Towards European Innovation and Diffusion Policy for the Knowledge-Driven Economy

Some Analytical Guideposts

By

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1.Introduction: What we knew about the economics of innovation, and when we knew it

This discussion paper attempts a kind of intellectual Astock-taking.≅ Does the European Commission approach to Ainnovation policy≅ stand in need of updating? One way of tackling such a question is to ask in what directions research on the microeconomics of innovation and the diffusion of new technologies recently has been evolving, and whether the analytical rationale upon which public policy in this area was grounded may have become dated, if not obsolete. To be sure, this can only furnish a partial answer. Changes in socially and politically shaped goals, or shifts in the relative importance accorded to particular policy objectives, also would warrant re-examination and possible realignments of programs. The focus here, however, will be on questions of the first kind.

Implicitly this presupposes a broad measure of agreement in the view of technological change as being socially valuable for its potential to contribute to social welfare. We speak of techological innovations as constituting Aprogress≅ because those that are brought into practical application in the context of market economies (and rationally planned economies) generally have the effect of enhancing the quality of existing products and services, or create new commodities with superior attributes, or reduce the real resource costs of a given production program. But, recalling Schumpeter=s reference to the process of innovation as one that entails Acreative destruction,≅ it is important to bear in mind that the pace of technological progress itself is a matter of policy choice. Innovation in this domain is not unproblematic. It is a source of uncertainty in economic and political affairs, and history attests fully to its capacity to profoundly disturb social and legal institutions, challenge the economic viability of existing organisations, alter the relative and absolute valuations of various forms of tangible wealth, displace workers from traditional occupations, and pose troubling ethical issues about the propriety of utilising whatever new powers that thereby have been placed in human hands. Appreciation of such disruptive potential suffices to establish to point that there is no basis for proceeding on the assumption that maximisation of the rate of Atechnological progress≅ must be the socially optimal policy.

While not slighting the importance of these qualifications, and the consequent need eventually to situate the design of science and technology policies within a more general economic policy context, a more restricted start can be made by reviewing the salient features of the microeconomic framework that informed the frankly Apro-innovation≅ policies of the EC and the EU=s member nations during the early 1990's. This is done with extreme brevity, in Section 2. The following four sections then take up a sequence of themes that have emerged in the literature, building in some cases upon the systems approach to technological change, and, in other cases questioning some of the rationales for familiar science and technology policies. The sampling of Anew directions≅ reviewed here includes a brief review of the reformulation of the rationale for public support of the science base (section 3); the attention to Atacitness≅ and the re-assessment that this has promoted of the traditional thrust of public policy regarding subsidies for R&D (section 4); the shift of interest away from the generation of new technologies, towards a recognition of the significance for Ainnovation≅ of enhancing access to the relevant knowledge base. The latter directs attention to the institutional and public policy determinants of the Aknowledge distribution power≅ of national and regional Ainnovation systems,≅ and to the role of the economics of knowledge codification within that context (section 5). Lastly, we notice the recent revival of interest in the effects of localised knowledge spillovers as a source of innovative activity, and a promoter of spatial agglomeration of small and medium-sized firms in high-tech industrial and business service Aclusters≅ (section 6).

2. Past Mileposts: From the linear model to the national innovations systems perspective

A convenient intellectual bench-mark is provided for our purposes in the 1993 document edited by Luc Soete and Antony Arundel, *An Integrated Approach to European Innovation and Technology Diffusion Policy: A Maastricht Memorandum.*[1]

The systems approach to technological change

The conceptual framework of that report reflected the prevailing consensus among economists that a Asystems approach≅ to understanding the dynamics of technical change is more realistic, and provides a more useful policy guide than does the simpler scheme based upon the linear stage model. The latter, which depicted the aggregate process as a flow diagram starting with basic research and moving through applied research, invention, commercial market testing, and ultimately to diffusion, was held to be generally deficient as a guide to policy formulation. It ignored important feedback loops among the distinct Astages≅, and hence the potential for both synergies and perverse interactions among policies that were Atargeted≅ to affecting one or another stage.

By contrast, the systems approach emphasised the importance of designing policies that recognised that innovations only affect social welfare when they come into adoption, and that policies directly primarily to inducing investment in the R&D stages at best ignore possibility that more favourable prospects of commercial adoption would encourage innovative efforts, and, at worst, fail to note that a high anticipated rate of technological obsolescence may be detrimental to the deployment of technologies embodied in durable assets -- human and non-human. The Soete-Arundel (1993) memorandum also drew attention to the fact that a parallel message had emerged in the management literature during the 1980's, favouring the closer strategic integration at the level of the individual enterprise among R&D activities, market research, product design and production engineering.

Beyond those points, the dynamical systems approach recognises that a wide array of influences impinge upon a society=s capability for transforming the products and modes of production in ways that enhance economic welfare. Some among these are more or less directly affected by governmental actions, as is the case for R&D subsidies and tax credits, and infrastructural support for education and training programs that improve the supply of skills required to implement as well as to generate new technologies and organisational designs. Macroeconomic conditions also affect the capability of the private sector to undertake investment in changes that often entail

[1] Publication no. EUR 15090 EN, Commission of the European Communities, Luxembourg, May 1993.

heavy fixed-cost investments associated with the introduction of new production systems, especially when these entail intangible assets that must be financed internally. Financial institutions, including venture capital -- which, in turn, is dependent upon access to IPO markets and responsive to the tax treatment of capital gains, directly influence the ease with which it is possible to form new business enterprises. But the technological sophistication of commercial bank loan officers and venture capitalists also can be a critical factor in the selection among the myriad of new entrepreneurial ideas that are generated.

Perhaps the most important implication of considering European innovation policy from the dynamical systems perspective is the significance of *co-ordination* activities for the success of the array of action programs.

Another very important implication of the foregoing approach is that some goals must be approached as emergent system properties that cannot be expected to be achieved quickly, and might well be attained via indirect means. The goal of creating Aa culture of innovation≅ in the provinces of Europe would seem to be of that nature. A culture of innovation is not likely to be something that governments can hope quickly to form by direct measures, say, by the recent proposal in the UK to require instruction in business methods to be a part of the training of graduate students in science and engineering; or by emulating US institutional arrangements for the management of intellectual property based upon publicly sponsored research --arrangements that have arisen in the US only since the mid-1980s. Rather than being instantly formed by setting up institutions borrowed from one notably innovative societies, Acultures of innovation≅ are *emergent properties* of the economic, political and social systems in which they develop historically, and so may manifest themselves in rather different forms. To take one, concrete example, it is often remarked that European countries should seek to create a more innovative and entrepreneurial ethos among the members of university faculties and public research institutes in the fields of science and engineering; the ostensible aim is to emulate the high propensity of academic researchers in the US to form Astart-up≅ companies based upon their technological advances. Although a wide array of sticks and carrots have been employed to encourage university administrators, and public funding agencies to link faculty access to resources to their readiness to form partnerships with business ventures, and yet it appears that academic researchers in Europe remain less Aentrepreneurial≅ than their American counterparts. Part of the explanation may lie in the difference between the antecedent university research funding environments in the US and Europe. By comparison, the antecedent infrastructure of US public science had the effect of better preparing individual faculty researcher to face and deal with the practical problems -- and respond to new and changing opportunities -- of managing Athe business≅ of keeping laboratory-based research programs running.

Two points may be noted from this example. First, in a system context it is likely that there will be unintended consequences of policies and actions: it was not an objective of US science policy to create entrepreneurial attitudes among university researchers. Indeed, the availability of public funding for a long time meant that such attitudes and motives were directed away from the sphere of business and commercial applications, and towards government sponsored scientific research. Nonetheless, the unintended consequence was that a cadre of young researchers was trained under conditions that rewarded individual initiative and creativity not only in science, but in the management of science-based organisations that were always engaged in undertaking something new and uncertain.

Second, one should expect that in dynamical systems the past often continues to exert a strong influence in shaping responses to new conditions. The existence of a multiplicity of funding agencies, conditions of competition among young researchers for support for their work as independent investigators, combined with university policies that permitted successful researchers to retain control over some portion of overhead support associated with their grants, contributed to a greater predisposition to explore new sources of support for research in response to cutbacks in public grant support. Without the preparation in a climate where such attitudes and capabilities could be rewarded by success and thus reinforced, the response of European researchers holding appointments in hierarchically structured public institutes would be, and was quite different when public funding was cut back.

The Peculiar Nature of Information and Knowledge as Commodities

In calling for integration between public measures aiming at successful deployment of innovations as well as at the generation of more innovations, the *Maastricht Memorandum* accepted the prevailing view that public subsidies for R&D were economically justified on Amarket failure≅ grounds. Economists during the previous three decades had elaborated cogent reasons why the price system and competitive markets should not be expected to do a good job in producing or distributing knowledge and information. This conclusion rested upon the fundamental insight that ideas -- especially ideas tested and reduced to codified scientific and technological information -- have some important attributes found in "pure public goods."

Acknowledging the peculiarity characteristics of the economic commodity that is created by reducing knowledge Ainformation≅ is a starting point in the modern economic analysis not only of R&D activities, but of the totality of Athe knowledge-driven economy.≅ An *idea* -- as distinct from an inexpressible feeling, or inner mental state -- is a thing of remarkable expansiveness, being capable of spreading rapidly from mind to mind without lessening its meaning and significance for those into whose possession it comes. In that quality, ideas are more akin to fire than to coal. Thomas Jefferson remarked upon this attribute, which permits the same knowledge to be jointly used by many individuals at once: "He who receives an idea from me, receives instruction himself without lessening mine; as he who lights his taper at mine receives light without darkening me...."[2]

Economists since Arrow (1962), therefore, have pointed out that the potential value of an idea to any individual buyer generally would not match its value to the social multitude. The latter value, however, is not readily expressed in a willingness to pay on the part of all who would gain from the illuminating idea; once a new bit of knowledge is revealed by its discoverer(s), some benefits will instantly "spill over" to others who are

[2] This remarkable passage is quoted in full and discussed in P. A. David, APatronage, property and the systems dynamics of technological change,≅ *Annual Bank Conference on Development Economics*, 1992, eds. L. Summers and S. Shah, Washington DC: World Bank, 1993

therefore able to share in its possession. Commodities that have the property of "expansibility," permitting them to be used simultaneously for the benefit of a number of agents, are sometimes described as being "non-rival" in use. This characteristic is a form of non-convexity, or an extreme form of decreasing marginal costs as the scale of use is increased: although the cost of the first instance of use of new knowledge may be large, in that it includes the cost of its generation, further instances of its use impose at most a negligibly small incremental cost.

It sometimes is noticed that this formulation ignores the cost of training potential users to be able to grasp the information and know what to do with it. But, although it is correct to point out that there can be fixed costs of access to the information, these do not vitiate the proposition that re-use of the information will neither deplete it nor impose further costs. It may be costly to teach someone how to read the table of the elements, or the differential calculus, but any number of individuals thus instructed can go on using that knowledge without imposing further costs either on themselves or upon others.

The second property of ideas that has been noticed here is that it is difficult, indeed, costly to retain exclusive possession of them whilst putting them to use. Of course, it is possible to keep a piece of information or a new idea secret. The production of results not achievable otherwise, however, discloses something about the existence of a method for doing so. Often results obtained by methods that are not, or cannot be revealed, are felt to be less reliable, and more in the nature of magical performances than the application of reliable knowledge. Even a general explanation of the basis for achieving the observable result jeopardises the exclusivity of its possession, for the knowledge that something can be done is itself an important step toward discovering how it may be done.

Public Goods and the "Appropriability Problem"

The dual properties of non-rival usage and costly exclusion of others from possession define what is meant by a "pure public good." The term "public good" does not imply that such commodities cannot be privately supplied, nor does it mean that government must produce it. But competitive market processes will not do an efficient job of allocating resources for the production and distribution of pure public goods, because when such markets work well they do so because the incremental costs and benefits of using a commodity are assigned to the users.

One may see the problem posed by the public goods characteristics of knowledge by asking how ideas can be traded in markets of the kind envisaged by disciples of Adam Smith, except by having aspects of their nature and significance disclosed before the transactions were consummated? Rational buyers of ideas, no less than buyers of coal, and of fish and chips, first would want to know something about what it is that they will be getting for their money. Even if the deal fell through, it is to be expected that the potential purchaser would enjoy (without paying) some benefits from what economists refer to as "transactional spillovers." These occur because there may be significant commercial advantages from the acquisition of even rather general information about the nature of a discovery, or an invention -- especially one that a reputable seller has thought it worthwhile to bring to the attention of people engaged in a particular line of business.

This has led to the conclusion that the findings of scientific and technological research, being new knowledge, would be seriously undervalued were they sold directly through perfectly competitive markets. Some degree of exclusivity of possession of the economic benefits derived from ideas is therefore necessary, if the creators of new knowledge are to derive any profit from their activities under a capitalist market system. Intellectual property rights in the form of patent and copyright monopolies are rationalised as serving this end. But imposing restrictions on the uses to which ideas may be put also is recognised as saddling society with the inefficiencies that arise when monopolies are tolerated. This is a point that has been harped upon by economists ever since Adam Smith., but it has been borne home more recently by the attention of the US Department of Justice=s Anti-Trust Division to the Microsoft Corporation=s use of its dominant position in the PC operating systems software market to leverage its monopoly power in other, complementary ICT markets. In addition, the secrecy practices that accompany serious commercially oriented research aimed at the establishment of intellectual property rights are recognised as a further source of inefficiencies.

A broad range of considerations, extending well beyond the public funding of R&D, has been touched upon by the foregoing cursory review. Matter ranging from intellectual property rights provisions and competition policy, to higher education and the international movement of trainees in science and engineering, are seen to bear upon the generation and utilisation of technologically relevant knowledge. The systems-theoretic perspective that formed the core of the *Maastricht Memorandum* (1993) promoted the view that European Ainnovation policy≅ either needed to be conceived very broadly, or, if that term was to be applied in a more restricted way, the policies and programs involved should be formulated with explicit attention to the likely nature of their interactions with other, equally specific policy areas--university education and training and employment policies, intellectual property rights and competition policies, telecommunications and information technology regulation policies, etc.

This general outlook was reflected in the literature that blossomed in the early 1990's addressing the characteristics of Anational systems of innovation≅ and Anational innovation systems.≅[3] The systems in question were taken (by Bengt-Ake Lundvall, 1992) to include those elements of social organisation and behaviour, and the relationships among them that interact in Athe production, diffusion and use of new, and economically useful knowledge and which are either Alocated within or rooted inside the borders of a national state.≅ It was a tenet of some stands within this literature that governmental action at the national level could, and should be directed towards managing such systems, building Acompetitive capabilities≅ that would manifest themselves in the successful performance of countries=s firms in an environment of intensified global economic competition. But the enthusiasm for such an outlook was not universally shared, even among economists who found the national systems of innovation concept a useful framework for policy discussions.

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[3] See, respectively, B.-A. Lundvall, *National Systems of Innovation*, London: Pinter, 1992, and R. R. Nelson, *National Innovation Systems*, A Comparative Analysis, Oxford: Oxford University Press, 1993.

One source of qualifications derived from the view that the structural features and performance characteristics of these complex systems were more in the nature of Aemergent properties≅ than Adesigned attributes and intended consequences≅; they were themselves the outcomes of contingent, historical processes, involving mutual adaptations among the component parts. The notion that international comparative analysis could reveal Abest practices≅ that might readily be transplanted from one national context to another, on this view, was likely to be mistaken.[4] Secondly, the focus upon *national* strategies to promote economic success in technological rivalries also evoked some concerns, in that quasi-mercantilistic policies that sought to restrict rivals= access to new knowledge might well have the perverse consequence of impeding the circulation of such knowledge within the economy, as well as triggering mutually destructive retaliatory policies among nations. Coupled with this were a third source of worries, raised by the growing readiness of national governments (or regional coalitions of nation states) to retreat from support of multilateral trade liberalisation; to pursue instead quasi-mercantilistic, strategic trade policies of with-holding access to their domestic markets from producers in increasing returns industries who were identified with other countries, while using their bargaining power in international negotiations on a variety of issues to Aforce open≅ foreign markets for their own producing interests.[5]

A fourth set of qualifications that accompanied the national systems of innovation framework drew attention to the differences between the situations of the large and diverse national economies for which a more Aself-contained≅ systems model was relevant, and the many smaller economies (and, perforce, the economically distinct territories within national boundaries). Not only were the latter likely to be specialised, and highly Aopen≅ to factor flows as well as to commodity and service trade, but, scale considerations affecting research and training activities also made it necessary for economic agents in these countries to adapt their institutions and policies so as to be able to monitor, access and regularly interact with external sources of scientific and technological knowledge. International co-operative and collaborative institutional arrangements, and modes of co-ordinating national and regional policies so as to achieve productive complementaries and save resources -- for example, in shared use of large research facilities, and the specialised training programs -- ought, therefore, to

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[4] This point was made by P.A. David and D. Foray, AAccessing and Expanding the Science and Technology Knowledge Base,≅ (OECD) *STI Review*, no. 16, 1995: esp., pp. 21-22.

[5] Concerns on these scores were elaborated by S. Ostry and R. R. Nelson, *Techno-Nationalism and Techno-Globalism: Conflict and Cooperation*. Washington, D.C.: The Brookings Institution. 1995.

be regarded as integral elements within the Anational≅ innovation systems of some countries.

3. New Directions: A Rationale for Public Support of the Science Base Co-ordinated with Innovation Policy

A feature of the dynamical systems approach to innovation policy that distinguishes it from traditional thinking about science and technology policy is that the latter focused attention upon Amarket failures,≅ because these were the touchstone of the rationale for Agovernment intervention≅ in the sphere of R&D. More recent thinking, however, recognised that there is more to the process of innovation than R&D investment, and that many of the critical interactions between the generation of new scientific and technological knowledge and its successful exploitation depend upon non-market as well as market institutions. Consequently, a corollary of the systems perspective is a concern with Asystems failures,≅ including failures in the workings of institutions whose functions complement as well as correct the limitations of market processes of resource allocation. In this context, public sector science is seen as having a distinctive role from that of proprietary, business R&D; it is more than a channel through which more R&D investment can be funded in order to compensate for the tendency of the private sector to underinvest in the production of socially beneficial knowledge. Proper co-ordination between innovation policies and policies in the sphere of research and development requires a thorough understanding the system-functions that public sector R&D is uniquely suited to fulfilling.

The progress of scientific and technological knowledge is a cumulative process, one that depends in the long-run on the disclosure of new findings, so that they may be speedily discarded if unreliable, or confirmed and brought into fruitful conjunction with other bodies of reliable knowledge. In this way Aopen science≅ promotes the rapid generation of further discoveries and inventions, as well as wider practical exploitation of additions to the stock of knowledge. The economic case for public funding of what is commonly, if somewhat ambiguously referred to as Abasic≅ research, rests mainly on that insight; and upon the observation that business firms are bound to be put off in some considerable measure by the greater uncertainties surrounding investment that entails entering into fundamental, exploratory inquiries compared to commercially targeted R&D, as well as by the difficulties of forecasting when and how such outlays will generate a satisfactory rate of return.

The specific policy proposition at issue in regard to basic science funding is quantitative, not qualitative. It has been justly pointed out by Nathan Rosenberg (1990) that Afirms do basic research with their own money.≅ But one does not cannot adequately answer the question "Will there be enough funding by private firms?" merely by saying "There will be some." Indeed, the combination of corporate mergers and fixed cost-cutting to improve short-term earnings performance during the early 1990's became the occasion for increasing concern in U.S. policy circles that even such Abasic≅ research as did receive privately funding was becoming less exploratory and long-range, and more closely tied to strategies of specific product development.

Economists do not claim that without public patronage (or intellectual property protection), basic research would cease entirely. Rather, their analysis holds that there will not be enough basic research -- not as much as would be carried out were individual businesses (like society as a whole) able to anticipate capturing all the benefits of this form of investment. Therefore, no conflict exists between the theoretical analysis and the evidence of recent economic studies which show that R&D-intensive companies do indeed fund some exploratory research into fundamental questions. Their motives for this range from developing a capability to monitor progress at the frontiers of science, to picking up ideas there for potential lines of innovation that may be emerging from the research of others, to being better positioned to penetrate the secrets of their rivals' technological practices.

Nevertheless, it is a long-term strategy, and therefore sensitive to commercial pressures to shift research resources towards advancing existing product development, and improving existing processes -- rather than searching for future technological options. Large organisations that are less asset-constrained, and of course the public sector, are better able to take on the job of monitoring what is happening on the international science and technology frontiers. Considerations of these kinds are important in addressing the issue of how to find the optimal balance for the national research effort between secrecy and disclosure of scientific and engineering information, as well in trying to adjust the mix of exploratory and applications-driven projects in the national research portfolio.

Directly Valuable Additions to the Scientific Knowledge-Base

When scientists are asked to demonstrate the usefulness of research that is exploratory in character and undertaken to discover new phenomena, or explain fundamental properties of physical systems, the first line of response often is to point to discoveries and inventions generated by such research projects that turned out to be of more or less immediate economic value. Many important advances in instrumentation, and generic techniques, such as PCR and the use of restriction enzymes in "gene-splicing" are, indeed, available for mention in this connection. These by-products of the open-ended search for basic scientific understanding also might be viewed as contributing to the "knowledge infrastructure" required for efficient R&D that has been deliberately directed towards results that would be exploitable as commercial innovations.

Occasionally such new additions to the stock of scientific knowledge are immediately commercialisable and yield major economic payoffs that, even though few and far between, they are potent enough to raise the average social rate of return on basic, academic research well above the corresponding private rate of return earned on industrial R&D investment. Yet, the discovery and invention of commercially valuable products and processes are seen from the viewpoint of "the new economics of science"[6]

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[6] See, e.g., P. Dasgupta and P. A. David, "Information Disclosure and the Economics of Science and Technology," in G. Feiwel ed., *Arrow and the Ascent of Modern Economic Theory*. New York: New York University Press, 1987; P. A. David, D. C. Mowery and W. E. Steinmueller, "A Framework for Evaluating Economics Payoffs from Basic Research," *Economics of Innovation and New Technologies*, 2(3), 1992; P. Dasgupta and P. A. David, "Toward a New Economics of Science." *Research Policy*, 1994, 23, pp. 487-521.

to be among the rarer among the predictably "useful" results that flow from the conduct of exploratory, open science. Without denying that Apure≅ research sometimes yields immediate applications around which profitable businesses spring up, it can be argued that those direct fruits of knowledge are not where the quantitatively important economic payoffs from basic science are to be found.

Much more critical over the long run than "spin-offs" from basic science programs are their cumulative *indirect* effects in raising the rate of return on private investment proprietary R&D performed by business firms. Among those indirect consequences, attention should be directed not only to "informational spillovers," but to a range of complementary Aexternalities≅ that are generated for the private sector by publicly funded activities in the sphere of open science, where research and training are tightly coupled.

Complementarities between public and private R&D programs

Resources are limited, to be sure, and in that sense research conducted in one field and in one organisational mode is being performed at the expense of other kinds of R&D. But what is missed by attending exclusively to the competition forced by budget constraints, is an appreciation of the ways in which exploratory science and academic engineering research activities support commercially-oriented and mission-directed research that generates new production technologies and products.

First among the sources of this complementary relationship, is the intellectual assistance that fundamental scientific knowledge (even that deriving from contributions made long ago) provides to applied researchers -- whether in the public or in the private sector. From the expanding knowledge-base it is possible to derive time- and cost-saving guidance as to how best to proceed in searching for ways to achieve some pre-specified technical objectives. Sometimes this takes the form of reasonably reliable guidance as to where to look first, and much of the time the knowledge-base provides valuable instructions as to where it will be *useless* to look.

One effect this has is to raise the expected rates of return, and reduce the riskiness of investing in applied R&D. The central point that deserves emphasis here is that, over the long-run, the fundamental knowledge and practical techniques developed in the pursuit of basic science serves to keep applied R&D as profitable an investment for the firms in many industries as it has proved to be, especially, during the past half-century. In this role, modern science continues in the tradition of the precious if sometimes imprecise maps that guided parties of exploration in earlier eras of discovery, and in that of the geological surveys that are still of such value to prospectors searching for buried mineral wealth.

A policy implication of this conceptualisation is that access to informed, scientifically sophisticated knowledge provides effective guidance towards areas where investment in applied R&D and market niche creation may yield high payoffs in the near term -- whether through the launching of independent new economic ventures, or diversification of existing businesses. Having access to researchers who are keeping up with the fast-moving frontier of science provides just that sort of timely information when the technical personnel also are given some prospective (equity) stake in the new ventures. But to provide this represents a substantial fixed cost, some large part of which that might best be borne collectively by coalitions or formal consortia of small and medium-sized firms, each of which would then be able to finance having a smaller Ain-house≅ source of technical expertise to advise on positioning the enterprise vis-à-vis the evolving technological opportunities. Of course, the collectively supported research activities would have to be organised to focus upon Apre-competitive≅ development, so as to avoid making it the basis for cartelisation of the emerging industrial branches.

Open Science and Research Training: Externalities for the Private Sector

A second and no less important source of the complementary relationship between basic and applied research is the nexus between university research and training, on the one hand, and on the other the linkage of the profitability of corporate R&D to the quality of the young researchers that are available for employment. Seen from this angle, government funding of open exploratory science in the universities today is subsidising the R&D performed by the private business sector. Properly equipped research universities have turned out to be the sites of choice for training the most creative and most competent young scientists and engineers, as many a corporate director of research well knows. For this reason, primarily, graduates and postdoctoral students in those fields are sent or find their own way to university labs in the U.S. and the U.K. It also explains why businesses participate (and sponsor) "industrial affiliates" programs at research universities, and also is part of the reason for U.S. industrial research corporations' broadly protective stance in regard to the federal budget for Abasic science.≅ For Europe the question to be considered is whether continuation of institutional structures in which advanced undergraduate and graduate teaching remains separated from publicly-funded research represents a failure to full exploit these potential benefits.

Technology Transfers via the Circulation of Researchers

A key point deserving emphasis in this connection is that a great deal of the scientific expertise available to a society at any point in time remains *tacit,* rather than being fully available in codified form and accessible in archival publications. It is embodied in the craft-knowledge of the researchers, about such things as the procedures for culturing specific cell lines, or building a new kind of laser that has yet to become a standard part of laboratory repertoire. This is research knowledge, much of it very "technological" in nature -- in that it pertains to how phenomena have been generated and observed in particular, localised experimental contexts -- which is embodied in people. Under sufficiently strong incentives it would be possible to express more of this knowledge in forms that would make it easier to transmit, and eventually that is likely to happen. But, being possessed by individuals who have an interest in capturing some of the value of the expertise they have acquired, this tacit knowledge is transmitted typically through personal consultations, demonstrations and the actual transfer of people.

The circulation of post-doctoral students among university research laboratories, between universities and specialised research institutes, and no less importantly, the movement of newly trained researchers from the academy into industrial research organisations, is therefore an important aspect of "technology transfer" -- diffusing the latest techniques of science and engineering research. The incentive structure in the case of this mode of transfer is a very powerful one for assuring that the knowledge will be successfully translated into practice in the new location; for the individuals involved are unlikely to be rewarded if they are not able to enhance the research capabilities of the organisation into which they move.

A similarly potent incentive structure may exist also when a fundamental research project sends its personnel to work with an industrial supplier from whom critical components for an experimental apparatus are being procured. Insuring that the vendor acquires the technical competence to produce reliable equipment within the budget specifications is directly aligned with the interests of both the research project, and the business enterprise. Quite obviously, the effectiveness of this particular form of user-supplier interaction is likely to vary directly with the commercial value of the procurement contracts and the expected duration and continuity of the research program.

For this reason, "big science" projects or long-running public research programs may offer particular advantages for the collaborative mode of technology transfers, just as major industrial producers -- such as the large automotive companies in Japan -- are seen to be able to set manufacturing standards and provide the necessary technical expertise to enable their suppliers to meet them. By contrast, the transfer of technology through the vehicle of licensing intellectual property is, in the case of process technologies, far more subject to tensions and deficiencies arising from the absence of complete alignment in the interest of the involved individuals and organisations. But, as has been seen, the latter is only one among the economic drawbacks of depending upon the use of intellectual property to transfer knowledge from non-profit research organisations to firms in the private sector.

Although Ainnovation programs≅ in Europe have come to be organised with responsibilities for actions that are primarily commercial, and thus quite distinct from publicly-funded science and engineering activities, the foregoing makes it evident that there should be co-ordination between these two spheres. The objective of policy should not be to turn universities and government research institutes into commercial R&D shops (a mistake that one fears is being made in the case of the UK), nor is it to promote an approach to business formation through strategies built around basic research. Rather, it is to manage the inter-actions between the two spheres in a way that promotes positive, self-reinforcing feedbacks between them.

4. New directions: second thoughts about the policy implications of tacit knowledge

With increasing frequency during the 1990s references have appeared in the economics literature to Atacit knowledge≅. More often than not the meaning of this term itself is something that remains literally tacit X which is to say, those who employ it are *silent* as to its definition. Something is suggested nevertheless by the common practice of juxtaposing mention of tacit knowledge and references to Acodified knowledge.≅ Michael Polanyi[7] introduced the term into modern circulation, by pointing to the existence of Athe tacit dimension of knowledge,≅ a form or component of human knowledge distinct from, but complementary to the knowledge explicit in conscious cognitive processes. Polanyi illustrated this conceptualisation by reference to a fact of common perception: we all are often aware of certain objects without being focused on them. This does not make them the less important, as they form the context that renders focused perception possible, understandable, and fruitful.

Subsequently, the term tacit knowledge has come to be widely applied to forms of personal knowledge that are not readily transmitted as Ainformation≅ which itself is thought of as an ideal-type good having peculiar economic features that differentiate it from other, conventional economic commodities. As a consequence of the growing practise among economists of referring to tacit knowledge when alluding to what is in effect a residual category of knowledge, the original psychological and contextual usage of the term has been largely discarded. Tacit knowledge thus has come to signify an absolute type, namely: Anot codified≅ knowledge. As such, however, the label now covers the implicit complement of a category of containing a various forms of information and social knowledge, but which itself usually is left undefined and undifferentiated.

The lead in bringing the significance of Atacit knowledge≅ to the attention of economists was taken by Richard Nelson and Sidney Winter (1982), whose discussion of the parallels between individual human skills and organisational capacities gave prominence to Polanyi=s concept.[8] What Nelson and Winter (1982) say about the nature and significance of tacitness in knowledge conveys not one sharply defined concept, but a nexus of meanings, each carrying somewhat distinctive implications. Their first reference to the term (1982, p. 73), for example, offers only a parenthetical clarification:

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[7] Michael Polanyi, *Personal Knowledge: Towards a Post-Critical Philosophy.* London: Routledge & Kegan Paul, 1958; *The Tacit Dimension*, Garden City, N.J.: Dobleday Anchor, 1967.

[8] Richard R. Nelson and Sydney G. Winter, *An Evolutionary Theory of Economic Change,* Cambridge, MA: Belnap Press, Harvard University, 1982. See Ch. 4, esp.

AThe knowledge that underlies skilful performance is in large measure tacit knowledge, *in the sense that* the performer is not fully aware of the details of the performance and finds it difficult or impossible to articulate a full account of those details.≅ [Emphasis added.]

Yet Nelson and Winter accepted Polanyi=s (1967) account of such situations as being contextual, rather than absolute: Athe aim of a skilful performance≅ may Abe achieved by the observance of a set of rules which are not known as such to the person following them.≅ Reference was made to Polanyi=s earlier philosophical work, *Personal Knowledge* (1958, p. 49), where an example is presented of a swimmer keeping himself buoyant by regulating respiration, yet remaining unconscious of doing so. In other words, Nelson and Winter (1982, p. 77) do not insist, any more than did Polanyi, that tacitness implied Ainarticulability≅; even though the inarticulability of some (personal) knowledge logically implied that the latter would remain Atacit≅. They thus recognise that the skilful performer may have Asubsidiary awareness≅ of the rules that are being followed, while being Afocally aware≅ of some other X most probably novel X facet of the task in which she is engaged. This reinforces an appreciation of the contextual boundaries within which knowledge will be Atacit≅ rather than explicitly recognised and articulated. Yet, if one can describe behaviour in terms of Arule conformity≅, then it is clear that the underlying knowledge is *codifiable* X and indeed may have previously been Acodified≅, or at least articulated.

More than merely a topic of idle talk, tacitness has become an increasingly Aloaded≅ buzzword, freighted with both methodological and policy significance for the economics of science and technology, and economic growth more generally. Indeed, recognition of a tacit dimension of human knowledge has been used both to attack and to defend government subsidisation of science and engineering. Among the most notable of the uses to which the idea of tacit knowledge is being put on the more mundane levels at which most economists operate, and certainly the uses that have the greatest impact in economic policy circles, has been the qualification X and in some instances the outright rejection X of the practical policy conclusions drawn from the classic information-theoretic analysis of the economics of R&D activities.

Following the seminal work of Kenneth Arrow (1955, 1962) and Richard Nelson (1959), an entire generation of economists treated scientific and technological knowledge as Ainformation.≅[9] As has been noted above, they took this assumption as warrant for regarding the output of research activities as possessing certain generic properties of public goods. Much of the case for government subsidisation of science and engineering research, and for innovative activity more generally came to be grounded

[9] See Kenneth J. Arrow, AEconomic Aspects of Military Research and Development,≅ RAND Corporation Memorandum D-3142, August 30, 1955 (RAND Archives, Santa Monica, CA.). This little cited paper is discussed by David A. Hounshell, AThe Medium is the Message, or How Context Matters: The RAND Corporation Builds and Economics of Innovation, 1946-1962,≅ Presented to the Dibner Institute, MIT, Conference on the Spread of the Systems Approach, 3-5 May, 1996. Far more familiar are the published papers: Richard R. Nelson, AThe Simple Economics of Basic Scientific Research,≅ *Journal of Political Economy*, 67(2) (1959): 297-306; Kenneth J. Arrow, AEconomic Welfare and the Allocation of Resources for Invention,≅ in The Rate and Direction of Inventive Activity, ed., R. R. Nelson. NBER Special Conference Series, v. 13. Princeton, NJ: Princeton University Press, 1962: 609-626.

on the proposition that *qua* information, such knowledge could not be optimally produced or distributed through the workings of competitive markets.

But, more and more frequently one reads of a newer understanding of science and technology as being pursuits inextricably involved with tacit knowledge, with the implication that the old public policy rationales are exploded; the essential understandings are said to be the portion of knowledge that remains uncodified, and so deprived of the public goods properties that would result in informational spillovers and market failure. Thus, as this argument concludes, the traditional economic case for subsidising science and research in general collapses, as there is little or no basis for a presumption of market failure.

On the other hand, tacit knowledge is being invoked today by defenders of government subsidisation of science as part of a strategic innovation policy. A standard argument against public subsidy to science is that foreigners engaging in applied, commercially oriented R&D would free-ride (since information is a public good and travels freely) by exploiting the basic knowledge discoveries that *our* researchers vie to codify for disclosure in the scientific journals and similar archival publications. To this, the proponents of tacit knowledge reply, nations, and regions, like individual enterprises undertaking R&D investments, can count of the benefits of Asticky data≅ Xto use Eric von Hippel=s arresting term.[10] Knowledge does not travel freely, a condition that rests largely on the importance of tacit knowledge residing only in the heads of the scientists and engineers engaged in its production. Codified knowledge may have low marginal costs of transmission and is thus slippery and hard to contain, but that is largely irrelevant if what one needs is its Asticky≅, tacit counterpart.[11]

According to this view, the inherent Astickiness≅ of certain kinds of knowledge enables business (or other) entities to protect their ability fully to appropriate the benefits derivable from their research investments by controlling access to the repositories of uncodified knowledge. For this, minimal recourse is required to the protection of intellectual property in the form of patents and copyrights; a mixture of trade secrecy law and labour law (master-servant relations) governing the behaviour of current and former employees, may be enough. Thus, curious though it may seem, the tacit dimension of scientific and technological knowledge has found a new career for itself in science and technology policy debates: it is beginning to supplant its now dubious companion, Acodified knowledge≅, as the core of a new rationale for government research funding intended to build national and regional Acompetitiveness≅ through innovation.

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[10] Eric von Hippel, ATrading in Trade Secrets,≅ *Harvard Business Review*, February/March, 1988:59-64.

[11] In subsequent work Eric von Hippel [≅Sticky Information and the Locus of Problem Solving: Implications for Innovation,≅ *Management Science*, 40(4), April: 429-439] , generalizes the idea so that it covers all situations in which there is an appreciable cost of transferring information, especially that relevant for innovative activities. In principle, at least, von Hippel=s use of the notion of Astickiness≅ makes no distinction between transfer costs consisting of pure rents imposed by the owners of intellectual property rights, on the one hand, and real social resource costs such as those entailed in physically transporting an expert for the purpose of demonstrating the proper use of a novel product or process in a distant location.

Following on from that application of the argument, even though the essential tacit knowledge concerning how to exploit what has been invented might be less than perfectly Asticky≅, its economic benefits are only available to be captured locally. In other, more formal, terms, it is asserted that the marginal costs of knowledge transmission rise very rapidly with Adistance≅ from the context in which such knowledge was generated. Research by-products in the form of technological knowledge X being concerned with how best to get instrumentation involving chemical, mechanical, electrical and optical processes to work X are seen as inherently more strongly tacit in nature. That is held to be particularly beneficial for would-be commercial developers who are able to situate closer to the locus of such discoveries.[12]

A further broad policy implication is that for an economy to have a strong, innovative manufacturing sector, it is necessary also to have correspondingly strong applied and basic research activities situated in close proximity to the production operations themselves. The following passage extracted from an article by John Kay (1999, p. 13) in *Science and Public Affairs*, is illustrative of the more elaborate statements of the new innovation strategy perspective that has now formed around the concept of tacitness in the business management literature:

> ASince >knowledge that= X the characteristic discoveries of natural science X is easily transmitted, one solution [to the problem of creating >knowledge-based competitive advantages=] is to continually innovate and stay one step ahead. And that kind of innovative capacity depends on knowledge that isn=t >knowledge that=, but >knowledge how= X i.e. tacit knowledge.

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[12] See e.g. Keith Pavitt, AThe objectives of technology policy,≅ Science and Public Policy, 14 , 1987: 182-188; Pari Patel and Keith Pavitt, APatterns of technological activities: their measurement and interpretations,≅ in P. Stoneman, ed., *Handbook of the Economics of Innovation and Technical Change*. Oxford: Blackwell, 1995; Richard R. Nelson, AWhat is >commercial= and what is >public= about technology, and what should be?,≅ in Technology and the Wealth of Nations, N. Rosenberg, R. Landau, and D. Mowery, eds., Stanford CA: Stanford University Press, 1992.

> ATacit knowledge can take many forms, but it cannot be written down. It is unique to an organization X and therefore cannot be copiedΨ The benefits of
>
> such tacit knowledge arise only through a culture of trust and knowledge-sharing within an organization....Tacit knowledge isn=t a phenomenon exclusively existing within a single organizationΨ It also exists between companies, consumers, suppliers and scientific laboratoriesΨ≅

Thus, a notion that took its origins in the psychology of individual human motor skills has been wonderfully transmuted, first, from an epistemological category into a phenomenon of inarticulable inter-organisational relationships, and thence to one of the keys to corporate, and perhaps also national competitive advantage.

A corollary of this class of arguments is that the case for granting public subsidies and tax concessions to private companies that invest in R&D would seem to be much weakened, were it not for the difficulties caused these firms by the circulation of their research personnel.[13] Scientific and engineering staff are able to carry critical tacit knowledge off to potential rival firms that offer them better terms of employment, including equity ownership in Astart-ups≅ of their own. In the logic of this approach, recognition of the criticality of tacit knowledge argues for further strengthening of trade secrecy protections, to block those Aleakages≅ and altogether eliminate the market failure rationale for governmental support of the performance of R&D by the private sector.[14] That leaves the way open for those who wish to mount an essentially Atechno-

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[13] We can observe that the more things change the more they stay the same. We have moved from the view that the problem to be solved arises from the fact that a firm=s *knowledge* is easily appropriated by other firms. Acknowledging the importance of tacit knowledge, and thus that the initial problem may not be so severe, we face a Anew problem≅ stemming from the fact that a firm=s *knowledge workers* are easily appropriated by other firms. In both cases the general issue remains however X fluidity of knowledge or information (whether transmitted through codified knowledge or labor mobility) is good for the economy but bad for the individual firm.

[14] See, e.g., Terrence Kealey, *The Economic Laws of Scientific Research*, London: MacMillan, 1996, on industrial secrecy as the suitable Aremedy≅ for the problem of informational spillovers from research, and the critique of that position in P. A. David, AFrom market magic to Calypso science

mercantilist≅ argument for R&D subsidies, grounded on the idea that the country can benefit from job-creation, etc., if its firms win the race to be first to launch new products in international markets. It is, in effect, a new strategic trade policy argument, grounded on the claim that tacit knowledge permits national appropriation of the direct and indirect benefits of monopolising international product riches by being Afirst to invest.≅

The notion that the economic case for public support of science and engineering should now be based upon the inherently tacit and Acraft≅ nature of research activities certainly is rather paradoxical. Taken at face value, it suggests that intellectual property protection is unjustified, since, in the Anatural≅ state of things, there are no Aexternalities≅ of new knowledge. By implication, the patent system=s exchange of monopoly of use for Adisclosure≅ allows the patentee to retain the tacit knowledge without which the information contained in the patent really is useless.

Recently, Cowan, David, and Foray (1999) have argued that the much of the foregoing new rationale for science and technology policies is rests upon semantic and taxonomic confusion. These confusions stem from a failure to distinguish between the unarticulated and the inarticulable. But what is unarticulated may be so because of the prevailing the balance between benefits and costs of codification, which are subject to being altered by economic policy. The mistaken acceptance of Atacitness≅ as an inherent and unalterable property of some kinds of technologically relevant knowledge is thus being exploited to advance economic policy arguments that cannot claim to be empirically grounded.

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plicy: a review of T. Kealey=s, >The Economic Laws of Scientific Research,= *Research Policy*, 26 (May), 1997: 239-255.

Cowan, David and Foray, therefore, recently have proposed an alternative, explicitly economic framework for the study of knowledge codification activities.[15] The latter complements the view that greater attention should be directed to analysis of the microeconomics conditions affecting access to, and full utilisation of the knowledge base for both technological innovation and application, a theme taken up by the next section.

5. New directions: towards accessing as well as expanding the knowledge base

In reaction against the strong emphasis on technology generation in the early contributions to the literature on national innovation systems, there has been a growing reconsideration of the significance of features of a society=s institutions and policy measures that affect the ability of its members to identify and access the relevant base of scientific, engineering and organisational knowledge.

This shift in attention may be traced to the point made in the late 1980's by Henry Ergas, that a major problem in solving the particular technological problems, or responding to the specific commercial conditions through innovative activity lay less with the creation of new knowledge that with mobilising the knowledge that already existed somewhere in the system. The more recent line of analysis, broached by David and Foray in their 1995 OECD memorandum, has added the consideration that the creation of new technologies is, in many fields, becoming increasingly a matter of deft recombination of existing bodies of knowledge.[16] Thus, even a policy directed towards achieving leadership in the generation of technological novelty, could be advanced by measures that improved the accessibility of the relevant knowledge base.

Such measures range from support for information and communication infrastructures, digital archives, and electronic search and filtering engines, to Asofter≅ elements of the infrastructure: the intellectual property regime, knowledge brokerage services, education and training to support multi-disciplinary R&D activities, etc. Interest in the comparative performance of such configurations of technological, legal and cultural structures has encouraged exploratory efforts (e.g., by the OECD-DSTI=s TIP

[15] R. Cowan, P. A. David and D. Foray, AThe Explicit Economics of Knowledge Codification and Tacitness.≅ Paper prepared for the EC TSER Program=s TIPIK Project Workshop, held in Strasbourg, 24 April, 1999.

[16] See P.A. David and D. Foray, AAccessing and Expanding≅ (1995).

Working Party) to supplement the conventional S&T indicators with measures of Athe knowledge distribution power≅ of national systems.

Codification and its benefits

Wherever there is a community of agents who have made the necessary initial investments to develop a technical nomenclature (which often requires operational definition and standardisation of scientific and engineering concepts), and to maintain efficient procedures of language acquisition for new entrants into the field, the transfer of messages can be assimilated to transfer of knowledge. Storing messages in this context means recording knowledge, i.e., codification.

On the benefit side, the efficiency of codification will be greater in very large systems having specific requirements regarding co-ordination among agents. The specific circumstances in which this is likely to be of practical importance have been adumbrated recently by Cowan, David and Foray (1999).[17] Five classes of situations may be distinguished: (i) systems involving many agents and many locations; (ii) systems strongly based on re-combination and re-use and which take advantage of the cumulativeness of existing knowledge (rather than on independent innovation); (iii) systems that require recourse to detailed memory; (iv) systems which need particular kinds of description of what (and how) the agents do; and lastly, (v) systems characterised by an intensive usage of information technologies. Something further may be said in regard to each of these, to elaborate the significance of public support for undertaking codification activities whose benefits extend beyond those of Aclub goods≅ -- code created for use by voluntary members of a closed group.

First, codification will provide high benefits in stable systems characterised by specific requirements of knowledge transfer and communication. This kind of requirement can result from a tendency towards de-localisation and externalisation or from the development of co-operative research, entailing a spatial distribution with activity at many places. This first effect can be appreciated without any ambiguity, for example in science. It operates, however, within a given Aclique≅ or network X that is a community which shares common codes and the tacit knowledge to interpret them. If access to the network is gained on the basis of Acompetence≅ and opportunities to acquire the tacit knowledge are not made a source of socially unregulated professional, or commercial Arent-taking,≅ there is likely to be a more compelling case for public support of such codification activities -- such as in setting standard technical nomenclatures, classification systems for libraries.

Second, in (stable) systems of innovation where advances and novelties mainly proceed from re-combination, re-use and cumulativeness, benefits of codification are important. W. Wyat Gibbs[18] claims that the very limited progress in the productivity of software engineering is due to an excessive dependence on craft-like skills (in contrast for example with chemical engineering). The schema that Gibbs has in mind is that once an

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[17] See Cowan, David and Foray, AEconomics of Knowledge Codification and Tacitness,≅ (1999), especially section 7.3.

[18] W. Wyatt. Gibbs, AThe crisis in software,≅ *Scientific American*, 1994;_____.ATaking computers to task,≅ *Scientific American*, 277 1997: pp. 64-71.

algorithm is written as apiece of code, it can be used in many applications X at least in principle. The practical difficulty in doing so arises in part because of a lack of standardisation both in the way code is written and the way algorithms are employed. This lack of technological rationalisation impedes the full realisation of the opportunities provided by there-use and re-combination model.

Third, systems that require extensive memory and retrieval capacities (e.g. firms with long development cycles, high rates of turnover, some particular demographic problems or institutions confronted by a big technological bifurcation) will greatly benefit from codification. In those systems, too little codification increases the risk of Aaccidental uninvention≅. MacKenzie and Spinardi (1995) showed, for example, that specific local and tacit knowledge was so important in the nuclear weapons design process that there was always a risk of losing critical elements of the knowledge base simply due to the turnover of scientists and engineers X a risk of technological retrogression, or at best costly reconstruction of previous tacit capabilities.[19]

The same argument is readily extended to cover situations in which knowledge has been thoroughly codified in the form of algorithms, or operating instructions, but the text of the Asource code≅ for these X or an understanding of the language in which it was recorded X has ceased to be readily decipherable, or has simply been misplaced, or destroyed. The result is a paradoxical one: the technology in which the knowledge has been embedded may continue to work, as is the case when the computer implements the machine-language version of its instructions. But, as has been found to be the case with some major pieces of Alegacy software≅, the human agents who can no longer read or write the source code are unable to emend or elaborate those machine-language encoded instructions, or repair defects in the original source code that have become evident. It is possible that even beyond the range of such algorithmic technologies, cultural inventions and culturally transmitted skills important for activities upon which social welfare depends X such as those involved in dispute resolution X may become lost because Athe market≅ for agents possessing tacit knowledge of that kind is undermined by the competition of more fully codified (legal) procedures.

Large public mission agencies and private corporations alike may find it worthwhile to undertake codification and archiving, so that high rates of personnel turn-over and organisational memory loss do not become dysfunctional. Insofar as the benefits of the latter are internalised by private sector organisations, the argument for public support would be restricted to the case for providing superior classification tools, and search and retrieval techniques of a generic sort that many organisations could apply for idiosyncratic purposes but that none would be prepared to bear the full cost of developing.[20]

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[19] D. MacKenzie and G. Spinardi, ATacit knowledge, weapons design and the uninvention of nuclear weapons,≅ *American Journal of Sociology*, vol. 101 (1), 1995.

[20] It is possible that a business services supplier might undertake the fixed cost investment if it appeared possible to recover it by making the Atools≅ proprietary as a form of intellectual property, or by bundling the techniques within a service, rather than making them available for implementation. Either approach is likely to suffer the drawback that utilisation of the techniques would be restricted. Public sector organisations, which face man of the same problems of

Fourth, systems, which need accurate descriptions of what agents are doing (either to meet quality standards constraints, or to patent innovations, or to enter into contractual relations with a partner), will benefit greatly from codification. Here we can also include systems confronted with inefficient market transactions, where the traditional mechanisms of legal warranty, insurance, reputation and test are not efficient means to mitigate the effects of information asymmetry. [21] Recording production practices, which is a form of codification based on recent language innovation (in the form of creating standards for record keeping) is aimed at reducing these asymmetries.

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maintaining organizational memory, might well support the production of Adual use≅ (public-private) information systems.

[21] See, e.g., P. Gunby, *Explaning adoption patterns of process standards*. Unpublished Economics Ph.D. Dissertation, The University of Western Ontario. 1996.

Fifth, and last but not least, a sort of cross-situation deals with the lack of productivity gains from the use of ITs, due to incomplete codification. Fully taking advantage of the potential productivity gains of IT typically demands not only the adoption of the technology but also organisational change.[22] But a firm undergoing organisational change does not want to lose functionality in the process. The firm must develop jointly the new technology and organisational structures that will reproduce old functions and create new ones. It is obvious that if too much of the old functionality resides in tacit knowledge, or depends heavily on it, this task will be extremely difficult. When the presence of tacit knowledge operates as a bottleneck, impeding the full realisation of productivity potential, the firm can expect great benefits from codification. This, indeed, may be the role of management consultants, referred to earlier.

In all these cases, where important operations of transfer, re-combination, description, memorisation and adaptation of existing knowledge (to ITs) are required, it would be very costly and inefficient to keep this knowledge tacit. Thus, there can be under-investment in codification, co-existing with Aexcess of tacitness.≅ Given the nature, degree and pace of recent technical change, it is likely that the current equilibrium involves an allocation of resources devoted to knowledge generation and transmission under conditions of tacitness which is neither socially nor privately efficient, because knowledge that should be made more widely available in codified form remains uncodified, whereas a lot of resources are poured into the production of differentiated Ainformation≅ that is idiosyncratically coded in the hope of being able to capture private rents.

6. New directions: clusters, regional policy and the economics of locational tournaments

The 1993 *Maastricht Memorandum* pointed to the role that could be played in encouraging regional industrial agglomerations in Europe by policies promoting rapid diffusion of best-practise technologies and scientific and technological infrastructures. Of particular interest to the former were policies supporting intermediary or consulting organisations that would facilitate the access of local firms to best practice techniques, whereas the latter would be beneficial in providing a skilled workforce that would assimilate such methods, and provide a foundation for the development of networks and linkages with other regions.

A good deal of subsequent research has focused upon local knowledge spillovers and human resource externalities as sources of localisation, or Aclustering≅ of high technology industries. Localised knowledge spillovers that occur in the social transactions among research scientists and engineers, are widely believed to play a major role in the geographical clustering of R&D-intensive firms. Historical studies of micro-level positive feedbacks affecting innovation activities, and their effects in promoting geographical clustering, point to the recurringly important part that Marshallian externalities have played in the localisation of new industries in earlier eras, as well as being a feature of

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[22] See e.g., R. Cowan, AThe informatization of government as an economic opportunity,≅ (OECD) *STI Review*, no.16, 1995; Erik Brynolffson, AProductivity Payoffs from Information Technology,≅ MIT Sloan School of Management Working Paper, 1997.

modern times. It really is the latter which is the more paradoxical, given the miracles of digital information transmission via modern global telecommunications. Yet, for a variety of reasons, some having to do with trust, as well as the nature of the knowledge being communicated, initial exchanges of ideas about nascent technologies and enterprises intended to exploit them commercially, tend to require face-to-face contacts.

On the other hand, the competition among such firms for highly qualified employees operates as a form of Acongestion≅ that bounds the cluster size, especially when informational exchange among researchers (and hence indirectly among the firms employing them) is very localised. The dynamic responses in such a system to shocks caused by the growth of final demand for R&D-intensive products have been are explored by Cowan and Cowan (1998) using stochastic simulation methods. Since R&D input enters as a fixed cost, the expansion of the market is found to generate a two-phase response, in which the ubiquity of R&D-intensive production first increases, and then gives way to the re-agglomeration of such firms into to localised clusters. [23]

The problem of locational tournaments: is national or European co-ordination needed?

It seems worthwhile re-emphasising the analytical point that policies that foster local externalities through encouragement of specialist services, and information provision, are likely to have more beneficial resource allocation consequences than local programmes that aim to attract industry to particular sites by means of tax concessions and other subsidies.

Many western European governments have constructed elaborate systems of region-specific development aid and assistance, policies that have been perpetuated in the EU's administration of its Structural Funds.[24] The governors of American states, and mayors of American cities, equally, have been among the star adepts in the quest for regional employment-creation through Aforeign" direct investment lured by tax rebates, local infrastructure subsidies, and labour force training programs -- all paid for from public funds. More recently, they have been promoting the policies aimed at engendering regional revitalisation through the formation of clusters of high-tech firms located in and around research parks situated in the environs of universities. They are joined in such endeavours by others throughout the developed nations, including the French civil servants who directed the creation of the ATechnopolis≅ at Sophia-Antipolis in the hills above Nice, and their Italian counterparts who did the same on the outskirts of Bari in Apuglia.

In view of this, a return to considering the economics of locational rivalries seems in order.[25] Because market demands, or supplies of requisite factors of production, or

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[23] R. Cowan and W. Cowan, AOn clustering in the location of R&D: Statics and Dynamics,≅ *Economics of Innovation and New Technology*, 6(2-3), 1998:pp. 201-229.

[24] See, e.g., R. L. Martin, "Reviving the Economic Case for Regional Policy," in R. T. Harrison and M. Hart, eds., *Spatial Policy in a Divided Nation*, London: Jessica Kinglsey (1993), pp. 270-290; J. Collier, "Regional Disparities, the Single Market and the EMU," in J. Michie and J. Grieve Smith, eds., *Unemployment in Europe*, London: Academic Press (1994), pp. 145-159.

[25] This draws upon the discussion in P.A. David, AKrugman=s Economic Geography of Development: NEGs, POGs and Naked Models in Space,≅ *International Regional Science Review*, August, 1999.

both, are limited in the near term, governmentally sponsored contests among rival sites to attract firms from essentially footloose industries take on a quasi-zero-sum character. Add to this the effect of endogenously determined transport routes, and you have Aexclusion≅ or Ashadowing≅ effects of one centre's success in attracting industry and trade. That gives these regional contests a tournament-like payoff structure, in which runners-up get little or nothing, whereas the winners take all.

Economic analysis of the sorts of locational tournaments in which authorities possessing local tax powers can engage, points to the conclusion that the inefficiencies which are most likely to ensue are those characteristic of monopolistically competitive equilibria. Suppose that local authorities are aware of winner-takes-all payoff structure, and can issue bonds (with some government guarantee) to finance subsidies designed to attract a pre-specified critical mass of symmetric firms to their respective neighbourhoods. Suppose, also, that any bond-issuing local authority also would announce its intention *eventually* to impose taxes on all producers entering the site after the target "critical density" of firms has been achieved, so that the debt-service charges and the principle could be paid. A transversal balanced-budget program of development will be credible if the scheduled tax revenues do not completely offset the net agglomeration benefits arising at the site, since there is then an interest in further growth until those benefits are exhausted. The effect of such competition is that were these authorities to proceed independently -- i.e. without strategic interaction -- they simply wind up transferring most of the net site rents created by agglomeration to the owners of the mobile factors, i.e. the firms who are quick to shop among locations for the best Adeal.≅ (This might well apply equally to the situation of national governments seeking to attract direct foreign investment from transnational corporations.)

The market for the development bonds of the various localities would resemble a lottery, however: high risk premia would likely be attached to the bond issues, thereby limiting the amount of funds that actually could be spent up front for local development infrastructure provision. This constraint on the ability of any single locale to substantially outspend its rivals increases the likelihood that the outcome of such a contest would be to spread the industry out among a number of different sites, none of which would achieve critical mass sufficiently quickly to go on to absorb most of the industry. The outcome in that case would be socially inefficient, in that the potential agglomeration economies would have been dissipated; of course, it also would saddle tax payers at the rival sites with the burden of meeting their respective debt charges for the creation of under-utilised infrastructural capacity.

7. Envoi, Not a Conclusion

The foregoing notes are far from exhaustive of either the new developments that have marked the literature devoted extending our analytical and empirical understanding of the micro-economics of innovation and its implications for economic policy, or of recent reappraisals of public policy measures in the EU and OECD countries. Thus, this cannot be a conclusion, but an *envoi* to further discussion.

Under the first heading, for example, it would be appropriate to consider the implications of work on the dynamics of market-driven processes of technology adoption in which there are strong positive feedbacks. The general thrust of theoretical and empirical investigations is that the market is vulnerable to bandwagon movements that may prematurely commit the industry to technological and business models that might be discarded if more time were allowed for exploration of alternatives. In network industries, and consequently in many specific areas of ICT and information service industries, these problems assume considerable importance. Whether there is a practical role for public sector actors to invest in exploration and trials of such alternatives remains a subject of debate. But the same issues arise also in regard to the development of technologies that a compatible with local environmental sustainability, because many of those involve potentially strong complementaries and externality effects.

With regard to specific policies, the area of intellectual property protection and its intersection with competition policy, is one that has come in for serious second thoughts among academic economists. The general thrust is that the pendulum may have swung too far in the direction of strengthening protections for intellectual property, and extending the system of protection through *sui generis* legal devices. The EU Database Directive of March 1996 is one example of an effort to encourage European firms to enter the database service business, at the expense of privatising information that was in the public domain because it was otherwise not copyrightable, or its copyright protection had expired. One unintended effect of the provisions of this directive would be to be deleterious for the scientific research community, and it this consequently provides a striking instance of the failure to consider proposed policies in their systems contexts.

Given the nature of information goods, such problems are likely to arise when policy is designed in isolation, as has been the case with regard to the application of full intellectual property protection to proprietary interface standards. Market established, *de facto* standards, such as those embedded in a dominant computer operating system, or in the Alook and feel≅ of computer spreadsheet software, takes on the characteristics of an essential facility -- innovators cannot readily reach consumers with new features without building upon, or Aporting through≅ those complementary pieces of technology. Allowing the proprietors to either extract large rents, or subsidise their own complementary offerings has strong anti-competitive effects, especially inimical to Schumpeterian, dynamic competition based upon the entry of innovators. Whether some forms of compulsory licensing of such Aessential facilities≅ is the appropriate public policy solution, remains another subject that currently remains under debate.

In short, the task of re-appraising and updating European innovation policy for the twenty-first century is one that is exciting and challengingly complex from the viewpoint of economic science, as well as of enormous societal importance.