation for

Standardisation (ISO) and in committees of the International Electrotechnical Commission (IEC). The initiative came to revolve around the Open Systems Interconnection Reference Model (OSI), a general framework for the development of standards for the vendor independent interconnection of IT equipment. In 1987, ISO and IEC established a Joint Technical Committee (JTC1) to co-ordinate OSI development.

The telecommunication aspects of computer communications, however, are still largely the purview of the International Telecommunication Union (ITU). Although there are direct links and cross-references between OSI and ITU standards frameworks for digital telephony, links between the ITU and JTC1 have remained informal, reflecting the structural separations that persist between the telecommunication and computer industries.[12]

Historically, the dominant direction of flow for technical input into international standards projects had been from national SDOs to international SDOs. OSI involved ISO/IEC in a major forward planning exercise and required that it establish a proactive "upstream" approach with respect to the technology. Institutionally, however, this "upstream" emphasis is far more complex. Although OSI established the principle that IT standards should be initiated at the international level and that national standardisation programmes should be essentially "downstream" efforts to implement international standards according to national conditions, much of the technical input into OSI comes from multinational IT vendor firms via nationally-based standards bodies. The common model in countries with high IT capabilities is for the national SDO to maintain a committee structure, which, to a large extent, "mirrors" that of JTC1. In this way, it is possible to monitor the JTC1 committees closely, co-ordinate inputs, and provide a forum for decisions about "upstream" contributions and "downstream" implementations.

OSI and the current IT standardisation structure

The production of OSI standards has increased steadily over 30 years. If measured by the extent of their implementation, however, the net influence of these standards is questionable. Only a tiny handful of them have found any degree of acceptance in the market. Furthermore, many OSI standards cannot be implemented, either because they refer to obsolescent technologies, or because they are too "theoretical" for practical application.

On the other hand, a convincing case can be made that the OSI initiative provided significant, timely, and perhaps decisive support for the *concept* of the "open system" which has since achieved considerable currency in commercial and policy circles. Significantly, government agencies in many countries, particularly in Europe, elected early on to support the "open systems" initiative in principle, and to link it to their strategic plans for IT procurement and application. The "*open network concept*" is now commonly related to telecommunication applications, software, operating systems, electronic data interchange (EDI), and many other areas.

Most subsequent IT standardisation programmes can be said to relate to OSI in one way or another. There is an identifiable OSI "camp" centred in ISO, national SDOs, governmental and inter-governmental agencies, industry consortia, and OSI application consultancies. Other programmes have sprung up in reaction to OSI – either out of concern that OSI is not developing to meet the real needs of industry and the market, or out of interest (often proprietary) in establishing alternative approaches to interconnection and interoperability.

As a result, the IT standards environment is now much larger than JTC1 and involves a fluid and often bewildering array of industry standards *consortia*. Informed estimates have been made that the rate of growth for these consortia in the late 1980s was about six per year![13] Consortia fall into two basic categories:

- *OSI support consortia*. Some of these organisations engage directly in standards development and contribute to JTC1. The European Computer Manufacturers Association (ECMA) was founded before ISO TC 97 and remains a principal contributor to JTC1, and also produces standards in its own right.[14] Other organisations – like the Corporation for Open Systems (COS) in the US, and the Promoting Conference for OSI (POSI) in Japan – engage in defining functional profiles, tests, and certification procedures, as well as engaging in OSI promotional activity.[15]
- *Rival and supplementary consortia*. Consortia have formed around various alternative approaches to "open systems". MAP/TOP and TCP/IP consortia are prominent examples.[16] However, it is now also common for *ad hoc* industry groups to form around special standardisation problems, often related to leading edge technologies. There are also consortia concerned primarily with operating systems – X-OPEN, and the Open Software Foundation (OSF) are among the most prominent.

Much current activity in ISO and in the consortia relates to the problem of functionality. Simple conformance to interconnection standards does not ensure that equipment will actually interoperate to perform a task. For a number of years, ISO has been working on International Standard Profiles (ISP) which are essentially sets of selected open system standards aimed at specific information processing functionalities.

The regionalisation phenomenon

A complication in the institutional structure of IT standardisation is the rise of regional blocs. To date, regional relationships have been formalised primarily in the telecommunication area.[17] However, there are also distinct, regional "open systems" communities in the computer sector. Regionalisation became a general standardisation concern largely in reaction to the European Union (EU) initiatives to establish a "single European market", and the consequent incorporation of the European regional standardisation system into that policy structure.

Although many governments have officially embraced the concepts of "open systems" and "open networks" in domestic policy, only the EU has formalised this commitment in a distinct political context. However, owing to their high design and production capabilities in IT, the United States and Japan have become the centres of "virtual" standards regions.[18] Following the recent ratification of the North American Free Trade Agreement (NAFTA), some of the standardisation relationships between the United States, Canada, and Mexico may become more formal. There is also an emerging Asian presence in IT standardisation through bodies like POSI, the Asia-Oceania Workshop (AOW), and the Asian Forum for Standardisation of IT (ASFIT).

Inter-organisational and inter-sectoral links

Effective participation in IT standardisation now requires the monitoring of many organisations, situated in several countries, and affiliated with at least three regional "centres of gravity". Through their international subsidiaries, it is now common for major multinational IT firms to be members or observers of all of the principal standards organisations. Moreover, reflecting the increasingly shared technology base in computing and telecommunication, it is now common also for computer firms to participate in telecommunication standards committees, and for operators of telecommunication networks and their equipment suppliers to become members of computer industry standards bodies.

There are as yet few general operational or planning connections between these organisations other than the overlap in personnel which may occur in their respective committees. In some specific areas, inter-organisational co-operation is becoming more formal. Electronic Data Interchange (EDI) standards, for example, are now co-ordinated through an Inter-Agency Working Group involving ISO, IEC, the International Telecommunication Union, and the UN Economic Commission for Europe. Nevertheless, this Working Group has no powers to take decisions on its own – its recommendations must be ratified independently by each participating organisation.[19]

Professionalisation

The proliferation of standards and standards organisations, along with the increasing profile of standards as business and public policy tools has led to the creation of a community of *professional standardisers*. Most leading IT firms now maintain standards departments, and their standardisation activities are becoming increasingly co-ordinated with R&D and marketing objectives, and targeted strategically at selected standards organisations. Likewise, standards divisions are becoming common in government departments.

However, there are potential problems with the professionalisation of standardisation. *Standardisers* can spend significant amounts of time in standards committee meetings and can develop affinities with particular committees in individual SDOs. Individually, they can become respected figures in these SDOs and can even initiate projects on their own. Where the standardiser's remit is closely integrated within the structure of his or her organisation, this influence can be used as a strategic tool. Where integration is poor, the standardiser can become a virtually autonomous entity, but one who nevertheless speaks in the name of a participating organisation.

III. STANDARDS POLICY

Public sector intervention in standardisation can be seen to be warranted in a number of circumstances. The most common relate to various forms of "market failure". Where it is perceived that the market fails to provide sufficient information about products to enable purchasers to make rational decisions, standardisation is often proposed by public and/or private sector bodies as one method of compensating for this failure. Specific interventions by the public sector can be deemed appropriate in cases where industry fails to set standards, or where the market seems likely to standardise on sub-optimal or inappropriate technologies. All of these situations, however, are prone to subjective and often inadequate assessments of technological and market conditions.[20]

Public sector intervention can be directed also at promoting efficiency and fairness in the standardisation process. In most cases, this kind of action involves "adjustments" either in terms of applying pressure for structural and methodological changes, or in terms of supplying incentives in the form of financial and political support for selected standards projects that are deemed to be in the public interest. In other cases, it can involve facilitating the participation of under-represented groups. Users of technology, for example, are chronically under-represented in SDO committees, and a number of schemes to increase their involvement are supported or advocated by public sector bodies in several countries. In extreme cases, public sector intervention extends to the establishment of new standards institutions, or the restructuring of relationships between existing ones. The most prominent example of this is the ongoing reorganisation of the European standards system (see below).

A theoretical case can be made for the importance of standards to the growth of the generic technology base, and it is in this respect that the case for public sector intervention can be seen to have some of the strongest antecedents.[21] At one level, IT is generally considered to be "generic" in that it is an "enabling" technology which could add to the general efficiency of national economies if applied widely to all industrial sectors. As such, much of the standards policy for the IT industries is focused upon implementation strategies which support the diffusion of IT products and services. Standards are sought that will reduce ties with particular suppliers, and lower technology adoption and conversion costs.

In the case of developing and newly industrialising countries, standardisation can become part of national policies respecting the acquisition of technical information and technology transfer. Indeed, ISO actively promotes this function as a primary rationale for the participation of less developed countries in ISO.[22] In developed economies, reflecting the "upstream" nature of standards in many high-technology areas like IT, some policy-makers have drawn a link between standards and "pre-competitive" R&D – *i.e.* R&D aimed not at specific commercial products, but at technologies that are considered "generic" to product development. In the European case, for example, standardisation objectives are explicitly linked to EU-backed collaborative, pre-competitive research programmes like ESPRIT and RACE.[23]

It is probably in these areas of industrial policy, however, that the use of standards as policy instruments is most contentious, and its results the least predictable. SDOs take the general position that the use of voluntary/consensus standards is an aid to industrial efficiency. Policy-makers may accept this generality and opt simply to promote voluntary standards activities throughout industry. On the other hand, they may decide to support particular standards or to target certain industries for the application of standards. Sectors producing goods for export, for example, could be pressured to implement internationally recognised quality control standards. Such decisions can be supported by domestic regulations and procurement policies.

Technical harmonisation is seen by the "competition" and "single market" Directorates General (DG III & DG IV) of the European Commission as an instrument of both industrial policy and trade policy. Common technical standards are regarded as prime facilitators in establishing a European free trade zone. They are seen also, however, as mechanisms for directing the R&D efforts of European companies towards common goals in developing a distinctly "European" technology base.[24] This dual "upstream" and "downstream" stance can (and has) generated contradictory signals to EU trading partners.

Standards are important elements of trade policy, but it is here that they have shown their dual nature most clearly. Idiosyncratic national standards and certification requirements continue to be used to protect domestic markets. In the late

1970s, the General Agreement on Tariffs and Trade (GATT) identified national standards as potential technical barriers to trade, and drafted a "Standards Code" which established the principle of "transparency" in international standardisation. Signatories agreed to inform the international community of additions and revisions to national standards, and, where they existed, to use international standards in preference to national ones.[25] GATT, however, had virtually no power to enforce the Standards Code.

On 1 January 1995, GATT was replaced by the World Trade Organisation (WTO), a body with formal powers to make rulings in international trade disputes. Exactly how the terms of the GATT Standards Code will become transposed into this new structure is not yet certain. What is certain, is that the new WTO powers to make binding judgements on trade disputes will accentuate the importance of international standards agreements as an element of trade strategies at national and regional levels.[26]

A basic taxonomy of intervention

It is clear that there is ample scope for public sector intervention in the standards-making process. The question is always: Why, where, and when should policy be directed explicitly at standards, as opposed to being directed at the situations in which standards are applied? This question may have no unequivocal answer, but there are some taxonomic distinctions that may be helpful on a case-by-case basis.

Potentially, there are two broad areas that can be addressed by standards policies:

- *Production* – Policies related to the use of standards in increasing industrial efficiency and in supporting the development of technological capabilities.
- *Distribution* – Policies related to domestic consumption and international trade.

Within these areas, there are basically two standards policy scenarios that pertain to IT strategies.

- Policy is used to influence or direct the standardisation process in the expectation that standards will improve the efficiency of the production and distribution system in selected areas.
- Standards and the standardisation process are used as explicit instruments of government policy in the expectation that they can set directions for technical development and implementation, create favourable trade conditions, and influence investment patterns.

Dangers for standards policy

In formulating a standards policy of any description, there are some basic dangers to avoid. The *first danger* involves becoming fixated on standards. Standardisation is less likely to be a general panacea for an industrial and/or trade problem, and more likely to be a partial solution to an individual aspect of this problem. Standards may facilitate production and distribution, but a strong policy on standards cannot be expected to compensate for inadequate general policy frameworks for trade and industry.

In some instances, standards are developed by industry even where other mechanisms may achieve the same or better ends. Thus, standards policies must have the flexibility to take alternative mechanisms into account. Some of these may yield the desired result in a much more straightforward and controllable way. Product and service performance parameters, for example, might be most effectively ensured by contractual instruments – warrantees, guarantees, and the like. These can be far more detailed and specific than voluntary industry standards and they can also give the user more secure recourse to legal remedy where the specifications are not met.

The *second danger* is to assume that where industrial sectors share a technology base, there is similarity and complementarity in the standardisation requirements of these sectors. Such common ground cannot be taken for granted. Even though the IT and telecommunication sectors are now closely related technologically, for example, the motives, rationales, and methodologies employed in standards development in these sectors still reflect quite distinct configurations of national and industrial interests.

The *third danger* concerns attempts to reorganise national standards-making methods to reflect policy goals. As with any organisational structure, there is certainly a case to be made for streamlining procedures in standards bodies, and the public sector can justifiably press for these adjustments. However, the consensual nature of the negotiated standard must never be overlooked. A mediation structure must take account of opposition as well as agreement. The point at which consensus has to be coerced or subverted by externally applied pressures is probably the point at which the use of voluntary/consensus standards in pursuit of policy ends must be questioned.

The *fourth danger* is to assume that there is an adequate degree of affinity between the respective goals of industry standards-makers, and those of legislators and regulators. Sponsors of a standard must take into account that there is an inevitable loss of control when the drafting of technical specifications is referred to an SDO. The desirability of this course of action must be assessed on a case-by-case basis, as must the scientific and technical capabilities of the standards bodies in relation to the particular responsibilities they will be given.[27]

The probability must also be taken into account that SDO committee members may act autonomously to some degree – there is no guarantee that the positions put forward in committee meetings are actually congruent with those of the corporate or public interests represented.[28]

Finally, there is a major problem when it comes to the evaluation of standards policy. How can it be determined if the allocation of resources to standards has yielded the desired results? Appropriate and reliable indicators may prove difficult to identify.[29] The costs and benefits of standards development are typically neither visible in the operating budgets of SDOs, nor transparent in the accounts of firms and agencies sponsoring committee delegates. It is equally difficult to evaluate the consequences of the degree of formality present in the public/private sector relationship in standardisation. Comparative studies often fall into the trap of claiming that one system works better than another without first setting out how the performance of a standardisation system is to be measured in the first place.

IV. PUBLIC SECTOR STANDARDISATION STRATEGY FOR IT

The following is a synthesis of some of the principal approaches to establishing public sector standardisation strategies for IT that have been adopted during the past 10-15 years. The examples are not presented as models to be emulated, but as heuristics for illustrating some of the dangers as described above, and for determining some of the requirements for effective standardisation strategies. Much of the focus of this section is on OSI. OSI is a particularly appropriate initiative in this context in that: *i)* it was a standardisation project supported broadly over a long period of time by governments with diverse trade and industrial policy philosophies, *ii)* it has clear "upstream" and "downstream" implications; and *iii)* its significance and future is currently the subject of much controversy.

Engagement or disengagement?

In strategic terms governments can opt officially for engagement or disengagement in standards activities. Japan, for example, opts for direct engagement and full state subsidy of the operational expenses of the Japanese Industrial Standards Committee (JISC).[30] Most development of voluntary standards in Japan occurs under the auspices of JISC, and the organisation has direct ties to the Ministry of International Trade and Industry (MITI).[31]

The US situation, on the other hand, is an example of how difficult it can be to draw a line between engagement and disengagement. Attempts to establish a formal US public sector presence in the co-ordination of national and international standardisation activities have yet to meet with political favour. This is despite repeated calls from government agencies and standards development bodies alike for a more formal government presence.[32] For a number of years, questions have been raised concerning the extent to which the United States might be disadvantaged internationally as a result of government reluctance to assist in co-ordinating a US position on standards.[33]

In practice, there is considerable input from US government agencies into the IT standardisation process, but the various initiatives do not always seem complementary or co-ordinated in policy terms. OSI-related standards initiatives developed by or with the support of the US National Institute for Standards and Technology (NIST), for example, have been subsequently promulgated by the private sector American National Standards Institute (ANSI) as US national standards. NIST also contributes to the development of conformance tests related to IT standards. Moreover, much of the research in the US OSI community has been co-ordinated through OSINET, a government/industry research network maintained by NIST. On the other hand, the US Defence Department was the developer of TCP/IP, which, due to its relatively high rate of implementation, has come to rival OSI as an approach to "open" systems.

With respect to the nature of government involvement, the standards systems of most OECD countries fall somewhere in between the poles exemplified by the Japanese and US systems. There are two basic but by no means unconnected routes which government agencies have followed in seeking to guide and influence the standardisation process for strategic purposes – leading by example, and initiating institutional change. In taking these paths, various degrees of commitment have been shown to the "efficiency gain" and/or the "direction setting" policy scenarios as outlined above.

Leading by example

Governments are by far the largest group of IT purchasers. Estimates are that the annual US government IT procurement budget currently tops US$20 billion, and United Kingdom spending is about US$4 billion.[34] Some government IT implementation and procurement programmes are now buttressed by the adoption of sets of functional standards profiles. These are usually based in principle on the international OSI framework. Such programmes are typically centred in government departments concerned with budgets and finance, although usually they acquire "partners" in ministries concerned with science, technology and industry policy.[35]

In the 1980s, for example, in both the United States and the United Kingdom, government agencies initiated Government OSI Profile (GOSIP) programmes. The US GOSIP was developed through the National Computer Systems Laboratory (NCSL, a division of NIST), and it was promulgated as a Federal Information Processing Standard (FIPS) by the US Department of Commerce in 1988. The US GOSIP programme was a joint effort between NCSL and various consortia of US IT vendors and users.

The UK GOSIP programme was initiated in 1984 by the Central Computer and Telecommunications Agency (CCTA), the section of the Treasury Office concerned with government IT and telecommunication procurement. The first version was promulgated in 1988 and several revisions have followed. UK GOSIP consists of "sets" drawn from international standards and directed at specific user applications. The "Purchaser Set" is aimed at those wishing to implement an open systems environment and is mostly framed in non-technical language. The "Supplier Set" contains the technical specifications required by vendors and manufacturers.

The main objectives of GOSIP are:

- to facilitate public procurement and aid certification of conformance to standards;
- to assure a basic levels of functionality in an interconnected multi-vendor environment;
- to provide guidance to manufacturers in formulating future product development strategies.[36]

Although framed primarily in terms of government procurement requirements, UK GOSIP is also supported by the Department of Trade and Industry (DTI) as part of its general policy objective to promote a more open market for IT goods and services. An IT Standards Unit has been in operation in the DTI since 1982 with the aim of contributing to the development of international open systems standards.

The general impact of these GOSIP programmes is difficult to judge. As yet, little enthusiasm for them has been shown outside government, and there has been very little private sector penetration. In the private sector, GOSIP must vie commercially with proprietary networking solutions, like Novell, and with established user networks based around alternative protocol sets like TCP/IP and MAP/TOP. Furthermore, there are signs that public sector support for OSI (the basic protocols for GOSIP) may now be waning. In the United Kingdom, for example, a wave of pragmatism is sweeping government IT circles. It is being accepted that practical open systems applications are likely to be hybrids that incorporate a mixture of proprietary and non-proprietary technical approaches.[37] In the United States, moreover, the GOSIP programme has been virtually abandoned. NIST is actively looking for alternatives to OSI (TCP/IP being the most prominent) to serve as the foundation standards for open systems implementation in the US government.[38]

UK GOSIP remains particularly significant, however, in that it has evolved into a Europe-wide programme supported by the EU. A 1987 Decision of the Council of Europe requires that EU member States specify conformance to agreed international IT standards for all public procurements in excess of ECU 100 000.[39] In pursuit of practical implementations of this Decision, the European Commission accepted the UK GOSIP profiles as the basis of a European procurement initiative – the European Procurement Handbook for Open Systems (EPHOS).

The eventual goal of EPHOS is to harmonise European public procurement specifications for IT. It will draw primarily upon standardised functional profiles as developed by the European Standardisation Committee (CEN), the European Electrotechnical Committee (CENELEC) and the European Telecommunications Standards Institute (ETSI). It is expected that these profiles will be based wherever possible upon international standards, particularly the International Standardised Profiles as developed by ISO. At present, responsibility for the development of EPHOS is being shared primarily between CCTA, the French government budget office, and the German interior ministry.

Initiating institutional adjustment

In order to employ IT standardisation in a strategic role, public sector agencies often must address the institutional structure of standardisation. Pressures can be exerted for the revision of existing structures and methodologies, and also for the creation of new institutions. The most visible recent examples of this kind of initiative have occurred at the regional level in the European Union. The mobilisation of standards as a strategic instrument of IT policy in the EU required substantial changes in the institutional structure of standards-making and deployment. Five direct steps were taken to reorganise European IT standardisation activities into a regional structure:

i) *Official recognition* – The existing European regional standards bodies – CEN and CENELEC – were given official recognition, and it was specified that although application of their standards was to remain voluntary, EU member States were obliged to use European standards, where they existed, instead of national standards.[40] Similar recognition followed for ETSI.[41]

ii) Re-organisation – The 1987 Green Paper on telecommunication recommended that the national telecommunication monopolies (duopoly in the United Kingdom at that time) relinquish their control over the development of telecommunication standards, and establish a regional body, ETSI, which would operate as a voluntary/consensus SDO with participation open to all interested parties. IT standards development was to be delegated to CEN/CENELEC and telecommunication standards to ETSI.

iii) Streamlining and harmonisation of practices – This was done haphazardly. European regional SDOs were required to adopt harmonised "weighted" voting procedures.[42] On the other hand, national SDOs retained exclusive rights of representation in CEN/CENELEC, whereas ETSI membership was opened to individual entities. Attempts were made to streamline ETSI procedures further by contracting Project Teams to work full-time for specified periods on technical problems related to standardisation. No such mechanism has been adopted by CEN/CENELEC.[43] The principle of charging membership fees to participants was also adopted uniquely by ETSI.

iv) *Indication of strategic directions* – In addition to specifying standardisation requirements and objectives in policy documents, the European Commission was empowered to send funded "standards mandates" to the recognised regional standards bodies. Mandates are issued according to the "new approach" principle whereby, in effect, the Commission contracts the recognised European regional SDOs to develop the technical specifications required to support the objectives of EU Directives.[44] To date, the computer and telecommunication sectors have been the single largest beneficiaries of EU mandates.[45]

v) *Harmonisation of testing, certification and approval mechanisms* – In order to solidify the European regional standards system, the possibility had to be avoided that the deployment of regionally agreed standards might be impeded by idiosyncratic national testing, certification and approval mechanisms. The basic principles were established that: *a)* products could be certified in any EU member State using the results of a single agreed set of tests; and *b)* there would be "mutual recognition of test results and approvals throughout the member States".[46]

To support these changes, various additional bodies were set up. The European Commission is advised regarding IT standardisation policy by a panel of senior officials from industry called the Senior Officials Group for Information Technology (SOGIT). A similar group was set up for telecommunication (SOGT). Within the CEN/CENELEC framework the European Workshop on Open Systems (EWOS) was set up to co-ordinate the activities of the many European OSI support consortia in their contributions to CEN/CENELEC and ISO. The European Organisation for Testing and Certification (EOTC) was set up to provide a focus for certification activities.

In terms of EU policy goals, however, there have been many problems with the European regional standards structure. Many of these were identified in a 1990 Green Paper on standardisation.[47] The quantity of European standards produced under the new system, for example, was considered to be below the levels required to support the economic and political goals of the "single European market" initiative. A lack of efficiency in the working relationship between the national and regional bodies was also cited. None of the more radical recommendations in the Green Paper were implemented. These included a proposal to set up a supra-European standardisation bureaucracy.

Institutional adjustments can also be made at the national level. In the United Kingdom, for example, following many months of high-level discussions and the commissioning of a report, the DTI and the British Standards Institution (BSI) embarked upon an initiative to restructure IT standardisation activities in the United Kingdom.[48] In 1989-90 BSI established its DISC project, a semi-autonomous division devoted to IT standardisation.[49] In addition to standards development, DISC was intended to create a forum which would serve to disseminate information about IT standards as widely as possible throughout UK industry. The project was designed to be financed by participants through the payment of fees. These were structured so that members could participate at a level and cost commensurate with their needs and the size of their operations.[50]

V. A CHECKLIST FOR THE DEVELOPMENT OF A PUBLIC SECTOR IT STANDARDISATION STRATEGY

The above discussion has illustrated that there are many ambiguities, uncertainties and pitfalls inherent in the appropriation of voluntary technical standards for policy purposes. Nevertheless, it is also clear that standards are an integral part of the R&D, manufacturing, marketing, and implementation processes for IT. A public sector strategy must be the result of an assessment of the existing structural relationships between government, industry and the standardisation organisations, as compared to the level of national capability in the technical areas concerned. Such an assessment is the basis for decisions concerning the upstream or downstream allocation of resources.

Individual decisions concerning the use of standards as instruments of a general IT strategy should therefore be based upon three basic criteria:

i) Prior clear identification of *general* policy goals and priorities for the development of the national IT infrastructure.

ii) Realistic assessments of current national technical capabilities in IT.

iii) Evaluation of existing national SDO activities and the state of the relationship between public and private sector standardisation activities.

Once these criteria have been met, the following factors should be taken into account:

- Official government disengagement is probably only an option for countries with a high and broadly based IT design and production capability. The United States is alone among countries in this category in maintaining a policy of disengagement with the national voluntary industry standards system, and even the US position is now under domestic scrutiny.[51] It is imperative for the effective development and use of standards that there be close communication between the IT industry and the political structure.
- In developing institutional structures for IT standardisation, governments should always differentiate between the principle of "open" voluntary standards, which now finds wide acceptance, and specific standards frameworks which often do not. OSI programmes have consistently failed to attract implementation commitments from the private sector. Governments played a vital role in the establishment of the open standards principle through support of OSI, but the significance of the OSI commitment may now be historical. The emphasis of any national IT standards programme should be upon the development and implementation of functional standards profiles that promote the principle of "open systems", and not upon slavish commitment to particular ways of constructing these profiles.
- Although computer and telecommunication equipment is now closely related technologically, the respective rates of technology implementation are often not synchronous, and the commercial structures surrounding each sector remain very different. Nevertheless, given the increasing proclivity for the IT and telecommunication supplier firms to become members of standards organisations in each sector, it is imperative that standards activities in the two areas be considered in a co-ordinated way for policy purposes.
- Although on the surface standards committees seem ideal fora for the exchange of information between various IT interest groups, in practice, they tend to be dominated by representatives of large multi-national IT firms. The sheer number of standards bodies and committees, and the range of complex areas they cover virtually precludes effective monitoring of the whole process by all but the largest entities. Strategic standards policies in countries with limited IT capabilities will have to adopt selective monitoring approaches and participatory criteria which are linked both to domestic implementation programmes and R&D strengths. Although it may be difficult to separate the "upstream" and "downstream" aspects of the process, "upstream" participation has to be focused on areas where the backup capability exists to make and/or assess technical contributions.
- Strength of representation in the international standards arenas is still largely dependent upon the collective R&D and market strengths of national IT firms, and upon the existence of a well organised national

standards system. It is important, however, that national standards systems take account of the fact that significant standards activity may originate in fora outside the mainstream SDO orbit. It is important that there be also a national standards information capability to monitor developments in all fora – SDOs, consortia, and proprietary ventures.

- Especially for countries in the earlier stages of developing a national policy for the development of the IT infrastructure, it is vital to integrate all of the domestic IT interest groups, particularly users, into the standards development system. There may be a "latecomer" advantage to these countries in that their IT standards systems can be structured from an early stage to identify and mobilise user as well as supplier requirements for standards.
- National standards policies must be designed, monitored and assessed in terms of the increasingly regional frameworks in which they must operate. Owing to the advanced and formal state of regional standardisation in Europe, this is an especially important decision for countries in the wider geographical and economic orbit of the European Community.
- The backbone of most government initiatives to use standards as strategic tools has been procurement power. The ability to use this power effectively is dependent upon the ability to judge whether there has been compliance with specified standards, or, for that matter, whether compliance can even be determined. For these reasons, government standardisation programmes are highly dependent for their success upon the parallel development of conformance testing and certification programmes.

VI. CONCLUSION

The above discussion has illustrated that technical standards for IT are much more than a technical matter, and that the results of public sector intervention in this area can be very unpredictable. Nevertheless, the need to determine a better strategic basis for assessing and addressing standards-related problems is not unique to the public sector, and the above observations do not nullify in principle every rationale for public sector participation and intervention.

Indeed, as the profile of IT standards becomes raised in our increasingly interconnected world, the possible positive *and* negative implications of standards and standardisation processes are becoming clearer to a much wider range of social and economic constituencies. Frequently, these constituencies have conflicting interests and objectives where standards are concerned, and many of these conflicts stretch across political boundaries. Increased awareness and conflict intensifies the demand for effective mediation. As a result, there is a strong likelihood that the subject of standards will be imposed on public sector agendas, irrespective of the proclivity of individual governments to be proactive in this area.

The various scenarios for public sector intervention in the IT standardisation process are particularly prone to ambiguities concerning both motivations and outcomes. These ambiguities can only be dispelled by a concentrated effort to refine the criteria that are currently being used to determine an appropriate public sector role. This will be a multifaceted and complex undertaking, as it is clear that the issue for governments is much broader than the mere selection or non-selection of standards as a policy instrument. Governments must have access to more knowledge of the kinds of problems that can actually be addressed by action on standards, and a better understanding of how standards can be best shaped and utilised to support indigenous national IT requirements and capabilities.

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2. See B. DANKBAAR and R. van TULDER (1991), "The Influence of Users in Standardisation: The Case of MAP", Maastricht Economic Research Institute on Innovation and Technology (MERIT), Working Paper 91-013.
3. See P.A. DAVID (1985), "Clio and the Economics of QWERTY", *American Economic Review*, Vol. 75, No. 2, pp. 332-337; and W.B. ARTHUR (1989), "Competing Technologies, Increasing Returns, and Lock-In by Historical Events", *Economic Journal*, Vol. 99, pp. 116-131.
4. *ISO Member Bodies,* Sixth Edition, ISO, Geneva, 1991. In 1991, only Ethiopia and the United States reported no direct financial support from government for their respective recognised national standards bodies.
5. The countries in what used to be loosely called the "socialist bloc" had no official private sector as such. Thus, the full costs of the working committees in their national SDOs were met by government.
6. It is not unknown, however. An example is the policy in the European Union of subsidising the expenses of "user" participants in committees of the European Telecommunications Standards Institute. This is only done where the standard concerned is being developed with EU funding.
7. See D.J. LECRAW (1981), *Voluntary Standards as a Regulatory Device*, Economic Council of Canada Working Paper No. 23 , Economic Council of Canada, Ottawa, July.
8. *Ibid.*
9. L.C. VERMAN (1973), *Standardisation: A New Discipline*, Archon Books, Hamden.
10. G. WALLENSTEIN (1990), *Setting Global Telecommunications Standards: The Stakes, the Players and the Process*, Artech House, Dedham, pp. 19-20.
11. C. CARGILL (1989), *Information Technology Standardisation: Theory, Process, and Organisations,* unpublished, Digital Press, *pp. 32-35, 59-60.*

12. There is much overlap between OSI and the Integrated Services Digital Network (ISDN) framework developed in the ITU. One of the objectives of ISDN is, in fact, to support OSI-based data-networking. The most widely implemented OSI standard is "X.400" (messaging), which is also an ISDN standard.

13. R.M. O'CONNOR (1992), *Standards, Technical Regulations and Quality Assurance – What Will Change? What Implications for Community S&T Policy?*, European Commission DG XII, Luxembourg, October, p. 40.

14. Although it develops and publishes many standards which find their way directly into the ISO system, ECMA is a private organisation with no recognition by any official body. This is in contrast to an organisation like the Computer and Business Equipment Manufacturers Association (CBEMA) in the United States which is also a private organisation but is accredited as a standards developer by the American National Standards Institute (ANSI). CBEMA sponsors the ANSI X3 committee which is the primary OSI development forum in the United States.

15. In Europe, the Standards Promotion and Application Group (SPAG) fulfilled a similar function to COS and POSI until 1994 when the organisation was disbanded due to lack of industry support. See *Communications Week International*, 28 March 1994, p. 1, 39.

16. The Machine Automation Protocol (MAP) and the Technical and Office Protocol (TOP) are open system protocols developed in parallel with OSI by consortia of large (originally US) corporations. The Transmission Control Protocol/Internet Protocol (TCP/IP) was originally developed by the US Department of Defense.

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19. See the *Report of the Inter-Agency Working Group for Co-ordinated Open EDI Standards Development*, Geneva, IEC, ISO, ITU, UN/ECE, August 1993.

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25. GENERAL AGREEMENT ON TARIFFS AND TRADE (1980), "Agreement on Technical Barriers to Trade", in *Basic Instruments and Selected Documents, Twenty-sixth Supplement, Protocols, Decisions, Report 1978-1979 and Thirty-fifth Session*, The Contracting Parties to the GATT, Geneva, March. For an explanation of the "Code", including a discussion of the special treatment it accords to developing countries under certain special circumstances, see J. NUSBAUMER (1984), "The GATT Standards Code in Operation", *Journal of World Trade Law*, Vol. 18, No. 6, Nov./Dec., pp. 542-552; and R.W. MIDDLETON (1980), "The GATT Standards Code", *Journal of World Trade Law*, Vol. 14, No. 3, May/June, pp. 201-219.
26. See *The Results of the Uruguay Round of Multilateral Trade Negotiations: The Legal Texts*, GATT, Geneva, 1994, pp. 138-162, and pp. 451-452.
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34. These estimates are taken from *Networking*, May 1992.
35. See L. SALTER and R. HAWKINS (1990), *The Standards Environment for Communications and Information Technologies*, Vol. I, Communications Canada, Ottawa, March.
36. This description is taken from *OSI Products - 2nd Report* , DTI and CCTA, London, 1988, p. 1-39.
37. See recent report in *Communications International*, August 1993, pp. 7, 9-10.
38. See *Communications International*, August 1994, p. 13.
39. Council Decision of 22 December 1986 on standardisation in the field of information technology and telecommunications (87/95/EEC).
40. For implementation purposes, European regional standards must be transposed into national standards by the SDOs in the member States. In selected cases, mostly related to EU public procurement Directives, the implementation of specified European standards is mandatory.
41. Grounds for the recognition of CEN and CENELEC were provided under the provisions of the Council Directive (83/189/EEC) of 28 March 1983, laying down a procedure for the provision of information in the field of technical standards and regulations. ETSI was officially recognised in 1992, in an amended annex to 83/189/EEC. See Commission Decision of 15 July 1992 amending the lists of standards institutions annexed to Council Directive 83/189/EEC.
42. "Weighted" voting is a procedure commonly used in the EU in response to the situation that some EU member States are much more populous than others. As the basic principle is "one country one vote", assigning "weights" based upon population, prevents EU initiatives from being controlled by a majority of Members who nevertheless do not represent a majority of the population. The practice is not common in standards bodies outside of the European orbit. For an analysis of the implications of weighted voting, see S.M. BESEN (1990), "The European Telecommunications Standards Institute: A Preliminary Analysis", *Telecommunications Policy*, December, pp. 521-530.
43. CEN has adopted a system whereby it can contract preliminary standardisation work to Associated Standards Bodies (ASB). At present there are two ASBs – the European Association of Aerospace Manufacturers (AECMA) and the Western European EDIFACT Board.
44. See the Council Directive (85/C 136/01) of 7 May 1985 on a new approach to technical harmonisation and standards.
45. The most recent available cumulative figures available show that show CEN/CENELEC and ETSI received just under ECU 19 million in mandate funding by

the end of 1991. See Communication from the Commission, Standardisation in the European Economy (Follow-up to the Commission Green Paper of October 1990), COM(91)521(final), Brussels, 16 December 1991.

46. The basis for the harmonisation of conformity testing and approvals was laid down in the "new approach" Directive (see footnote 43). The objectives were laid down in "A Global Approach to Certification and Testing", COM(89)209(final)-SYN 208, Brussels, 24 July 1989, and the European certification system is currently conducted under a Memorandum of Understanding between The European Commission, the European Free Trade Association (EFTA), CEN, and CENELEC, dating from 25 April 1990.

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49. "DISC" stands for "delivery of information technology solutions to customers".

50. Basic membership is open to any organisation or individual upon payment of a modest fee. Members in the "basis" category are entitled to receive all DISC information, to participate in the General Assembly and in any of the four Standards Policy Committees. As such, basic membership does not extend to membership of technical committees. Technical committee participation requires payment of a subscription assessed according to the commercial turnover of the participating organisation. DISC also operates a Business Strategy Forum which charges a flat membership fee, and several kinds of specialised working groups which are self financed.

51. US CONGRESS, OFFICE OF TECHNOLOGY ASSESSMENT, *op. cit.*

THE ROLE OF USERS IN INFORMATION TECHNOLOGY STANDARDISATION

CONTENTS

This article was written by L.J. Rankine, President of Rankine Associates, a consulting company specialising in international management services. He is former Chairman of the American National Standards Institute, Director of Standards for IBM and the Founding Chairman of the ISO/IEC Joint Committee on Information Technology (JTC1). He is a member of the United Kingdom Engineering Council and is former Vice-Chairman of BIAC/ICCP.

I. INTRODUCTION

The ubiquitous application of Information Technology (IT) throughout science, industry, commerce, academe and almost every aspect of our highly communicative society is increasingly dependent on a hierarchy of timely, complex and internationally-based standards.

In view of the fact that standards are a vital element in deriving the maximum benefits of technology, it is essential that the users of standards have a key role in their development. If the needs of the users are not clearly stated and understood, inevitably there will be shortcomings in the emerging standards some of which may become serious barriers to economic and social progress on a wide front.

Users need to be widely involved both directly and indirectly in order to exert a judicious influence on the process of standardisation.

One of the most easily made and frequently heard comments about user involvement is that is insufficient.

This report examines first what is meant by the broad term "user" and secondly how the needs of the various kinds of users are reflected into the standards process.

It will be seen that user participation and influence is considerable and, with rare exception, beneficial. Government involvement on behalf of users can be a two-edged sword but the needs of governments as users are important.

The international standards process is expensive and poorly understood by government and private sector executives and this leads to a proliferation and duplication of effort. An educational challenge exists for the standards bodies and academe in this regard. New and existing technologies should be exploited for dispersing standards and standards information to users.

The report concludes with concisely stated Conclusions and Recommendations.

The report has been written, as far as possible, with the minimum use of the legion of acronyms and esoteric terms that so easily confuse and ultimately bore those who make an attempt to understand the politically and technically complex field of information technology standardisation.

II. USER CLASSIFICATIONS

In the field of Information Technology (IT) the term "user" is widely used and poorly defined. The writer of this report working on a personal computer is a user. Électricité de France, Boeing Aircraft, Shell Oil, Royal Bank of Scotland, Air Liquid and thousands of other companies are all users. Machines Bull, DEC, IBM, Philips, Olivetti, Siemens and all other manufacturers of IT equipment are also users. PT&T's, radio, television and publishing companies are users, as are lawyers, doctors, dentists and insurance companies. A child learning math on a computer is a user. Indeed it is hard to think of those in today's society who are not users, in one way or another, of IT equipment.

Among the many kinds of users mentioned there is wide disparity in their interest, if any, in IT standardisation. Some could not care less what kind of equipment they are using, far less to which standards it adheres. All they care about is results. Some, on the other hand, are deeply interested in the architecture of their equipment and its associated standards. Of the latter, many have no desire to participate, but they are interested in what the standards community is doing and how their interests and investments might be affected or represented.

In order to get some coherence into the term "user" for the purposes of this report, we shall consider the following classifications:

Level 1 users

The sophisticated users who are making use of computers and computer networks on a widespread basis throughout their own enterprises and often on an inter-connected basis with other enterprises. The user's personnel are highly educated in regard to the technology involved and have a key interest in driving new developments and technological offerings by suppliers. Examples are Boeing, Électricité de France, General Motors, Dow Jones, etc.

Level 2 users

The knowledgeable user who has a general familiarity with the technology being employed and sometimes a need for special adaptations of the technology to meet his or her requirements. Examples are the grocery industry's role in the development of supermarket systems, power plant control systems, security alarm system companies.

Level 3 users

The large body of users who purchase or use computer systems in the course of their occupation or domestic activities and in general have little or no interest in the technology involved apart from considerations of safety, ease of use and other ergonomic factors. Examples are users of bank teller machines, home computers, and terminal operators.

Finally, there is a special category of user that has not been referred to so far, namely, governments. Governments are not only very large users, they frequently act also on behalf of users and this is further discussed under the heading "Governments as champions of users".

III. HOW USERS ARE INVOLVED

National standards organisations

The national standards bodies that are members of the International Organisation for Standardisation (ISO) and the national committees of the International Electrotechnic Commission (IEC) operate on a basis of representing a broad spectrum of user interests. For example the Swedish Standards Institution (SIS) has more than 700 technical committees and working groups. More than 6 000 experts from industry, trade, governmental authorities, research and testing institutions, labour unions and consumer organisations participate. There are about 7 500 Swedish standards. The annual production runs about 400-600 new or revised standards comprising 5 000-7 000 pages. Most of the Swedish standards are based on international standards. Exclusively Swedish standardisation work is less than 10 per cent of the total. SIS has been a long-standing and major participant in ISO and IEC information technology standardisation.

National standards committees

Despite the perception by some that users are insufficiently involved insofar as IT is concerned, this is not necessarily the case. For example, in the American National Standards Institute (ANSI) X3 Committee (ANSI X3), less than half of the participants are from the manufacturing community.

ANSI X3 is the key committee in the United States insofar as the IEC/ISO Joint Technical Committee 1 (JTC1) on Information Technology is concerned.

The user participation in ANSI X3 is made up essentially of Level 1 and Level 2 users. Aerospace, photographic, GUIDE and SHARE (see "User organisations"), government agencies, universities, consultants, research, libraries, nuclear, power engineering, telecommunications, laboratories and other general interest groups participate. Almost a quarter of the members of ANSI X3 come from the United States Government.

International and regional organisations

The General Assembly meetings of the International Electric Commission (IEC) are attended by National Committees of the member nations. While standards are not developed at the General Assembly, policy decisions regarding directions in standards are made. It is through the National Committees that user views are reflected, therefore representation of user viewpoints is important. For example, the United States National Committee (USNC) to the IEC at the IEC General Assembly in Beijing, China, in October 1990, was made up of a dozen Level 1 and Level 2 users out of a total delegation of thirty-six. The remaining two-thirds of the delegation was made up of representatives from four information technology manufacturers, laboratories (including the well-known Underwriter's Lab), universities, professional societies, consultants and staff members.

A similar situation exists in regard to CENEL the European counterpart of IEC because the National Committees from the European nations attending CENEL are essentially the same as those attending the IEC.

In the case of the International Standards Organisation (ISO) a generally similar situation to IEC exists. A key difference is that the ISO General Assembly is attended by almost one hundred countries having delegations averaging from three to five persons. Often two members of each country's delegation come from that country's national standards body which represents a broad spectrum of national interests. The remaining members of a national delegation are usually from industry and frequently from Level 1 and Level 2 users. The delegation leader is most frequently from a user or government.

The European counterpart of ISO is the CEN and the member bodies comprising the CEN are the European member bodies of the ISO so, again, a similar situation exists in the CEN as in the ISO in regard to user and other representation.

At the international level, user involvement on a broad social scale is surprisingly strong. For example, in ISO Technical Committee 46 (ISO TC46) on "Information and Documentation", 28 national standards bodies are involved and liaison is maintained with over 40 international organisations such as the Arab League Educational, Cultural and Scientific Organisation, the International Federal Library Associations (IFLA) and several of the United Nations Agencies such as the UN Conference on Trade and Development (UNCTAD), the UN Economic

Commission for Europe (UN-ECE) and the UN Scientific and Cultural Organisation (UNESCO).

ISO Technical Committee 68 (ISO TC68) on "Banking and Related Financial Services" has 19 national standards bodies participating and is dominated by banking interests mostly at User Levels 1 and 2. Close liaison is maintained with user interests such as those represented by the Society for Worldwide Interbank Financial Telecommunications (SWIFT) and a score of other user organisations.

A similar picture exists in regard to IEC technical committees which maintain close liaison with user interest groups such as the College international pour l'étude scientifique des techniques de productions mécaniques (CIRP) and Computer Aided Manufacturing International Inc. (CAM/I) as well as the Comité consultatif international pour la télégraphie et la téléphonie (CCITT); the latter representing both a producer and user of information technology standards working on behalf of the PT&T's which are among the largest of Level 1 users.

User organisations

The introduction of general purpose digital computers to the marketplace led very quickly to the formation of user groups. For example, the IBM 704 computer was one of the early computers used by a wide variety of engineers and scientists from universities and industries such as aerospace, pharmaceutics, petroleum, nuclear power generation and the military. As the users met and exchanged ideas they found that they were, in many cases, writing similar programs and engaging in redundant effort. This gave birth to the Society to Help Avoid Redundant Effort, now known commonly as SHARE.

In the area of commercial applications another IBM user group called GUIDE was also formed to be followed by user groups identified with the other computer systems such as DEC, UNISYS, NCR etc.

The user groups have grown rapidly to a point where their annual conferences are major convention events with attendance from around the world. Furthermore, the user groups have gone well beyond exchanging information and programming work. Realising that they have considerable influence and power, they do not hesitate to point out to the manufacturers any shortcomings they see in regard to hardware and software but also in regard to directions in standards writing and implementation. If they feel that a manufacturer is being unnecessarily slow in either supporting or implementing a standard they will not hesitate to voice their opinion and, if necessary, indicate that they will go to another manufacturer who will meet their needs.

Conversely, if user groups feel that the standards writing bodies are not being sufficiently responsive or are going in the wrong directions, they will get involved at the national and international levels.

In addition to user groups associated with specific equipment manufacturers, there are also groups speaking for a wide variety of user interests independent of any manufacturer. An example is the International Telecommunications Users Group (INTUG) which brings together the users of telecommunications from around the world. Generally, these are Level 1 and Level 2 users.

Recently INTUG has been concerned about what it perceives as a need for the European Telecommunications Standards Institute (ETSI) to have broader user participation. INTUG has voiced its concern in the following manner:

"ETSI has been successful in engaging the public network operators and manufacturers in its technical committee activities. It has had considerable more difficulty in involving users. There is a certain logic in saying that users are ETSI's most important members. They are the community ultimately paying for the services provided by the public telecommunications networks. They are the purchasers of the large corporate private telecommunications networks that are now becoming commonplace. The users could play a significant role in the standardisation process in shaping standards to meet their needs. Further, if a large body of the user community could be involved in the preparation of European Telecommunications Standards, it could generate some loyalty whereby they express a preference for services and systems to ETSI standards. However, getting users into ETSI and fully participating in ETSI's Technical Committees has not proved easy. This is despite best efforts by a number of people.

There may be several explanations for this lack of user participation in standards-making activities. The most likely is that, in the past, the PTT dictated what was available, how much it would cost and when it would be delivered. This gave users little to decide. Therefore, not unreasonably, companies could not see a relevance in releasing staff to take part in standards-making activities. Standardisation was viewed as a PTT affair. There is another possible explanation. The historic lack of choice meant that companies did not employ many highly qualified staff for ordering telecommunications facilities. The few qualified staff are now so stretched meeting their companies' demands that they have no time to take part in ETSI's activities. Either way, only a relatively few users have managed to take part in ETSI's technical committee work.

ETSI will need to make an effort to attract users to its technical work. It will need to get across to the large users of telecommunications facilities that participation in standards work by their staff is likely to lead to wiser investment decisions. Companies' views will hopefully change as they realise the full extent of the choices now opening up to them in telecommunications products and services.

Having such a wider choice substantially increases the investment risks for users. ETSI needs to study carefully how best to attract users. The resources for this effort, however important, are limited as for everything else. Such an effort needs to be focused. The best way forward is to set up an *ad hoc* group of qualified members who can examine the problem and produce an action plan for the consideration of the Technical Assembly."

In an effort to be responsive, ETSI has been holding sessions to analyse the reasons for the relatively low participation of users in ETSI Technical Committees and to brainstorm ideas for improving the situation at both the national and the international levels.

User groups are increasingly exerting their influence on the standards process in essentially the following ways:

- Letting manufactures know what they expect in regard to standards directions and implementation.
- Seeking more liaison with and representation on national and international standards writing committees.

Participating in higher level policy-making dialogues such as those taking place in arenas such as the OECD Special Sessions on Telecommunications, and the International Chamber of Commerce (ICC) Commission on Computing, Telecommunications and Information Policies (CTIP).

The influence of user groups is likely to increase as their awareness of the significance of standards to their interests increases. They exercise increasing influence over manufacturing, policy making and government circles because of the powerful national and international economic interests that they represent.

Standards setting by user groups

There are occasions when a specific user grouping such as the banking and transportation industries will unilaterally initiate a significant standards-making activity. In such cases the group may well turn to established standards bodies in order to develop a commonly accepted standard. The coding of bank cheques and pallet sizing in air transport are examples. However, there are occasions when a user grouping wants a standard very rapidly and perceives the voluntary consensus standards-making process as taking too long.

One of the clearest examples was the grocery industry which saw the need for coding grocery items so as to speed consumer checkout, maintain better inventory control, reduce costs and avoid the inaccuracies inherent in manual checkout methods, as well as other benefits. This initiative was launched primarily by the Level 1 and Level 2 users within the grocery industry and, within the United

States, the National Retail Merchants Association (NRMA) was also involved. It soon became apparent that some of the largest grocery chains getting together with some of the well-known computer manufacturers and deciding on a standard was not going to be that easy. Complaints came immediately from consumer protection groups who perceived the whole idea as a scheme to defraud the end users in that the grocery stores could change prices on items between the time of a consumer picking an item off the shelf and getting to the check-out counter.

Smaller grocery stores who could perceive the benefits of such systems, felt that they could not afford them and claimed that they would be put out of business by the large chain stores being able to cut costs and offer lower prices which the small stores could not meet. Labour unions complained that store personnel would lose their jobs and those remaining would become automatons subservient to computers. Shoppers were alarmed by media reports that laser technology would be used and children who might stare into a laser beam would be blinded. There was also the general question raised of "what happens if the computers make a mistake?"

Another significant issue that arose very quickly was the question of anti-trust actions. Several technologies existed to meet the grocery industry requirements, namely, magnetic stripe reading, optical character recognition and optical bar code reading. A few large grocery chains deciding on a specific manufacturer's technological approach could easily lead to charges of conspiracy to exclude other offerings from the marketplace.

In effect, the grocery industry came very quickly up against the hard fact that standards setting generally proceeds best on a voluntary consensus basis wherein all interested parties have the opportunity to be heard.

At that point the grocery industry could have resorted to the established standards bodies but, wanting to expedite the process as much as possible, it chose a different course. This was to engage Battelle Institute in effect to referee the whole process of deciding the standard. Battelle did this very effectively providing the opportunity for all to be heard, the ultimate result being the laser-read optical bar code which is now so familiar on a wide spectrum of products purchased by consumers.

Interestingly, the many fears that were raised at the outset of the process and had the potential to kill it have now evaporated in favour of a strong consumer preference to shop in grocery stores that employ the systems largely due to faster checkout and far more detailed and informative receipts.

In summary the grocery industry example is a clear case of users taking upon themselves control of the standards process using independent mechanisms.

Whether or not the grocery industry's need could have been met more expeditiously through the traditional standards-making bodies will never be known. Nor shall we know if greater uniformity worldwide might have been achieved not only within the grocery industry but also with other industries such as the retail industry some of which opted for a magnetic stripe solution.

Manufacturers as users

Just as the shoemaker must wear shoes, the manufacturers of IT equipment are heavily dependent on that equipment in their research, development, engineering, manufacturing, distribution, sales, marketing, planning, reporting, legal and financial activities. Furthermore, manufacturers are highly dependent on both national and international information networks for the conduct of their business.

All of this positions the IT manufacturers among the most experienced of Level 1 and Level 2 users and exerts a major influence on a manufacturer's participation in standards-making. An illustration of this point is the case of establishing a noise level standard for office equipment. Engineering and manufacturing may seek a liberal standard that permits the choice of a wide range of technology including, for example, impact printing which is inherently noisy. Sales and marketing may disagree strongly with this in view of a desire to expand sales to hospitals, libraries, banks and the executive floor where silence is at a premium. Legal may intervene to demand a low noise level so as to minimise the likelihood of lawsuits. All of this may force development to re-examine design and decide that electro-mechanical noise can be reduced by using fewer moving parts thus lowering costs to users or, alternatively, by using technologies such as laser and ink-jet.

Similarly, in regard to systems communications architecture, research and development may wish to promote a unique approach which they feel to be superior and not be inhibited by a standard. On the other hand, sales and marketing see a standard architecture as a vital way to increase the inter-connectability of systems and so expand their markets by catering to a key user need which is also backed by the manufacturer's own needs as user.

A key characteristic of investment in IT equipment by users is that they buy solutions rather than equipment – in other words a system that will meet their applications needs rather than specific products from a particular manufacturer. As a result manufacturers are keenly attuned to user needs because if they do not meet them another supplier will and there is no profit in a product line that has been designed to what a manufacturer wants to sell as opposed to that which solves the customer's problem.

In effect, what has happened is that within their own houses manufacturers have in many ways become sub-sets of the consensus standards-making system in that they have to take into account a wide disparity of views that are, more often than not, decided by user considerations.

The role of professional societies

Representatives of Level 1, Level 2 and Level 3 users participate in various professional societies that are active in participants in information technology standardisation. A key example of this is the Institution of Electrical and Electronic Engineers (IEEE) a North American based institution that has a very active membership worldwide. There are approximately 627 IEEE standards, many of which are related directly to IT requirements. Good examples are the IEEE standards for Local Area Networks (LANs) now in widespread use. Technical experts developing such standards come from organisations that are manufacturers and users of all kinds, as well as from academe and research and even private individuals acting on their own behalf as engineers. IEEE members participating in IEEE standards committees are required to act as individuals in their own right and not as representatives of companies. While there is little doubt that in some cases organisational rather than personal views may be expressed, the fact remains that those are representative of Level 1, Level 2 and Level 3 users of all kinds.

IV. GOVERNMENTS AS CHAMPIONS OF USERS

Being themselves large users of IT systems, governments can adopt the role as spokesman for representing and protecting user interests in the standards-making process. For example, the American Standard Code for Information Interchange (ASCII) was strongly promoted by the US government both in national and international committees as well as by force of government procurement power when the US government issued a Presidential directive that all equipment purchased by the US government after a specified date had to have ASCII capability.

While there is no doubt that government involvement advanced the acceptance of ASCII, there were costs and inconveniences caused. User demand for ASCII at the time was not at the same level as government demand, the latter being driven by the political notion that if "all computers spoke the same alphabet (ASCII)", users could buy their equipment from any vendor without risking incompatibilities. Accordingly, the government could shop for the best price regardless of vendor, and the government would enjoy enormous economies in procurement costs. Unfortunately, the manufacturers were at the same time focused on the needs of their own user communities which were based on the systems architecture of the specific manufacturer involved. With rare exception, this was not ASCII based.

The result was that manufacturers scrambled to provide software and hardware to enable ASCII to be written in and out of their non-ASCII systems, resulting in costs that had to be borne by the user community including the various US government agencies, many of whom saw more inconvenience than benefit in the ASCII requirement that was being forced on them. Accordingly, many government departments applied for and received waivers enabling them to buy that which best met their specific needs regardless of the ASCII requirement.

Concomitant with the ASCII requirement the US Government also embarked on the notion that computer equipment should be completely interchangeable via a standard input-output interface (I/O interface). In this way, it was argued, users could buy central processing units, printers, displays, tape and disk drives from different sources at the lowest cost and have them operate as a system because of their compatibility with the standard I/O interface. In promoting this concept the US Government felt that it was not only championing its own needs as a user but was also benefiting the taxpayers through greatly reduced procurement costs. There was also the political notion that such an interface would discourage the emergence of any dominant supplier in government procurement.

The non-government users were for the most part disinterested in the need for a standard I/O interface and the computer systems manufacturers were, with rare exception, opposed to it because each felt there was a competitive advantage in their respective systems architecture that would be eroded by a standard. Furthermore, each manufacturer had his own vision of what his next interface should be and saw no need to share this with his competitors in a standards committee.

The political pressure, however, was on and the US National Bureau of Standards (NBS), now the National Institute of Science and Technology (NIST), then introduced the concept of the "black box" standard. The "black box" would be a standard device to which equipment from the various manufacturers could be attached and would be in effect a " stand alone I/O interface."

The "black box" concept immediately gave rise to several questions. The first was who was going to pay for it – the user presumably? Secondly, who would be responsible if the resultant system failed to perform satisfactorily? For example, if A's tape drives did not operate with B's central processing unit who would be held responsible – the tape drive supplier, the central processing unit manufacturer or the maker of the "black box"? Furthermore, what would be the legal exposures in such a situation? In an attempt to keep the "black box" alive NBS considered being the referee but finally abandoned the concept.

However, the political pressure for a standard I/O interface was still on and, in a desperate move to find an answer and ensure continued federal funding of its activities, the NBS finally ruled that the IBM 360 interface would be the standard I/O interface for US Government procurement purposes. IBM voted against this proposal because it foresaw the ultimate obsolescence of its own interface and considered it unwise for the US Government to impose upon its own agencies a requirement that could deny them the ability to purchase the most advanced technology – a view shared by many of the agencies. The non-IBM manufacturers were, for obvious reasons, outraged by the NBS decision and several joined together in a legal suit against the government in an attempt to block it. This was not successful but the concept finally died of its own weight.

Nonetheless, the US Government continues to play a strong role in IT standardisation through NIST and the various US Government agencies such as the Department of Defense, the State Department, the Department of Commerce, etc. As of the writing of this report, NIST participates strongly in the ANSI X3 committee and chairs the US Technical Advisory Group (TAG) which is responsible for and chairs the US delegation to the ISO/IEC Joint Technical Committee (JTC1) on information technology. Thus far, NIST has not championed the cause of user participation and has supported rules that would require the JTC1 Chairman to come from "a larger company", thus excluding the small independent user.

Finally, in looking at governments as champions of the user, the more recent case of Open Systems Interconnection (OSI) is an interesting one. In the late 1970s the information technology standards community came under considerable pressure from governments for the development of international standards for open systems interconnection. The objective of this drive by governments was to enable users in any part of the world to interconnect their computer systems regardless of their manufacture.

The objective was worthwhile and the effort timely. Insofar as the computer manufacturers were concerned they also understood that over the long range the market for computing equipment would be greatly expanded by interconnection capability worldwide or, as it came to be known, the "interoperability" of systems.

Accordingly, in 1977, the Technical Committee 97 (TC 97) of the International Standards Organisation (ISO), which dealt with IT standardisation at that time, initiated work on the OSI 7-Layer Reference Model. So began what is probably the most complex and difficult standardisation effort ever undertaken. It required dozens of committees involving hundreds of highly experienced technical experts, many with differing views.

At this point a digression is in order to explain what happened next. Let us suppose that we wish ISO to standardise which side of the street the world's traffic should utilise. The involved standards committees in the Americas and most of Europe will clearly elect for the right-hand side of the street. However, this will not be supported by the United Kingdom and many of the countries in the Orient and the Far East, Japan, China and Australia being examples. This then means reaching consensus on a worldwide basis in such a fashion that neither interest bloc is more or less damaged than the other. The answer has to be that the ISO standard should call for us to drive down the centre of the street. However, when the ISO standard is issued on such a basis, we can expect that those who drive on the right will seek an option to the standard whereby they can continue to do so.

Similarly, those countries who drive on the left will seek a reciprocal option that will permit continuance of their preference for the left.

Before the reader dismisses this example as totally frivolous, it should be realised that it is exactly what happened in OSI standardisation. Given the complexities of the computer systems, communications facilities and applications involved, the OSI standardisation effort became rich in options from which choices had to be made in order to ensure true "inter-operability" worldwide. This situation in turn spawned a plethora of nationally- and regionally-based organisations around the world to decide which options should be selected. These organisations were frequently fiercely competitive with each other and they consumed an enormous amount of time and talent directed more at competitive survival than at achieving truly international standards.

Meanwhile, as all of these standardisation, political and competitive efforts were going on, so also was the real world. Innovative manufacturers, seeing the valid user need for interconnection and inter-operability of systems, were quietly producing and marketing proprietary solutions that for the most part rendered the OSI standardisation effort irrelevant. Indeed, privately, governmental personnel are prone to acknowledge that "OSI is dead".

The lesson to be learned here is that powerful governmental pressures on behalf of users caused the expenditure of huge resources which failed to deliver what a few market driven and innovative suppliers managed to do on behalf of the user.

V. OTHER CHAMPIONS OF THE USER

The media

The field of information technology is highly populated with publications dealing with user needs and requirements. For the most part these are weekly, biweekly or monthly publications. As this report is being written there is on the writer's desk a current copy of the popular newsweekly *Computerworld* which carries on its front page three headline articles dealing with standards with special emphasis on the user point of view. Also at hand is the current issue of *PC Magazine* in which there is an article on the likely successors to the well established Disk Operating System (DOS) standard. Again this article is written strongly from the viewpoint of user needs and reactions to the various offerings available and being considered.

There is no doubt that the media exerts a considerable influence on the standards-making process through its readership which comprises both users and suppliers. There is no manufacturer who welcomes an article that positions his products as incompatible with existing standards or his representatives in standards committees as taking positions that are incompatible with user needs.

A key question in regard to media influence on the standards process is how accurately do some of articles being written reflect user needs versus the personal views and prejudices of the author. For this reason articles that are report facts rather than opinions are generally more useful as input to the standards process.

Consumer groups

In general, consumer groups have not involved themselves substantially in IT standardisation. A possible exception is the consumer groups' protests against the grocery industry's implementation of supermarket systems employing the barcode standard as described earlier. These protests were not, however, so much against adoption of the standard as they were against the systems implementing the standard.

For the most part, IT standardisation is a technically complex subject doing little to attract consumer group interest unless possibly someone decides to take exception to a standard specifying metric in a non-metric country or, *vice-versa* and much more likely, non-metric in a metric country. Similarly some group might take exception to the International Standards Organisation (ISO) issuing a standard that states that the preferred method of writing the date is year-month-day, and the national habit is, for example, the US one of month-day-year.

In regard to the example just given, it should be noted that the ISO does have a consumer council COPOLCO that does provide for consumer concerns at the highest ISO levels.

VI. USERS AS A NEGATIVE FORCE

It is generally assumed that user involvement in the process of standardisation is always beneficial and experience shows that indeed it is. Cases where users or user groups have hindered rather than helped the process are rare. Those that have arisen are almost always due to a certain user or user group wanting to maintain the *status quo* and viewing any change as being undesirable be it an entirely new standards direction or a revision of an existing standard. Some years ago the members of a standards committee working on one of the major programming language standards found themselves threatened by legal action by a large Level 1 user. The reason was that the user had made a major investment in an earlier version of the programming language standard and did not want to see it made obsolete. This concern is not uncommon. For example, the writer of this report has his information processing needs met by a modestly fast processor operating under the well-known operating system DOS. Accordingly, he has little incentive, if any, to support any change to a new standard which could diminish the value of the investment he has made in both hardware and software. Accordingly, if he were on a standards committee dealing with operating systems, he might well vote against a standard for a newer and more powerful operating system urgently needed by other kinds of users. Certainly he would be representing a user interest, but to the detriment of other user interests.

VII. FUTURE AVENUES OF USER INVOLVEMENT

New technologies benefit users

Technologies now available to users can greatly enhance their awareness of and participation in the standardisation process.

An example is the emergence of CD-ROM technology. On disks the same size as the "compact disks" which are now familiar to music lovers it is possible to record thousands of standards which can be readily accessed in seconds by users via a personal computer equipped with a relatively inexpensive CD-ROM Drive Unit. For example, the Worldwide Standards Service on CD-ROM supplied by Information Handling Services Inc., enables the writer of this report to track standards from standards writing organisations around the world without leaving his office. This saves time and travel costs and provides current information as the disks are updated regularly. Obviously, the existence of such services will enable users to be much better informed as to what is happening in the standards world that can affect their interests. Furthermore, the standards writing organisations are increasingly adopting CD-ROM as a means of providing readily accessible information on standards throughout their development, writing and publication.

One very useful aspect of CD-ROM services is the ability to search for standards on a "key word" basis. For example, if one were looking for any standards activity that deals with token ring local area networks going on in the International Standards Organisation (ISO) or German national committees, then 'ISO, Token, LAN, DIN, ring' would all become key words to be entered into the computer so that in a few seconds it could list all standards work that fits the category specified by the key words. This can narrow searches down from days to seconds if done on CD-ROM instead of manually.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

i) Users exert considerable influence over Information Technology standards.

ii) User needs are represented by direct participation in standards committees and also *via* user groups, the media and manufacturer's understanding of user needs.

iii) Government understanding and representation of user needs can often be distorted by political objectives as well as by the abuse of government procurement powers.

iv) The larger and sophisticated users (Level 1 and Level 2) have greater influence over standards than the smaller less sophisticated users (Level 3).

v) User participation is a vital and constructive element of developing truly useful information technology standards.

vi) Negative participation by users, user groups and consumer groups, etc. to combat and delay standards development and revisions has been infrequent and has stemmed, in some cases, from lack of understanding of the standards process.

vii) The IT standards process is increasingly complex, difficult to understand and subject to a proliferation of organisations, all of which is costly to users and all other participants.

viii) The emergence in 1994 of the Standards Project Automation (SPA) system of the Institution of Electrical and Electronics Engineers (IEEE) ushers in a whole new era of user involvement in participating on-line in standards proposals, drafting, balloting, publishing and accessing. SPA can greatly reduce costs to users in participating in standardisation and in strengthening the user's voice.

Recommendations

i) With rare exception, such as to acquire unique expertise, user participation in Information Technology standards development does not need to be specially funded by governments.

ii) Standards education at managerial and executive levels in both the private and public sectors is needed to ensure higher quality participation in the standards process and reduce the proliferation of duplicate organisations and efforts. Universities and business schools have a major void to fill in this regard.

iii) The role of governments, government departments and agencies in the IT standardisation process should be to reflect their needs as users rather than to attempt to speak for the needs of non-governmental users.

iv) Governments should refrain from using their procurement powers in order to achieve political and other objectives through IT standardisation.

v) Computer networking and CD-ROM technologies should be exploited to make standards information more readily available to users and to facilitate user input. Users should participate in the IEEE SPA system (para. 8, p. 25).

vi) Standards organisations at national, regional and international levels need to continue their efforts to avoid overlap and duplication of efforts, as the International Electrotechnic Commission (IEC) and the International Standards Organisation (ISO) have done by combining their efforts in the creation of their Joint Technical Committee in Information Technology (JTC1).

vii) The standards organisations at national, regional and international levels need to educate the management and executive levels of the user community (both governmental and non-governmental) as to their existence and the value of their services in meeting user needs expeditiously.

THE INFORMATISATION OF GOVERNMENT: FROM CHOICE OF TECHNOLOGY TO ECONOMIC OPPORTUNITY

CONTENTS

This article was written by Robin Cowan, Assistant Professor of Economics at the University of Western Ontario, Canada. It was prepared for the joint OECD/TÜBITAK Conference on "The Changing Role of Governments in Introducing New Information Technologies and Strategies in Establishing Relevant National IT Enhancement Plans", held in Ankara (Turkey) in September 1993. The author wishes to thank Claire Charbit, André Dubois and Norm Cheesman for their helpful comments and suggestions.

I. INTRODUCTION

Throughout the world governments are expressing anxiety about missing the information technology revolution. A new technology exists, and is thought to represent enormous potential for economic growth and increases in productivity. Needless to say, governments are worried about being left behind as others find ways of tapping this potential. Concern is expressed in two different ways. One is through policies that encourage the supply and use of information technology throughout the economy. The second is what is referred to here as the informatisation of government. By this we mean that governments themselves are adopting and using information technology in their own operations, intending to make government operations more efficient. There is a link between these two responses, as information technology has several properties such that government adoption and use can encourage and facilitate use in the private sector.

Governments differ from most other economic agents in two kinds of ways. The first, and most obvious, has to do with its goals. In principle, the purpose of government actions is to raise social welfare. Government activities are aimed at providing services that citizens want or need but that are not provided in other ways, and at the same time preventing actions thought to be "not in the public good". This feature distinguishes government from most other agents in obvious ways. A second type of difference has to do with the scope of government operations. National and even provincial governments are much larger, both in terms of the number of employees, and in terms of the size of their budgets, than are the vast majority of firms. National governments also have the feature of being geographically extensive. While most firms operate in local markets (although some of course are national and international), government operations, by definition, encompass an entire country. Furthermore, governments interact with virtually every agent in the country. Every citizen uses some government services, and in one way or another, every citizen is taxed. Again, the same is not true of firms, the vast majority of which interact with only a small number of other agents in the economy.[1]

The goal referred to above, namely raising social welfare, is, of course, ambitious, often difficult to achieve, and, indeed, considered by some to be folly. The properties of government enumerated in the second list, though, indicate an opportunity for achieving this goal. The fact that government is large and geographically extensive gives it the power to make significant changes in the way an economy works. These changes can be good or bad, but opportunity does exist to move the economy forward, from one type of equilibrium to another. The concern in this paper can be expressed as a question: "Given the size and scope of government operations, how does the adoption of information technology by the government interact with its broad goal of raising social welfare?". Before addressing this question directly, we must turn attention to the relation of information technology and welfare.

II. INFORMATION TECHNOLOGY AND ECONOMIC GROWTH

While information technology is thought to hold considerable promise for economic progress, it is progress of a sort that is relatively unusual. Many innovations provide economic growth through creating a new niche or industry and expanding within that industry. Typically, while not to be scoffed at, this does not provide massive increases in income. This analysis applies also to information technology. The IT sector in Canada accounted for only 4 per cent of GNP in 1992 and 4 per cent of job creation between 1987 and 1990.[2] The expected boost to growth arising from the information technology revolution will not come from the IT sector itself then, but rather from the integration and use of IT in other sectors. This is sometimes referred to as "enablement" or "the enabling effect". Enablement is seen to act on five levels.[3]

Enablement

Adoption of information technology by a firm, or incorporation of IT into a firm's operation can do one, or more, of five things. At the most basic level, it can reduce costs of current operations – either by reducing the inputs needed to produce a given level of output, or by permitting more output to be produced with the same amounts of input. The next level of enablement is quality improvement of existing products. Here quality refers not only to the characteristics of the product, but also the service that goes with it, for example the time it takes to process and deliver an order. The third level of enablement involves invention of new, IT-dependent products, examples of which range from numerically-controlled machine tools to the compact disk player. The fourth and fifth levels refer not to products but to organisations: adoption of IT will improve strategic management through its ability to process information quickly, and allow firms to respond more effectively to changing markets. And finally, widespread diffusion of IT encourages the emergence of new concepts and paradigms.

It seems clear that as we progress from reducing costs by automating current processes through to the development and deployment of new concepts and paradigms, the innovations implied become more radical. It is also to be hoped that they become more effective in raising productivity and fostering economic growth. Indeed one explanation of the so-called productivity paradox is that, so far, IT has largely been employed to "do what we were doing before only faster". The real gains will appear when we are able to change actual practices (for example, by shifting to just-in-time production). The key is in managing information – moving more of it, more efficiently and in different ways.[4]

The argument here is that the relatively small size of the information technology sector should not be deceiving. The main effects of IT will not be felt in the IT sector itself; its promise lies in its ability to transform products and production processes throughout the economy. But the full effects of IT will only be felt as we move from the replacement of current operations with IT-based technology, to the re-organisation of products and processes to take advantage of new abilities in information production, storage and communication. Thus the goal of government should be to facilitate "enabling" adoption of IT, and to encourage enablement at higher levels. Information technology has both users and suppliers, and government attention can be focused on either group. What the enablement-effect argument suggests is that with regard to this dichotomy, government should focus attention on the users, since it is through use that the enablement will occur. This is a dangerous strategy, though, due to the interaction of users and suppliers in this technology. This point will be emphasised below, and I will argue that suppliers are also very important in realising the economic potential of information technology.

Successful adoption of IT[5]

The enabling function of information technology takes place only if IT-based technologies are adopted by producing firms throughout the economy. It is therefore important to understand the situation of firms that adopt IT. Obviously, a firm will not adopt information technology if it sees no gain in doing so. A firm must perceive a potential cost saving, or increase in productivity or quality of service, or a new product line before it will consider any investment. That being said, the most salient feature of IT, and the IT adoption process, is that for many firms it is an unfamiliar technology. This lies at the heart of many of the features common to successful adoptions of information technology.

For most firms, information technology is new and unfamiliar. IT represents a new production technology, and one that has different sorts of properties from older technologies. It operates on information rather than material objects; it operates under increasing returns; and it operates most effectively when individual artefacts are used not in isolation, but in concert with each other. These properties are unusual in the experience of most firms, and mark a radical departure in the way that technology can be most effectively employed. What this implies is that most firms lack experience with the technology and, consequently, prospective users do not have an internal centre of expertise on which they can draw. There are four ways in which this affects a firm's ability to adopt successfully.

Difficulty in evaluation

One implication of a firm's unfamiliarity with information technology is that, for small and medium-sized firms especially, it will find it difficult to justify investing. Firms simply do not know how to calculate the costs and benefits of the investment. Managers of successful implementations often describe the need for "a leap of faith" because they cannot see a way to do a "hard" cost-benefit analysis of the investment, in order to go ahead. Indeed, Marc Gerstein includes "demanding hard-nosed criteria for evaluation of IT proposals" in his list of "nine rules for failure".[6]

Outside expertise

A second implication of the novelty of the technology is that firms rely heavily on outside expertise. Clearly, if internal expertise is lacking, decisions about both design and implementation are all taken in consultation with outside experts, often a representative of the vendor of the technology. Supplier competence is vital, but equally important is the user's faith in that competence. Unless a firm is willing to put the decisions in the hands of outsiders, which will only happen if the firm trusts the competence and motives of the "experts", it will be impossible for it to move forward with the investment. Both of these factors – outside competence and the relationship with the supplier or consultant – are often cited as crucial factors in the IT adoption process.

Internal motivation

In its study of successful information technology implementations, ISTC found that in small and medium-sized firms there was one member of the firm who championed the investment, and was willing to push it through. This is not surprising given the condition of general ignorance about the technologies and investments in question. In any operation in which none of the participants (excluding the vendors) are confident that they can see the way the operation should and eventually will work, including not being able to see clearly its benefits, the path of least resistance is to put off decisions, and ultimately, the entire investment. In this situation, someone willing to push the project through has been central to successful adoptions.

Flexibility

It is the opinion of many managers of IT investments that flexibility was very important. They were referring to flexibility in the implementation of the investment. This follows from the way in which IT is thought to be of value. One of the major benefits of IT is thought to be its ability to introduce flexibility into production processes. Firms who use IT to its fullest potential will be able to introduce a considerable amount of customisation into their production processes in order to meet the demands of individual clients. This implies, in turn, a certain amount of customisation in the IT-based technology itself. Every firm will want to do something slightly different with the technology it is employing. Investments, then, become more complex than simple investments in old-fashioned machinery. The installation process will include "tweaking" the technology to suit the firm's particular requirements. This will, of course, introduce delays into the installation process, as problems arise with the tweaking. Hence the need for flexibility in the implementation plan. In general firms find this need troublesome.

Social and cultural attitudes

The final aspect of successful innovation that needs to be emphasised does not necessarily stem from the novelty of the technology. It is the need for a willingness within the organisation to accept and encourage change.[7] Reluctance to accept the kinds of changes in organisation structure necessary to implement IT-based innovations can quickly kill an opportunity for progress. Because the full impact of information technology often occurs only with significant organisational changes, many people within an organisation feel threatened by the implied restructuring and re-training. This can be a significant problem. External to the organisation, of course, is the general atmosphere in the society and economy. Cultural habits and regulatory regimes can also impede these sorts of changes.

From this discussion, it appears that three things are crucial to successful implementation of an IT-based investment. Internal to the firm is the will to proceed in spite of the uncertainty involved. This usually comes in the form of one person who champions the project, and a general acceptance that change is a good thing. Also internal to the firm is some flexibility in the implementation process. A rigid timetable is almost certain to be broken. Finally, external to the firm, is a source of expertise. Without trustworthy, competent outside experts, most firms will be unable to employ information technology in a meaningful way. Any of these can appear as bottlenecks to the successful transformation of an economy to the new information paradigm. Policy-makers are intensely interested in ways of overcoming these bottlenecks. The informatisation of government is one tool, or perhaps one opportunity to do so.

III. THE ROLE OF GOVERNMENT

The informatisation of government has the primary goal of improving efficiency in government operations. It can also be used, though, as a tool to promote the informatisation of other sectors. This, in its least intrusive form, will come as a side effect of the procurement involved in introducing IT into government operations. The issue, then, is how to manage this procurement in such a way as to receive the most benefit in the second sense, without impeding the desired efficiency gains within government operations themselves. What should be the "IT-enhancement" goals of procurement? What can procurement do to facilitate IT adoption in other sectors? Before turning to the issues raised above, we discuss three general answers to these questions. All of these answers are related in one way or another to the concerns discussed in the previous section.

There are three short answers: Procurement can increase the incentive to adopt IT in other sectors; it can lower the costs of adopting in other sectors; and it can lower the perceived risks of adopting.

Increasing incentives

Investments are undertaken by firms in an attempt to improve profits. In this, information technology is no different from any other technology. As the potential to increase the profits of a firm through information technology increases, so does the incentive to adopt it. Government procurement of information technology can increase the profitability of similar investment by the private sector. When government services, such as customs or tax operations, are computerised, if this is done using a relatively open system, four types of effects can be seen.

Government efficiency

First, we can expect IT to improve the efficiency of those government departments through increased speed and accuracy in their operations. This effect can operate at all levels of enablement, ranging from cost reductions in current operations to the development and implementation of new services and management practices.

Private efficiency

Second, adoption of an open system by tax or customs operations permits electronic connections between firms and government. If the customs service is able to process information electronically, importers and exporters will have the incentive to file information electronically, as that will reduce the amount of time they spend producing forms, and speed up government processing of their information. (It will also reduce their expenditures on moving the forms from their offices to those of Customs and Excise.)

Beach-head effect

The third effect might be called a knock-on or beach-head effect. Some government IT programmes are designed to facilitate communication between public and private sectors. In order to take advantage of this facility, firms must adopt certain information technologies. Adoption (or adaptation) to take advantage of, for example, electronic tax returns, can reduce the costs of using IT for other tasks, simply through spreading the fixed costs of the investment. In addition, the value to a firm of electronic tax returns increases if income tax preparation is integrated with general accounting, and perhaps further with things like inventory control or, more generally, a centralised financial system.

Further, because of the government's ability to set *de facto* data interchange standards, its adoption of IT can have the effect of dramatically reducing the costs (or increasing expected benefits) to firms adopting some form of electronic data interchange. An important, and still largely untapped, potential of IT is to facilitate closer links between firms and their suppliers (or demanders).[8] This ability, when used, can transform the way enterprises interact, and create new organisational structures. Faster communication of more, and different, information has the potential to reduce costs and improve the quality of output.

When revenue or customs departments are informatised, firms have an incentive to create closer links to those departments. If many firms do so, this will facilitate closer private links; the cause lies in standards. One of the main obstacles to creating stronger electronic links between firms is the lack of standardisation in information technologies.[9] But if two firms adopt government standards in order to, say, file tax returns, then they can use the same technologies and the same communications standards to transmit information between themselves as well.

New IT services

The final way that governments increase incentives to adopt IT is through the provision of new, IT-based services. The Department of Justice in Canada has recently implemented the Online Access to Regulations and Standards system

(OARS). This is an online database which allows members of the legal community, and other interested individuals, to search for regulations and statues. A similar technology has been developed by the US military for keeping track of technology standards. Relative to old techniques, these services are easier and faster to use, and, through facilities like cross-referencing, are more intelligent providers of information. Taking advantage of these services can generate some of the beach-head effects discussed above. In particular, it can change the way a firm thinks about IT. Many firms employ simple forms of information technology such as word processing, and see IT in that mode. The provision of a totally new service involving information retrieval may have the effect of causing firms to see IT not as a better type-writer or calculator, but rather as a technology capable of transforming the firm's use of information.

Lowering costs

Government procurement lowers costs because of increasing returns. Most information technologies operate under increasing returns to scale. They typically have both high fixed costs, arising either from large R&D expenditure or capital intensive production technology, and low variable costs. Government procurement, especially if it is large, increases the scale of production of the product being procured, and thereby lowers the average cost of production.

A more important source of cost reduction lies in dynamic increasing returns. These stem largely from learning.[10] Learning about the properties of a new technology takes place over many years as it is adopted and used. Clearly, the more extensively a technology is used, the faster learning accumulates. This learning is about three things: what properties the technology possesses; what we would like to do with the technology; and how to increase its efficiency both in use and installation. The latter two types of learning are extremely important since initial versions of products and services are usually very different from the mature versions. As users use a technology, their experiences with it provide information that suppliers can use to change the design in order to make it more valuable to future users; computer networks around the world contain reams of information generated by users about the properties and problems of computer software. The process by which this happens is referred to as learning-by-using.[11] Thus, as a technology is adopted by more and more users, it evolves to satisfy their needs more efficiently, and becomes more valuable to users with similar needs.

Procurement also provides experience for vendors. As vendors gain experience customising systems, they build a stock of knowledge and a stock of "modules of functionality", both of which can be used in future installations. This learning on the part of vendors will clearly lower costs for future adopters.

Both of these type of learning – about design and about installation and customisation – point to the importance of user/supplier relationships. In order to use information technology effectively, users need to evaluate products and systems; adopt systems that meet their needs; develop user specifications; and be involved in the conception and development of new products.[12] Design will not improve and customisation will not become more straightforward if users have no way of passing their experience on to vendors. This indicates an unexpected importance for the local supply industry. If the local industry is simply re-selling foreign technologies, its ability to improve the design in response to local users' experience is severely restricted.[13] If the technology is designed and produced domestically, this is not the case. Just how important this consideration is depends on the nature of the technology and on how idiosyncratic are the needs of the local market. If the tasks performed by the technology are universally standardised, then the need for local customisation and design alterations will be minimal. If the technology is inherently flexible, and can meet the needs of heterogeneous users, then imported technology with high-quality local re-sellers will fulfil local needs. But if every installation is unique, then local skills become crucial.

A final way that procurement can lower costs is through infrastructure, both physical and human. Often, the technologies used to communicate between government offices demands high quality physical infrastructure, in particular, the telecommunications system. Upgrading the system to facilitate government activities obviously increases the possibility of private use of it. Human capital is also important though. In a survey of firms in the United Kingdom, Northcott and Walling found that one of the most important bottlenecks in IT adoption lay in the lack of skilled manpower.[14] Human capital, in terms of knowledge and skills, was discussed above, but a second important aspect of it exists in terms of attitudes, namely in the willingness to accept new information technologies. A general fear that is often expressed is the possible loss of privacy that IT implies. This brings to the fore the importance of data protection legislation as governments increase their information processing abilities. The existence of such legislation removes any similar problems that might be faced by the private sector.

Lowering risks

For private firms, investment risks arise from two sources: risks inherent in the technology itself; and risks from a lack of information on the part of the investor. Learning about the technology, as discussed in the previous section, can sometimes lower the risks inherent to the technology. Other than through that channel, there is little that procurement will do to reduce this type of risk. The same is not true of risks caused by lack of information.

As most firms are reliant on outside experts, including vendors, for information on the new technologies, the increase in the quality of information provided by vendors, as their experience increases, as discussed above, can be a positive effect of large procurements. But some government actions can also reduce the need for information. These are actions involving standards.

Lack of information is often cited as a difficulty in the decision to adopt and implement information technologies. Investors are unsure that a technology has value for them, and even if they believe that to be the case, they are unsure which vendor offers the best choice. The far-sighted investor knows that the more common is the system he adopts, the better will be its future developments. If an investor adopts common hardware, there will be a wide selection of software available currently, and future development will be actively supported by software vendors who are able to exploit a large market. Thus in technology adoption processes where technologies have needs for peripheral goods or which exhibit strong learning effects, there is a tendency for bandwagons to form. Adopters maximise benefits and lower risks by joining the largest bandwagon.

Somewhat more far-sighted investors realise that the future of information technology lies in connecting different firms, especially suppliers, distributors and final vendors. This is not yet a wide-spread phenomenon, but it is one that many people foresee. But, if this enters into decisions about current technology adoptions, a difficult problem arises. Interconnecting with other firms is relatively easy if the firms have compatible technologies. It is extremely difficult if they do not. Thus part of the investment decision involves predicting which standard one's suppliers and demanders will adopt for information storage and transmission.

In either of the considerations, government procurement can play a dramatic role. This is due simply to its size and extent. In adopting information technologies, the government, too, is faced with the same problem – which standard to adopt for information storage and transmission. This decision can have the effect of tipping a market towards one standard or another. No matter which standard the government adopts, because of its size, it will always provide a large market for future products that conform to that standard. Similarly, because of its scope, government adoption will tend to make firms and individuals throughout the economy lean towards the same standard because of the ease with which they will be able to communicate with government offices.

The issue of standards is pervasive in information technology, and is important enough that we will return to it later for a more detailed treatment. Before doing so, however, we turn to more specific issues in procurement, and how procurement can facilitate or encourage adoption in other sectors. In doing so, we refer to the characteristics of successful adoptions discussed above.

IV. MAIN POLICY INITIATIVES

Spillovers from procurement

Because of the size of government operations, procurement can have several effects on the rest of the economy. In particular, government procurement can influence the rate of adoption of new technologies. Three avenues for effects are open: there is a demonstration effect; an effect through information and training; and an effect through government acting as a source of demand for local industry. All of these effects are contingent, though, on the government being a progressive, innovative first user of technology. If the government is not progressive and innovative, or even if it is not perceived as such, it will be difficult for innovations made by government to have positive effects on the propensity of the private sector to innovate.

Demonstration

When an economic agent performs some action that is perceived to be to its benefit, other agents who operate in a similar way will try to emulate that action. This effect can operate at different levels of generality, and several levels exist in government adoption of information technology.

First, an adoption of information technology is simply an example of IT in action. If the adoption is successful, and is seen as being part of the same family of technologies as other forms of IT, it can provide a boost to the general view of the value of IT. At this level of generality, the demonstration effect is likely not to be identifiable. This is because of the difficulty in maintaining the integrity of the class of information technologies. Some technologies that are vastly different from each other are both considered information technologies, and so the successful adoption by government of word-processors is unlikely to have a large impact on the adoption of numerically controlled machine tools. There may be some effect of raising the profile of "the new, modern technologies".

A more important effect is a more specific one. There are many activities common to both public and private sectors: word processing; accounting; data storage and retrieval, to name only one class. Here the demonstration effect is immediate. If a government agency successfully automates one of these functions, this demonstrates first that it is possible, and second, if the adoption is successful, that automation implies a cost saving or quality improvement. In this case, the demonstration may be technology-specific, such as in the adoption of a particular piece of software, or it may be slightly more general, if the adoption is easily seen as part of a larger class of innovations, namely software that will automate a particular type of function rather than a specific task (financial analysis rather than book-keeping, or data retrieval rather than a personnel database). This would contribute to the beach-head effect referred to above. In either case, successful adoption by a government agency will demonstrate that there is a use for this technology, and that its benefits exceed its costs.

The demonstration effect may have its most profound impact on the ability of a potential adopter to justify an investment. The difficulty in justification stems largely from potential adopters not knowing how to evaluate the costs and benefits of the adoption. The existence of successful adoption of the same or similar technologies can yield important information about how costs and benefits manifest themselves, and therefore how they should be evaluated. For competitive reasons, private firms are likely not to want to reveal this information, so this operation falls to the government. Actual cost-benefit analyses of actual projects contain both information about costs and benefits and, more importantly, information about how to estimate, before the implementation, what those costs and benefits will be. If firms have access to this sort of information their ability to perform analyses of their own projects will be much improved.

How important the demonstration effect will be depends on two things. The first is the degree of openness of the government. Clearly if technology adoptions are kept secret, or are not publicised, there will be no demonstration effect. Demonstrations only work if people know about them. Secondly, whether the demonstration effect will be positive depends on there being a certain amount of respect for the government. In many countries in the Western world, government actions are viewed with considerable scepticism. One can sense a feeling that actions taken by the government are not viewed as something to emulate. Indeed, in its extreme form, the view is that if the government is doing something, then it is bound to be a bad thing to do. Clearly, if this is the sort of atmosphere in which the government operates, the scope for a beneficial demonstration effect is severely restricted.

Information and training

New technologies share the feature that, as they are used, information about them is generated, and this information can be used to improve their performance. In this situation every adoption has three effects: it provides a benefit to the adopter; it provides information about how to improve the performance of the technology; and it provides information about the properties of this technology relative to other competing technologies. In terms of spillovers from government procurement, the second two effects can be very important.

Improvements in the performance of technologies come from two sources: improvements in operation (including installation); and improvements in design. The former is called learning-by-doing, the latter learning-by-using. Knowledge gained through learning-by-doing is non-transferrable to a large extent. It is tacit knowledge about how operations work, and how they are made more efficient. Thus unless this learning is somehow made public and transferable, it is likely to have little spillover effects.

There is a type of learning-by-doing though which will be of value, namely that acquired by vendors. Though the knowledge may be tacit, and vested in the vendors, it can be applied in installations for any future users. For all but the most straightforward adoptions of off-the-shelf technology, installation of a technology involves customising it to the particular uses to which a firm will put it. This operation ranges from simply setting parameters in a relatively fixed technology to effectively designing a custom system using only the basic framework of existing principles. As installations become more like the latter, the ability to predict what should be done and how long it will take deteriorates rapidly. This accounts for the importance of flexibility in the installation plan. As vendors gain experience in installing systems, their ability to predict what will be needed, and how long the installation will take will improve. Furthermore, the time it takes to do the installation will decrease. This is a well-documented feature of new technologies.

As discussed above, learning-by-using refers to the feedback between users and suppliers of technology. Designs change and improve as users communicate their experiences to suppliers. This can be a very important effect if the technology is used extensively and there is active communication between users and suppliers. This information can have a large impact on profitability of future adoptions. Again, an active supply sector can be very important in actualising the potential benefits that lie in the information generated by early users.

Source of demand

When a technology is new, either to the world, or only to a single country, the firms developing it can face an obstacle that looks like a vicious circle. Early in the life of a technology, little learning has taken place, so costs are high. This limits demand. Lowering costs involves experience in using and producing the technology. But if there is little or no demand, this experience is impossible to obtain. Thus the technology cannot be developed, and local industry will be unable to enter that market. This is, in essence, the infant industry argument.

Government procurement, often through the defence sector, is a very common major source of demand for new innovations. In the early 1960s, the United States defence establishment provided 100 per cent of the demand for the new integrated circuit technology.[15] Similarly, the United Kingdom has a domestic supply of the composite materials made from carbon and boron fibre, largely because in the early stages of its development, Courtauld Plc. had a stable source of demand in the military. Courtaulds "found demand from defence projects to have been invaluable in getting under way."[16] More generally, Dalpé and DeBresson found that, of about 2 000 innovations produced in Canada between 1945 and 1978, the public sector was first user (sometimes jointly with the private sector industries) of 25 per cent.[17] Of innovations in communications equipment, and electrical industrial equipment governments were first users of 40 and 33 per cent respectively. This gives government a large influence on innovation in these sectors, and indicates its importance as a source of early demand. The influence is of positive value, though, only if the government is a sophisticated user, and is able to foster continued innovation in the industries from which it is procuring.[18]

Government procurement can and has been extremely valuable in assisting local industry to overcome the early, high-cost and high risk phases of technological development. Cases where this has been most successful exist where the government priority has been the services that some technology can provide, rather than the support of an industry. There is an inherent difficulty when the priorities are reversed. To develop an industry or technology successfully, the demanders of the service must have a vested interest in the quality of the services provided with the technology. Only in this case will the feedback from user to supplier be of high enough quality that technological development will be both rapid and appropriate. Clearly, this interest will be strongest and most effective when the government cares about the services rather than the industry.

The importance of interest in the technology points to a critical property of early intervention. Early entrants on either side of the market can have a large weight in determining the future trajectory of technological development. This is particularly the case if the entrants are large. Size can be defined in various ways, but the principle is that the actor has the ability, either deliberately or not, to force many other actors to follow in his footsteps. Two examples make the point. The early history of nuclear power reactors in the United States was dominated by the Navy. It had peculiar needs, and so developed a particular technology. The Navy was willing to spend considerable sums to speed this development, so the light water technology was developed much more quickly than others. So much so in fact, that its developers, General Electric and Westinghouse, were able to capture the market for civilian power stations using the same technology, even though it may not be the best suited to civilian needs.[19]

The second example is more current. In the late 1970s General Motors saw a need to integrate its many IT-based devices, (such a numerically controlled machine tools, robots and so on). These devices were obtained from many different vendors and were not inherently compatible so GM was forced to design expensive, customised interfaces between incompatible machines. To create a world in which these devices could all communicate, regardless of their vendors and without the need for gateway technologies, GM began to design the Manufacturing Automation Protocol (MAP) in 1980. Because of its size, General Motors was able to recruit many of its suppliers into MAP development. MAP has evolved considerably since 1980 and some doubt its eventual success but, because it was the originator of the system, and because of its size, General Motors was able to direct the early development of the system to ensure it had the features that were most important to GM.[20]

Early and/or large adopters have the ability to make a significant impact on the future technological trajectory. They can form the core around which later or smaller users cluster as they wish to ensure compatibility with the common technology. They can also simply push one technological variety along through their willingness to support development of the properties they wish to see in it. This ability brings with it a risk of pushing the technology the wrong way, as is thought to have happened in the case of nuclear power technology.[21] I return to this issue below, in the discussion of standards.

Government procurement as a source of early demand, then, can be very beneficial to the development of local industry. Probably the most important aspect is its contribution to local expertise. The only way a vendor can gain expertise is through experience supplying and installing technology. Similarly, and as important, the only way a vendor can generate trust in prospective clients is through having demonstrable experience in successful applications.

There are two issues which need to be resolved if this discussion is to be used to focus policy. The first pertains to the "level of supplier". Local expertise is needed, but expertise in what? Certainly in installation and set-up of information technologies. Whether expertise in the development and production of information technologies is necessary is a more difficult question. The answer depends very much on the technology in question, and the degree to which each application of it represents a separate development. If a technology is such that adopting it involves little or no customisation, then the technology can be thought of as stable, and off-the-shelf. Local expertise in its production and development is not necessary to have effective installation. On the other hand, if a technology requires significant tinkering in order to make it meet the requirements of individual users, then every installation can be seen as a separate product development. In this case, local expertise at a deep level will provide far more effective use of the technology than will simply the existence of re-sellers of foreign technology.

The second issue concerns "local". So far in this discussion "local" has referred to geographical locality, and the need to have experts residing in the country. Often, though, "local" is used to refer to ownership, and there is concern that locally-owned firms prosper. This is an issue that raises considerable contention, and one that I do not propose to resolve. Ownership and prosperity of locally-owned firms may matter for many different reasons. Strictly within the context of this discussion, though, the crucial thing is not ownership *per se*, but rather the presence of human capital that facilitates appropriate adoptions and adaptations of information technology. From this point of view, the importance of ownership lies in the relative propensity of foreign *versus* domestic firms to generate this human capital.[22]

Procurement and successful private adoption

I close this section by returning explicitly, but briefly, to the interaction between government procurement and the properties of successful IT adoption discussed above. Government procurement can have beneficial effects on information technology adoption in the private sector, but an understanding of how the benefits flow from one place to the other allows policy-makers to facilitate that flow.

Difficulty of evaluation

Private investors have difficulty evaluating potential adoptions largely due to ignorance about the technologies, and ignorance about how to evaluate them. Government adoptions of IT can alleviate both of these problems simply by publishing information about the adoptions, and their costs and benefits. This information can be synthesised and used to create techniques for evaluating similar investments. Any adoption will yield information about hidden costs and hidden benefits. Information about both of these is extremely valuable to anyone trying to evaluate similar projects.

A second way of easing evaluation is through the promotion of standards. The existence of a standard removes much of the risk involved. It does not tell a firm whether there are benefits from a technology, but it does tell a firm that adopting a particular variant will not lead to being stranded on a technological orphan in the future. This ensures future ability to communicate with other users of the technology, both about the technology and with the technology, if it is of the network type.

There is a final way of increasing the ability to evaluate investments. This is through increasing the general awareness of, and familiarity with, information technology. This is done simply through the education system. It is an indirect approach, and one that has a long gestation period, but one that is probably necessary if the economy is not to be polarised between those who are "IT-literate" and those who are not. This issue is a concern in many countries, particularly those with geographical disparities. Some educational districts have good access to curricula that involve and take advantage of information technology, and some do not. Students educated in the former will find employment in high productivity, IT-using jobs, and students educated in the latter will not. This, of course, feeds any geographical disparities and contributes to a two-tier employment structure, in which employment growth occurs in high-skilled and unskilled labour, but employment in semi-skilled occupations declines.[23]

Outside expertise

The lack of IT-experts in any country is alleviated only by experience. Potential experts become actual experts by taking part in many installations and operations of information technology. A certain amount of expertise can be gained through the experience of others, but only if their experience is published. This sort of information serves two purposes: first, to help local vendors learn about systems; but second, also to allow local users to learn about vendors and their experience in previous work. Again, training and education, while a long-term strategy, will increase the level of general competence, and so reduce the total reliance on outside experts that has been a noted feature of many IT adoptions.

Internal motivation

The role of a champion within the user firm, so common among the firms studied in the ISTC report, is elusive. No one knows how to produce entrepreneurs. The only feasible hope for government influence in this area is to reduce the need for them. They would not be needed, of course, if detailed, hard, cost-benefit analyses were possible for information technologies. They would also not be needed if there were a general familiarity with (and trust of) information technology. Both of these suggestions are discussed above.

Flexibility

Flexibility in the adoption and installation process was considered vital in successful innovation. This need arises from the inevitable unforeseen problems that occur as an installation takes place. The need for flexibility is often under-estimated, but this under-estimate can be reduced, in general, by publishing experiences of past adoptions, highlighting departures from and changes to the original plan. The other approach to this characteristic of adoptions is to attempt to reduce the need for flexibility. This is done, of course, through improving the installation process, improving the ability to plan this process, and reducing the number of unforeseen problems. Again, the way to do this is by increasing the quantity and quality of local expertise. The more experience vendors have, the fewer problems they will encounter, even when they are customising technology for idiosyncratic uses.

Social and cultural attitudes

Generating appropriate attitudes is also elusive. Two concrete steps can be taken to alleviate particular concerns. Legislation to protect individual and firm privacy in the face of the information revolution should be put in place early in the government's programme. Secondly, studies of the employment effects of information technology indicate that the concern that IT is employment-reducing seems to be misplaced.[24] The truth of this at a macro level, combined with demonstrations that IT can be used to increase labour productivity rather than to replace labour, will be very influential.

V. THE CHALLENGE OF STANDARDISATION

Standards

To a certain extent, the benefits from government procurement of information technology discussed above flow virtually automatically to the private sector. The size of government procurement cannot help but increase local expertise, which is one of the main obstacles to widespread adoption of IT. In addition, as government services are informatised, private agents adopt IT so as to be able to take full advantage of them.

There is, however, one very serious consideration regarding government adoption. This has to do with standardisation and choice of technology.[25] When a new technology (or family of technologies) appears, there are typically several variants that perform the same tasks. This often results in a competition among them for market share. Standardisation occurs if one of the technologies or standards decisively wins the competition.

Technological competitions have been extensively studied in the economics literature over the last ten years.[26] There are two results common to virtually all the theoretical work: under a wide variety of circumstances a market will lock in to a single technology; and under an equally wide variety of circumstances a market can lock in to an inferior technology.[27] The basic insight which produces these results, and which applies to most information technologies, is that as technologies are used the benefits from using them increase. Thus as more and more people use a particular technology, it is more likely that other people will adopt it, or switch to it, and eventually all agents in the economy will have adopted that technology. Clearly, when a process like this is taking place, if for some reason an inferior technology gains a lead in the race for market share, this encourages people to adopt it, and its lead is increased. A bandwagon can form and future adopters join it.

Two types of forces act to create this bandwagon. As discussed above (see text at and around footnote 11) IT is subject to learning-by-using. This can contribute to a bandwagon if one technology makes these changes faster than another. Many information technologies are sufficiently new, particularly in some parts of the world, that this force can be very potent. Vendors, of course, are particularly active in this regard, as they have a preference for installing those technologies with which they have experience, and vendors with more experience will be better able to make installations that avoid unexpected delays. The second force contributing to bandwagon effects is the existence of externalities in use. A major part of the benefit from information technologies as a class arises from its ability to facilitate transfers of information between different actors. This will only happen, though, if those actors are using compatible systems. If information transfer is a concern, there are very large advantages to adopting a technology that is compatible (in this sense) with those used by as many other agents as possible. Again, this has obvious bandwagon-forming tendencies.

The results of the theoretical literature on technology competitions are very likely to apply to information technology. Given that government is typically a large user, and thus its decisions can have large consequences in terms of pushing the competition towards one or other technology or standard, its choices must be made very carefully. In this context, government activities can be used in two equally important ways: to encourage standardisation; and to facilitate the adoption of a "good" standard.

Encouraging standardisation

Any large or geographically dispersed country must face the issue of market fragmentation. As discussed above, the value of information technologies increase to a user as there are more users in the economy. When a country is large, though, this effect is very likely to be localised – agents interact more intensively with nearby agents than they do with distant ones. Thus benefits to using IT increase more dramatically as nearby users adopt than as distant users adopt. This consideration obviously feeds into the arguments about standardisation enunciated above. What it implies is that standardisation can fail to take place because spatially separate markets follow different paths. One region of a country can adopt one standard while others adopt another. After all, some regions are more sophisticated than others, and regions may have distinct needs for the technology. As each pursues its own technological choice, each gets locked in.[28] This describes the history of the Australian railroad system in which three different track gauges survive. Spatial differences may not be a problem if the economy is segmented, but as the economy grows, different regions interact more and more with each other, and the non-standardisation may become a serious impediment to the complete exploitation of technological possibilities.

Government activities can have an influence in this situation in two ways. The first is simply by setting national standards. Because the existence of a standard reduces risks in adopting IT and makes the necessary decision-making easier, simply the announcement that there is a national standard that has been approved by the appropriate standards-making body will encourage agents throughout the country to adopt the same technology. In this sense, standards act as a co-ordinating device – agents wish to standardise in order to take advantage of the technology, but have difficulty knowing which will be embraced. The announcement removes this uncertainty.[29] Setting a standard by *fiat*, though, raises all the issues of which standard to embrace, which we discuss in the next section.[30]

The second way in which government activities can have a beneficial effect arises from its size and geographical extent. The government, because of its size, can set standards for some technologies simply by the act of adoption. Large-scale purchases drive the price down, from possible increasing returns and learning effects, and, for some technologies, desire to communicate with the government will encourage other agents to adopt compatible technologies. Because government operates throughout the country, co-ordination among government procurement decisions can prevent or reduce the problems that arise from different regions following different technological paths.

There are several over-arching activities that must take place if government actions in this area are to have an effect. The European Commission for example, sees the importance of (European) economy-wide standards:[31] European governments are urged by the EC to play an active role in verification and certification of standards. Equally important is the creation of guide-lines forcing procurement to pay attention to all relevant standards. The effects of government size will be eliminated if the government acts in a fragmented way. Its ability to exert any control over the standardisation process demands a certain amount of centralisation in this regard.[32]

Which standard?

If procurement is aimed solely at improving the efficiency of services, then technology choice is relatively straight-forward – choose the technology that will provide the desired service most efficiently. This advice is complicated, though, if possible future developments are considered. It may be that the technology in question could be used for interaction with other departments at some time in the future. Here, co-ordination is required. Either both agencies must co-ordinate on a technology now, in the anticipation of future benefits from inter-operability, or they must be willing to pay the costs of acquiring a gateway technology that will let the two technologies inter-operate. With an active central authority, not necessarily choosing technologies, but informing different agencies of the importance of co-ordination and standards, this sort of problem may not be severe.

If procurement is aimed not only at raising the efficiency of government, but also at facilitating information technology adoption and exploitation in the private sector, including further development of the technologies, there is another layer of problems. This has to do with the choice of technology or standard. Clearly, there is a desire to adopt a good standard; the problem lies in "good".

Domestic considerations

If the technologies or standards are new, then one of the biggest problems facing the standard-setting body is in the uncertainty surrounding the candidates. The characteristics and relative advantages of the technologies are not well-known, and can only be learned through use. Thus early adoptions of the technology not only provide benefits to the adopters, but also provide information about the properties of the technologies. Unfortunately, while the former is of value to the adopter, the latter is, generally, not. So while every adoption has two valuable features – the benefits it provides, and the information it provides – adopters typically care only about the former. The information-generating aspect of adopting will be under-valued by the market, the market will under-supply experimentation early on in the life of a technology, and so will standardise too early.[33] Procurement *per se* adds to this haste, but, if used carefully, as a tool for experimentation, it can be a mitigating force. If used this way, though, there will obviously be government adoptions that eventually turn into technological orphans. Because the goal of increasing the quantity of experimentation lengthens the competition, there will also be more orphans in the private sector. If the costs of switching these orphans over to the dominant technology are expected and planned for, then this approach to procurement can be beneficial to the ultimate outcome of the standards competition. If not, there is a serious risk of doing long-term harm to economic efficiency both in government and in the private sector, as agents will be technologically isolated from the standard.

These considerations apply most intensely when the technology being considered is relatively new. Often, however, technologies are well-developed, and the issue for standards is not one of uncertainty and information, but rather a question of the relative desirability of different options. This leads to international considerations.

International considerations

Occasionally the goal of technology policy will be to capture the world market with a domestic standard. In this case, the role of government activity will be inverted relative to the previous discussion. To get a good domestic standard, governments delay the moment of choice in order to gather information. To capture the world market, domestic standardisation should take place quickly, in order to build a large installed and manufacturing base, and the standard should be pushed early into the world market. It is, however, relatively uncommon for governments to be faced with this issue.[34]

A more common concern is the loss of control over domestic policy. Globalisation of the world economy, to which information technology has contributed no small part, has reduced the range in which domestic policy measures can be effective. Any decision on a domestic standard must be made in light of its effect on the ability of domestic firms to interact and/or compete with foreign firms. Choice of a standard for electronic data interchange, for example, will determine the relative costs of doing business with different overseas firms. As a result of considerations like this, it is common that the choice of a domestic technology must be made among several relatively well-developed world standards.

There are two reasons simply to adopt a world standard and force domestic suppliers to conform. The first is that it will lower costs. If a world standard has been written, then it is often the case that considerable development work has been done in the standardisation process and is relatively public knowledge. Because this reduces development costs, the costs of adopting the technology will be lowered. Costs are also lowered by the standard in that several suppliers of technology will be forced to compete on price.

The second reason to be relatively passive in technology choice has to do with integration into the world economy. Globalisation has dramatically increased the importance of international communication. The need for domestic firms to be able to communicate easily with foreign firms has become much more important than was the case in the past. Thus a choice of a domestic technology or standard that does not conform to world standards can harm the interests of domestic firms. In addition, the existence of a single global market has meant that export potential is a serious consideration for technology choice. The difficulty of exporting a non-standard technology was instrumental in the French decision in the late 1960s to abandon their own nuclear power technology and switch to the technology that was dominant in the world market. Thus the ability of domestic policy-makers to control domestic technology choices, either through deliberate policies or through the side effects of, for example, procurement, has been severely circumscribed in recent years. No longer can policy-makers simply attend to the domestic competition in the hopes of achieving a good domestic standard. Every decision must now pay attention to its effects on firms' abilities to integrate with and compete in the world economy.

On the other hand, there may be reasons to foster domestic firms and technology. The most obvious one is the existence of domestic idiosyncrasies. If a domestic industry has needs that are not satisfied by foreign technologies then, obviously, a domestic technology must be developed. In this case, all the advantages of government procurement as discussed above can be realised. Growth of a domestic industry to serve some particular need will, in all likelihood, have spillover effects into other industries in which domestic idiosyncrasies are less dramatic, but in which local expertise is still thin. This, of course, is the other reason to foster domestic industry – simply that this may be the only effective way of developing domestic expertise. It was stressed above that a major bottleneck in IT adoption is appropriate human capital, both in the adopting firms and in the vending firms. This human capital can only be developed with experience, and the complete absence of a domestic IT-supplying industry will effectively prevent this experience from accumulating.

There is a dilemma then. Domestic strength on the supply side is necessary to achieve enablement on the user side. In addition, idiosyncrasies, especially if a country is small, may not be well-served by international technologies. But economies of scale in the production of information technologies are such that failing to adopt world standards and common technologies will significantly raise costs.

A possible way around this dilemma lies in gateway technologies. Gateway technologies are technologies designed to make two apparently incompatible systems compatible. Effectively, they are translators – they translate information presented in one standard form into the same information in a different standard form. The better the gateway, the less information is lost in the translation. In situations where costs or export potential are the main considerations, then gateways can be used to add functionality to foreign technologies such that idiosyncrasies in local needs can be served. On the other hand, where particular domestic needs demand a local technological solution, gateways can be used to provide interconnectivity with other technologies. In either case, if the development of gateway technologies is encouraged, adopting a technology based on one consideration, either cost or local needs, need not preclude taking advantage of what the information technology in general offers in the other domain.

VI. CONCLUSIONS

Several conclusions can be drawn from this study. The general conclusion is that the priority of the government should be to encourage adoption and diffusion of IT-based technologies throughout the economy. There are several means to this end.

Demonstration

Government projects demonstrate costs and benefits of a technology and, equally important, how to calculate those benefits before investing.

Skills and knowledge

Government projects can encourage the development of local skill and knowledge relevant both to the use, and to the development and installation of information technology. To this end, in some circumstances, the health of the local supplier industry may be very important.

Market weight

Government must be very careful about the use of its market weight. It has the power to set standards either *de jure* or *de facto*. This is a two-edged sword, as standardisation in general is a good thing, but there is a risk of setting a bad standard. There is, further, a difficult trade-off between moving early in order to get benefits quickly, and waiting for better information before choosing a standard.

Beach-heads

By providing new services that agents want, government actions will force individuals to adopt IT in order to make use of these services. This can provide a basis on which future IT adoptions can be built.

Government co-ordination

To achieve these effects, government actions must be co-ordinated. Different departments must use the same standards where possible, and provide the same types of IT-based services throughout the country.

Social and cultural

Governments can help to change attitudes towards IT, particularly in encouraging projects that increase labour productivity rather than replace labour. Similarly, it can ease fears of the new technology through such things as privacy legislation and education policies.

Open, innovative government

None of the above effects will take place unless the government is open, and seen as progressive. The main bottleneck is information, and most of the effects above can be characterised as generating and publicising information. This is of no value unless the information is seen as trustworthy and valuable.

NOTES AND REFERENCES

1. Exceptions might be publishers and broadcasters in some countries, or entertainment suppliers.
2. STATISTICS CANADA, *GDP by Industry 1993*, and *Employment, Earnings and Hours*, various years. These numbers exaggerate the importance of the sector because they include all revenues from long distance telephone calls. Fully 30 per cent of the employment created in the IT sector was created in the telephone industry alone. See also OECD (1989), *Information Technology and New Growth Opportunities*, ICCP Report No. 19, p. 13.
3. This discussion of the enabling effect is drawn from *The Enabling Effect* published by the INFORMATION TECHNOLOGY ASSOCIATION OF CANADA (1988), Toronto.
4. See OECD (1992), *Information Networks and New Technologies: Opportunities and Policy Implications for the 1990s*, ICCP Report No. 30, pp. 17 and 26.
5. This section draws very heavily on *Putting the Pieces Together: Case Studies on the Deployment of Information Technology in Canada*, Industry Science and Technology Canada (ISTC) and Information Technology Association of Canada (ITAC) (1988) Ottawa; and a follow-up study, *Things Change, Economies Evolve*, ITAC (1992), Toronto.
6. Marc GERSTEIN (1987), *The Technology Connection*, Addison-Wesley, p. 174.
7. See especially ITAC (1992), *Things Change, Economies Evolve*; and OECD (1989), *Information Technology and New Growth* Opportunities, ICCP Report. No. 19. pp. 37 and 171.
8. See OECD (1989), *Information Technology and New Growth Opportunities*, ICCP Report No. 19, p. 44.
9. OECD (1992), *Information Networks and New Technologies: Opportunities and Policy Implications for the 1990s*, ICCP Report No. 30, p. 32.
10. Another type of increasing returns often discussed in the context of information technology is referred to as network externalities. The term is applied when the benefits from using a technology increase with the number of others who use it. Electronic data interchange (EDI) is an example of this type of technology and is an example of government procurement increasing incentives to adopt, as in the section above.
11. For a discussion of this effect, see N. ROSENBERG (1982), *Inside the Black Box: Technology and Economics*, Cambridge University Press.

12. This list is drawn from OECD (1989), *Information Technology and New Growth Opportunities*, ICCP Report No. 19, p. 41. See also ITAC (1992), *Things Change, Economies Evolve*.

13. Presumably, the local re-sellers could communicate the experiences of their clients back to their suppliers, but this route may be too circuitous to have the desired effects. von HIPPEL (1976), "The Dominant Role of Users in the Scientific Instrument Innovation Process", *Research Policy*, Vol. 5, documents an extreme case in which 80 per cent of significant innovations were in fact invented by users. In a second study, "Lead User Analyses for the Development of New Industrial Products", *Management Science*, Vol. 34, 1988, von HIPPEL and URBAN find that early users of CAD have "unique and useful data regarding both new product needs and solutions responsive to those needs", p. 569.

14. Jim NORTHCOTT with Annette WALLING (1988), *The Impact of Microelectronics: Diffusion, Benefits and Problems*, British Industry Policy Studies Institute, London.

15. John E. TILTON (1971), *International Diffusion of Technology: The Case of Semiconductors*, Washington, DC, Brookings Institute, p. 91, quoted in E. Steinmueller, "Industry Structure and Government Policies in the US and Japanese Integrated Circuit Industries", CEPR Discussion Paper, Stanford University, 1986.

16. P. GUMMETT and I. BATE (1988), "Defence-Civil Relations in the Development of New Materials in Britain", in P. Gummett and J. Reppy (eds.), *The Relations between Defence and Civil Technologies*, Kluwer, p. 286.

17. R. DALPÉ and C. DeBRESSON (1992), "The Public Sector as First User of Innovations" *Research Policy*, Vol. 21.

18. On the importance of users' technical sophistication see O. GRANDSTRAND and J. SIGURDSON (1985) (eds.), *Technological Innovation and Industrial Development in Telecommunications: The Role of Public Buying in the Telecommunication Sector in the Nordic Countries*, Research Policy Institute, Lund; and R. DALPÉ (1990), "Politiques d'achat et innovation industrielle", *Politiques et management public*, Vol. 8.

19. For a variety of reasons the United States wanted its technology to dominate the world stage and successfully established dominance by subsidising its adoption both at home and in Europe. For details of this history see R. COWAN (1990), "Nuclear Power Reactors: A Study in Technological Lock In", *Journal of Economic History*, Vol. 50.

20. For more detail on the history of MAP see T. BRESNAHAN and A. CHOPRA (1990), "The Development of the Local Area Network Market as Determined by User Needs", in *Economics of Innovation and New Technology*, Vol. 1; or B. DANKBAAR and R. van TULDER (1992), "The Influence of Users in Standardisation: The Case of MAP", in M. Dierkes and U. Hoffmann (eds.), *New Technology at the Outset: Social Forces in the Shaping of Technological Innovations*, Campus Verlag.

21. See R. COWAN (1990), "Nuclear Power Reactors: A Study in Technological Lock In".

22. On the debate about the importance of ownership see Michael PORTER (1990), *The Competitive Advantage of Nations*, Free Press; or Robert REICH (1991), *The Work of Nations*, Alfred A. Knopf.

23. See, for example, Howard WILLIAMS (1988), "Internationalization and the Production of Technology and Information", in R. Plant *et al.*, *Information Technology: The Public Issues*, Manchester University Press.

24. See OECD (1989), *Information Technology and New Growth Opportunities*, ICCP Report No. 19, p. 35.

25. Throughout this section I refer to choice of technologies. The discussion applies equally to choice of standards. The main issue here is the problem of choosing among several ways of performing the same task.

26. See W. Brian ARTHUR (1988), "Competing Technologies: An Overview", in G. Dosi *et al.* (eds.), *Technical Change and Economic Theory*, London, Pinter; P. DAVID and S. GREENSTEIN (1990), "The Economics of Compatibility Standards: An Introduction to Recent Research", *Economics of Innovation and New Technologies*, Vol. 1; or Dominique FORAY (1989), "Les modèles de compétition technologique: une revue de la littérature", *Revue d'économie industrielle*, Vol. 48, for reviews of this literature.

27. "Inferior" is defined here in an *ex post* sense, namely as a technology which, as the dominant technology, would yield less than maximal net benefits.

28. For a theoretical treatment of the situation of spatially distinct regions within an economy see R. COWAN and W. COWAN (1994), "Local Networks and Spatial Equilibria: On the Nature and Degree of Technological Standardisation", Research Report 9421, Department of Economics, University of Western Ontario. Cowan and Cowan show that if there are positive, local externalities in use, but negative global externalities, say from decreasing returns in the production of the technological artefact, then the equilibrium described in the text is in fact a common one.

29. See S. SCHMIDT (1992), *Negotiating Technical Change Through Standards: Technical Co-ordination in Market and Committees*, Max Planck Institute, Cologne, June.

30. There is a problem not directly referred to below: If there are installed bases of different technologies in different regions before a standard is set, the standard-setting body may face severe difficulties if the regions view themselves as politically distinct.

31. See the CEC Council Decision, December 1986, on standardisation in the field of information technology and telecommunications (87/95/EEC).

32. One possible exception to the need for centralisation in standards decision-making is when the government is trying to encourage experimentation with different standards, as discussed below. In this case, fragmentation of government actions might have the desired effect.

33. This can be exacerbated in a situations of fierce competition, as private firms will have incentives to keep their experiences with the technologies secret from one another.

34. For more discussion of this issue see OECD (1991), *Information Technology Standards: The Economic Dimension*, Paris, especially pp. 95 ff.

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