EQUILIBRIUM AND EVOLUTIONARY FOUNDATIONS OF TECHNOLOGY POLICY

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Equilibrium and Evolutionary Foundations of Technology Policy

Mainstream economic theory has provided a by now well known approach to the formulation of technology policy, an approach built around the related concepts of equilibrium and intervention to correct for market failure in the allocation of resources to innovative effort. In this regard the policy maker acts as if she were an optimizing social planner wielding a calculus of marginal costs and benefits to improve the behaviour of firms. Our intention in this paper is twofold: to make a case for the adaptive technology policy maker in contradistinction to the optimizing technology policy maker, and to relate this distinction to recent developments in thinking about a systems perspective on innovation. This is no small matter since it involves, we believe, a fundamental appraisal of the purpose of and limitations to policy action. The foundation for the discussion is an evolutionary perspective on economic change, with its emphasis on variety of behaviour and selection process: the latter to produce co-ordination and coherence, the former to provide the basis for all economic change and development. Central to this approach is an awareness of the division of labour, not only in relation to its traditional role in regard to the production of goods and services, but equally in relation to the production of knowledge and skill.

1. ECONOMIC EVOLUTION

Capitalism and equilibrium are fundamentally incompatible concepts. This is the legacy left by Schumpeter to guide generations of scholars interested in answering the question ‘Why does the Economic World Change?’ and, indeed one might add, change in such an unpredictable manner. For a central paradox of modern capitalism is its combination of highly decentralized and loosely co-ordinated institutional mechanisms to tap individual creativity, with strongly co-ordinating market mechanisms which resolve the results of individual creativity into patterns of economic change. Thus the process of economic growth and development proceeds simultaneously with the creation of new activities, the elimination of those which are obsolete and the continual resifting of the importance of existing activities. Whether we look into the broad division of activity between agriculture, manufacturing or services, or into the sectors within each broad division, or, <u>a fortiori</u>, between the firms within each sector the picture is always one of ongoing and pervasive structural change, the outcome of what is a strong development trend. The more we aggregate the less apparent are these essentially capitalist phenomena and while it is often fruitful to measure at the macroeconomic level, our understanding comes from comprehension of the emergence of endogenous innovations and responses to micro level variety. To provide such an understanding an evolutionary perspective is wholly appropriate since it deals naturally with the interaction between qualitative and quantitative change: novelty provides the material for change, co-ordination, through market and other non-market processes, resolves that material into the patterns of change we recognize as economic evolution.

Innovation and Evolution as a Three-Stage Process

The classical model of evolutionary change is often presented as a two stage process: there are stages for generating variety and stages for selecting across that variety to produce patterns of change. Several aspects of this standard evolutionary dynamic need to be stressed. First, the focus of analysis is upon populations of interacting entities and it is the difference in behaviour between the members of the population which are the crucial factors in evolution. A perspective based upon the notion of representative or uniform behaviour is quite incompatible with this approach. Secondly, an evolutionary perspective makes an important operational distinction between two modes of change, that within the relevant entities and that between those entities. The former is sometimes called transformational change and the latter variational change, change that is in terms of the relative importance of those entities in the population. A selection process is naturally dynamic, explaining why the entities grow at different rates and thus how their weight in the population changes. In modern analysis these dynamic processes are described by replicator mechanisms in which the changing relative importance of an entity depends upon how its behaviour compares with average behaviour in the population (Metcalfe, 1997). Here there is a close connection with the evolutionary notion of fitness provided we equate fitness with differential growth and remember that fitness is not a cause of evolution but a consequence of evolution (Metcalfe, 1997). Developmental change is, of course, closely related to innovation and the consequential differential behaviours of competing firms. Novelty and the creation of novelty is the central feature of an evolutionary framework. Such variation is necessary to maintain diversity in the population and it is diversity which makes selection possible. Thus evolutionary models naturally incorporate two central phenomena relevant to technology policy, namely innovation and the diffusion of innovation. In this regard economic evolution is open-ended and largely unpredictable in its consequences over the longer term.

Finally, it is important to emphasise that evolutionary thinking is a style of reasoning which can be applied quite independently of any connection with biological and related sciences. The biologists simply got there first. Thus, within the economic and social sphere we must pay close attention to the intentional nature of innovative activity, its dependence on hopes and expectations and its relation to the memory of past experience. Innovations are necessarily blind variations in that their consequences cannot be known in advance, and their consequences cannot be known in advance in part because they depend on the behaviour of individuals and entities beyond the control of the innovating firm. It is almost axiomatic that innovations as unique events cannot be treated in terms of a calculus of probability distributions. The point is simple, we cannot close the list and therefore do not know what weight to assign in probabilistic terms to those items which we do believe we can list.

The questions which naturally flow from the evolutionary perspective are questions about the world of change. 'What are the origins of different behaviours?', 'What are the constraints limiting differentiation of behaviour?', 'What are the selection mechanisms which resolve differences of behaviour into patterns of change?', 'Is there any natural limit or attractor to the evolutionary process?'. Putting the questions in this way it is easy to comprehend why economists whose primary interest was the study of technological change have found the evolutionary framework highly productive. Different behaviours correspond to innovations whether radical or incremental, and our concern is with the origins of innovation and the constraints by which it is shaped. Selection mechanisms correspond to a range of market and non-market processes in which the division of labour between organizations and individuals are co-ordinated to produce patterns of change.

As far as innovation is concerned many scholars emphasise the inherent unpredictability of outcomes and the interrelatedness between different innovations and innovating organizations. For present purposes we may summarize our understanding if we emphasise that technological and organizational innovations are not random events; rather they are guided and constrained by cognitive frameworks and the embedding of those frameworks in institutional rules and practices. Patterns of innovation reflect constrained variation limited by the sunk intellectual and institutional capital built up in their development. Innovation processes contain a strong sense of commitment and inertia which implies that radical innovations are comparatively rare, that development is cumulative and that most innovations emerge as a process of trial and error experimentation within previously accepted boundaries. Just as in biology most innovation experiments fail and the process necessarily appears to be wasteful and to encourage a belief that the intelligent social planner can improve the process by eliminating wasteful duplication. But, in general, this would be mistaken; unpredictability means generic uncertainty not calculable risk and which appears wasteful ex post is in reality valuable information on where not to search in the design space of possible innovations. It is particularly important to recognize that innovations flow from joint conjectures about technological and market knowledge and that the appropriate choice of market application is at least as important as the appropriate choice of technology in the narrow sense. In this case it is important to understand the evolution of demand and market knowledge as it is to understand the development of underpinning technology. Usually the two proceed in concert and reinforce one another and so technology policy in the narrow sense can only be one element in innovation policy more generally. Of course, this is what is implied in the old debate between technology-push and market-pull but the lesson is all too easily ignored: technological conjectures alone are not sufficient for innovation to succeed. The corollary is clear, it is the firm which typically draws together entrepreneurial conjectures about market and technology, and in this regard the firm is unique.

The final important point about innovation is that it is the kind of experimental, trial and error activity one would expect to find in complex adaptive systems. One reason behind the apparent complexity is that innovating organizations rarely innovate in complete isolation. Either formally or informally, they draw innovation inputs from a wider matrix of institutions to take advantage of a division of labour in the generation of knowledge and skills. We will have more to say about this below.

Let us consider further the role of selection mechanisms in the process of innovation driven evolution. Central among these are market institutions by which suppliers and users of innovations interact: institutions which are not to be judged by their optimality but by their facilitation of adaptation and change. Indeed the market process is essential in ensuring the spread through the economic system of new technology provided that that technology is judged to be “superior” to the prevailing alternatives. Markets co-ordinate the development of demand, investment and the growth of productive capacity together with the processes of learning which take place jointly between users and suppliers. But this is what we understand by competition not as a state of equilibrium but as a process of rivalry driven change in economic structures and the relative positions of individual firms and whole sectors. As such, market competition is synonymous with the process of diffusion of innovation whether product or process: the pathways by which innovation comes to have its economic consequences for employment, trade and the standard of living. Moreover, since innovation is more or less continuous in the aggregate we have a process of open-ended development which in relatively short periods of time can completely transform the prevailing patterns of economic activity. Market based diffusion is not the only source of relevant change. Processes of imitation must also be given due weight as facilitating the spread of technology through non-market moderated exchanges: the copying, legal or otherwise, direct or indirect, of existing practice. Clearly this matter is closely related to intellectual property rights and the ability to maintain a degree of secrecy about particular developments.

So far we have followed the traditional route of presenting evolution as a two stage process, variation and selective retention. However, in economic terms there is a third stage which is particularly interesting from a technology policy viewpoint, namely, feedback from the selection process to the development of further variation. This is a theme which we would rightly emphasise as endogenous innovation and it is this dimension which creates the apparent inevitability of the history of technology in which those technologies that get ahead appear to stay ahead. Of course, nothing remotely inevitable was involved, in an open-ended fashion that was how events worked out.

What endogeneity does is to create a close link between market co-ordination and innovation from the reverse direction to that traditionally implied by competition. Technologies normally develop as sequences of innovations within a cognitive framework of design concepts and constraints. How the sequence develops is surely shaped by the growth of the scale and range of application, by the inducements which user/supplier interaction provides to improve and apply in certain directions; and by the profit streams through which much of the development work is typically funded. Thus market mechanisms become devices not only for adapting to new opportunities but also devices for stimulating the development of new opportunities to create variety. This is of vital importance to what follows. Innovations require much more than scientific knowledge and technological conjectures. They also require conjectures as to what will be valued in the marketplace, an immensely subtle and detailed kind of knowledge.

Finally, we should note that the direct consequence of evolutionary competition is to destroy the variety which makes change possible: left to itself average practice converges on best practice and all other options are eliminated, whence change dries up. To keep evolution going variety needs to be replenished by further innovation partially endogenous but also exogenous. The policy question is then obvious, can intervention, broadly or narrowly defined, improve on this evolutionary process?

Adaptive Policy Making

Corresponding to our view of market processes as adaptive constructs there follows a view of the policy maker as an adaptive agent. Unlike the social planner blessed with Olympian rationality the technology policy maker is little different from the individuals and firms she seeks to influence. Bounded rationality and limited knowledge provide her domain and the only distinctive characteristic she possesses is political legitimacy and superior co-ordinating ability across a range of institutions. In all important aspects adaptive policy making is about facilitation. Operating in the context of complex innovation systems the policy maker must accept a considerable degree of indeterminacy and unpredictability in the consequences of policy initiatives. Complex systems are of necessity governed by ambiguity so that there is a strong case for policy experimentation and policy learning. As two of our former colleagues have put it, the wise policy maker uses many instruments and none to excess (Carter and Williams, 1957).

It follows from our previous discussion that the focus of policy can entail any combination of the three stages of evolution: innovation, diffusion and feedback. Mostly the emphasis is upon influencing the innovation behaviour of firms as producers of innovation but there is no need to be so limited: a wide range of institutions typically contribute to the innovation process. It is particularly important in this regard to recognise the role played by intelligent, advanced users in developing valuable improvements in technology. Then obvious questions arise. Is the policy about firms in general or specific firms in specific sectors? Should the policy be about specific technologies, conceived as bundles of knowledge skill and artefacts or general R&D programmes. If specific technologies, is the emphasis to be on skills, knowledge or artefacts or permutations of the three basic dimensions of technology? Questions such as these are central to the policy debate.

It will be noted that little emphasis is placed in the above discussion on market failure as a rationale for policy except in the broadest sense, and this requires more detailed explanation.

The market failure framework has served well the economist interested in technical progress, however, it is not at all clear that it has done the same for the technology policy maker as a practioner. While market failure provides a general rationale for policy intervention, it is inherently imprecise in its detailed prescription: a firm may spend too much or too little on innovation, it may innovate too quickly or too slowly, it may undertake excessively risky projects or be too conservative. The appropriate policy therefore depends on the specifics of the situation and requires the policy maker to have a detailed knowledge of what are necessarily conjectures held by firms. If one is not careful the firm and the Olympian policy maker become inseparable, a scarcely desirable situation at least within the Anglo-Saxon tradition of political economy.

If we take an evolutionary perspective on the traditional sources of market failure, the analysis changes in subtle but important ways. Consider first the matter of asymmetric information, a potent source of moral hazard and adverse selection problems in the equilibrium theory of competition. Far from constituting failures, they are essential if the competitive process is to work in an evolutionary fashion. Without asymmetry there can be neither novelty nor variety. Indeed innovations and information asymmetries are proper synonyms and it should not be forgotten that a profit opportunity known to everybody is a profit opportunity for nobody (Richardson, 1961).

Closely related of course, is the matter of spillovers which only makes sense in a world where firms are fundamentally differentiated with respect to what they know. If firm A is as knowledgeable as firm B, a spillover is a contradiction in terms. Of course, spillovers are important and relate fundamentally to imperfect property rights in information. But information is not knowledge and there is no reason to believe that if spillovers where multilateral that they would dull excessively the incentives to innovate. If they flow in one direction only that is another matter and ultimately an empirical question (Liebeskind, 1996).

Similarly with the public good aspects of knowledge. Knowledge is unique in that it is used but not "used-up" but this in no sense implies that it is a free good. With respect to the dissemination of knowledge there are reception costs and transmission costs and it is a consequence of this intellectual division of labour that firms have to invest in their own knowledge before they can make sense of the information flow from external sources. The point is simple, only if the transmitter and recipient have similar background knowledge is 'foreground' knowledge transferred easily. Of course this in no way ensures that the two parties derive the same "increment" to their respective knowledge bases from the same information flow. The value to the firm of the acquired knowledge clearly depends on how complementary that knowledge is to the firm's existing knowledge base. The public good perspective is simply not refined enough to comprehend these important distinctions. This is particularly so when we recognise the subtlety and the tacitness of much innovation related knowledge. This kind of knowledge is not like the scientific knowledge which is the paradigm of the public good perspective. The most one can say of science is that it provides boundary constraints on innovation not knowledge of specific innovations (Vincenti, 1991).

From this the evolutionary economist draws two broad lessons. The first is that private firms will willingly generate innovation related knowledge if it provides for them a differential advantage over competitors. Imperfect property rights may do little to undermine this in practice. Anyone who wishes to argue otherwise must confront history and the long sweep of private innovation since the industrial revolution. The second is that there is a strong presumption in favour of widespread innovative experimentation in the economy. The blindness of innovation means that its origins and content cannot be predicted: hence it should be stimulated on a wide front and often in unwonted places. It is this which gives the foundation for public support of generic knowledge and skills, a necessary condition for innovation but not of itself sufficient.

A Policy Dichotomy

It is clearly sensible to put firms at the centre of technology and innovation policy initiatives but this is only the first step. If the policy is to influence the rate of innovation it follows that innovation must be an endogenous phenomena and this implies that there are technical progress functions or innovation possibility frontiers confronting firms. These are assumed and idiosyncratic relations between innovation inputs and expected outputs which guide a firm's decision making. Without this step it is impossible to understand innovations as conscious decisions or to understand the allocation of resources to innovation. Thus relationships of this sort, naturally specific to individual firms, must be presumed if policy is to be effective. One useful way to think of innovation opportunity functions is to locate them in the context of the particular design configurations which underpin a particular activity: that is to say, those principles which define the purpose of a product or service, its method of manufacture and its method of use or application. Design principles reflect knowledge some of it scientific in the conventional sense, some of it technological about how rather than why a particular result is achieved, some of it codifiable much of it tacit. It is rarely the case in modern terms that design knowledge is drawn from single knowledge disciplines, rather we see increasingly the fusion of knowledge across traditional boundaries as the underpinning for new design possibilities (Kash and Rycroft, 1994). This is an issue which bears greatly on the technology infrastructure of an economy as we shall see below.

One way to view design configurations is as sets of latent opportunities for particular innovations through which sequences of products and applications emerge. Unless the set of principles is changed one must expect a limit to what can be achieved hence the emphasis upon sigmoid trajectories of development within specific design configurations (Georghiou et al, 1986).

At any point in time a firm will have accumulated a level of skill and body of knowledge specific to the articulation of a particular configuration. If it devotes resources to further innovation in that particular design, that knowledge acts "as if" it were the traditional fixed factor producing diminishing returns to innovative effort. Of course, to the extent that further effort leads to advances in knowledge this changes the constraining "fixed-factor" opening up new opportunities but again the inexploitation runs up against diminishing immediate returns.

Ultimately, of course, the sources of knowledge latent in the configuration are exhausted and progress on this particular design becomes infeasible (Machlup, 1962).

This granted, the range of innovation policies may then be divided into two broad camps[1]:

- policies which encourage firms to exploit their existing innovation possibility frontiers, given their prevailing knowledge, more intensively; and
- policies which enhance those innovation possibilities by adding to the firm's knowledge and capabilities so that the same effort provides greater innovative outputs (We are here begging a number of difficult questions about the measurement of innovative output and input).

In the first group of policies fall schemes to lower the cost of R&D through innovation grants, R&D subsidies and R&D based tax-breaks, together with public procurement policies which increase the demand for innovation outputs, and policies, such as technology demonstators which subsidize user firms to adopt new technology. Each of these can have positive effects on the returns and the incentives to innovate, although their magnitude remains contentious. From the policy viewpoint the key issue is additionality which in turn relates to the question of how quickly the conjectured marginal returns to innovation decline with extra effort: an issue which will be sectorally specific and dependent on the richness of the underlying knowledge base. In relation to marginal returns, it must not be forgotten that the relevant divergence between private and social returns to innovation is a divergence ex ante, which exists only in the minds of the relevant decision makers. It can be measured ex post but by then it is too late. Equally problematic in this field is the question of which firms to support, if it is not to be firms in general, and how the innovative capabilities of chosen few are to be assessed. For firms with good innovative ideas but little track record at managing innovation projects this may be particularly troublesome.

The second group of policies are quite different in nature. Rather than taking the innovation possibilities as given they seek to enhance them and to do so by bringing a greater degree of access to external knowledge to bear upon the firm's innovative efforts. These are policies to enhance capabilities at innovation. Closer connection with the science base, general research and development initiatives relevant to a particular sector and collaborative initiatives of various kinds are the hallmark of this policy group. In the main such policies recognize the division of labour in the generation of innovation relevant knowledge, that no individual firm is self sufficient in its knowledge and skills and that there are corresponding gains from linking firms with the wider matrix of knowledge generating institutions. They constitute policies for compound learning in which the rate at which a firm can learn depends upon the rate of learning in other supporting institutions and vice versa. This is the considerable insight contained in the innovation systems literature, with the emphasis on the bridging between institutions and the consequences of the resulting patterns of connection upon the mutual accumulation of knowledge. This sets a quite different agenda for policy making, to design and create organizations and institutional structures which support and enhance the innovation process (Justman and Teubal, 1995; Teubal, 1997; Freeman, 1987; Lundvall, 1992; Carlsson, 1997).

2. <u>EUROPEAN INNOVATION POLICIES</u>

Boundaries, diagnoses and broader trends

To discuss innovation policy in Europe it is first necessary to define some boundaries. In geographical and political terms, the concern of this paper is with Western Europe, and within that, largely with the fifteen Member States of the European Union (EU). These distinctions are reinforced by economic criteria, as the countries of Central and Eastern Europe, despite rapid progress in some cases, are still well behind their Western counterparts in terms of economic development. Beyond that, the Members of the EU have achieved a substantial degree of economic integration and have in common those innovation policies administered by the European Commission, principally the Framework Programme, a large multi-annual funding scheme which provides 50% of the costs of collaborative R&D projects, but also

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[1] Lipsey and Carlaw (this volume) are right to point out that many policies will involve both camps simultaneously. I make the distinction simply to enhance conceptual understanding. Their paper contains a very valuable discussion of different ways to present policy options e.g. their distinction between focused programmes and blanket programmes. [BACK]

including a variety of measures seeking to transfer experience and achieve network benefits in more downstream aspects of innovation policy and infrastructure.

The convenience of this delineation should not obscure the substantial diversity which persists within the EU in terms of scientific and innovative capacity. The three largest countries, Germany, France and the United Kingdom accounted for 74% of the EU's R&D expenditures in 1992[2], and 80% of US patents granted to EU members in all industries in 1993. Other countries such as the Netherlands and the Nordic Members have smaller but highly developed economies, while the Southern Members (with the partial exception of Italy) have been principally concerned with building up their R&D and innovation infrastructures from a relatively low base. During a period of economic austerity, reinforced by efforts to meet the criteria for entering a single European currency, these countries have been unusual in raising their Government R&D appropriations as a percentage of GDP in the past decade but the degree of convergence achieved remains limited and they remain well behind the average for the Union as a whole.

This diversity has not prevented a number of analyses of the position of Europe relative to the USA and Japan. Two significant policy documents from the European Commission summarise recent thinking. The first, the White Paper on Growth, Competitiveness and Employment[3] drew together the views of Member States on the problem of unemployment and drew attention to the EU's long term unfavourable position relative to the USA and Japan in terms of unemployment, shares of export markets, R&D and innovation and its incorporation into goods brought to the market, and the development of new products. Innovation policies, notably in the environment, health and the media are seen as having the potential for moderate but positive impacts upon employment.

A consistent tendency in Commission thinking has been to couch the central problem of innovation policy in terms of Europe's "comparatively limited capacity to convert scientific breakthroughs and technological achievements into industrial and commercial success."

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[2] European Union (1994), EUROSTAT/OECD in The European Report on Science and Technology Indicators 1994, European Commission EUR 15897. [BACK]

[3] European Commission, Growth, Competitiveness and Employment - The challenges and ways forward into the 21st century, White Paper, ECSC-EC--EAEC, Brussels, Luxembourg (1994) [BACK]

The second significant document, the Green Paper on Innovation[4] couches this analysis as the "European paradox" arguing that compared with the scientific performance of its principal competitors, that of the EU is excellent, but over the last fifteen years its technological and commercial performance in high technology sectors has deteriorated. This line of argument may be criticised on several grounds, including wide variability between sectors, but the main problem inherent in this analysis is that it embodies in policy terms a linear or sequential model of innovation. The Commission shares this position with other bodies whose principal policy instrument is funding of research. In this paper we shall argue that the major advance in European innovation policy in the 1990s has been a recognition that support for R&D is only one part of a necessary portfolio of policies. To be fair, the Green Paper goes a long way towards embodying this broader perspective, emphasising the importance strategic and organisational skills within innovative firms and of the regulatory, legislative and fiscal environment in which those firms operate, including intellectual property and the public infrastructure for research and innovation support services.

Analyses of this type have become increasingly common at national level. In the United Kingdom an annual White Paper on Competitiveness is published by the Government containing analyses of aspects of the business environment[5]; Ireland conducted a major review of its science and innovation policies through a specially convened body, the Science, Technology and Innovation Advisory Council[6]; in France, the national innovation agency, ANVAR has been reviewed in the light of the changing environment for innovation[7]; and in Germany a series of reports have raised concerns about the country's technological position[8]. The proliferation of these high level analyses in these and other European countries is symptomatic of several important trends. They reflect strong political concerns with perceived declining industrial competitiveness and high levels of unemployment. Technology and innovation are seen as key elements in addressing these problems.

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[4] European Commission, Green Paper on Innovation, ECSC-EC-EAEC, Brussels, Luxembourg (1995), subsequently followed up by The First Action Plan for Innovation in Europe, 1996. [BACK]

[5] Department of Trade and Industry, *Competitiveness: Helping Business to Win*, (CM 2563), HMSO: London, May 1994 [BACK]

[6] Science, Technology and Innovation Advisory Council, *Making Knowledge Work For Us*, Dublin: The Stationery Office, 1995 [BACK]

[7] Chabbal R. , *Le financement de l'innovation dans les PMEs*, Ministere des Enterprises et du Développment Economique, 1994 [BACK]

[8] NIW/DIW/ISI/ZEW, The technical capability of Germany, Report to BMBF, 1995 [BACK]

At the same time, Europe has seen structural changes impinging directly upon innovation systems in all three major sectors. At the corporate level three trends have been significant over the at decade. The first of these, globalisation of technological activities, has had an uneven effect in Europe. On the positive side there has been substantial inward investment, particularly by companies from the Far East (with 250 Japanese R&D laboratories in Europe in 1994) but this has been uneven with the UK the principal beneficiary. On the other side of the coin, the relatively high costs of performing R&D in Europe has created incentives for companies to relocate their laboratories to cheaper locations. Two high cost countries, Germany and the Netherlands have instituted specific incentives to persuade firms not to move. Even in more competitive European locations such as the UK, the threat of relocation by multinationals has become a part of the national science policy debate, with a recent report on the (poor) state of academic research equipment exposing some relocation by pharmaceutical majors motivated by the desire to be close to high quality and well equipped academic collaborators[9]. The globalisation of large companies may also be a partial explanation (along with their employment generating capacity) for another innovation policy trend, a focus on small and medium-sized enterprises (SMEs).

The second corporate trend, in common with other parts of the World, has been the decline of centralised laboratories, with research typically organised on a contract basis with most of the budget held by operating divisions. The consequence of this has been a focus of research upon current business problems, with a substantial reduction in longer term strategic research. Some major companies have contracted out their strategic programmes to universities (showing a remarkable lack of understanding of the externalities involved in performing research). The former corporate laboratories have become increasingly detached from their former parents, with many willing to undertake external contract work to survive. Their plight has been exacerbated by the third major trend, a decline in defence-related contract R&D following the end of the Cold War.

In the public sector, national laboratories have been subject to widespread reforms and restructuring throughout Europe. In some cases this process has been driven by expiry of the laboratories' original missions (for example, the development of civil nuclear power) but they have also been subject to wider reforms in government, often collectively termed "New

[9] Georghiou L., Halfpenny P. *et al*, (1996) Survey of Research Equipment in United Kingdom, London: Committee of Vice-Chancellors and Principals [BACK]

Public Management"[10]. This has involved changes such as the introduction of contract-based competitive supply, private sector management styles and an arms-length relationship with the government departments formerly responsible for them. In virtually every case these changes have been part of a drive towards commercialisation, with a demand for an increasing proportion of resources to come from external contract-based work, often paralleled by a requirement to compete for the work for government which was previously theirs by right. In some countries, notably the UK, this process has gone further to full privatisation. Innovation policies in several countries have sought to reinforce and exploit these changes by attempting to stimulate these laboratories to play a more effective role in support of industrial innovation.

In the third major technological sector, universities, the 1980s saw a strong move towards research collaboration with industry, through a succession of models[11] culminating in jointly performed research projects with partial public funding. These models were still essentially super-imposed upon traditional academic structures, epitomised by the proliferation of "technology-transfer offices" which sought to take the outputs from universities and to find applications for them. In the 1990s the model has progressed to the extent that universities are an explicit component of national innovation policies and research funding is increasingly expected to yield exploitable benefits. Gibbons et al[12] have described this as a transformation from knowledge generated in a disciplinary, cognitive context to knowledge created in broader trans-disciplinary social and economic contexts.

It is possible to identify several weaknesses in innovation systems as a consequence of the changes described above, including a convergence between the main classes of R&D performers towards an increasingly overcrowded contract research market. At the same time, the original missions of the three performers are at risk, with a loss of strategic capability in firms, a loss of competence-building capability to underpin independent advice in the public sector and for universities the question of how much externally-driven research can be performed without losing the directions arising from the dynamics of knowledge

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[10] Hood C., Accounting Organisations and Society, Vol.20, No. 2/3 [BACK]

[11] Georghiou L. and Metcalfe J.S. (1990) 'Public science, intellectual property rights and research administration', in De La Mothe J. and Ducharme, L.M. (eds) Science Technology and Free Trade, London: Pinter. [BACK]

generation. One policy diagnosis is that the fragmentation involved in these changes requires new channels of connection to be put in place.

However, these changes may also be seen as forces conditioning the development of innovation policy in Europe and as part of a broader effort to harness the science base and technological development to the pursuit of economic and social goals. In the next section we review some key recent innovation policy developments in Europe.

Innovation Policies

There have been several taxonomies of innovation policies, seminally that of Rothwell and Zegveld[13], recently brought up to date by Dodgson and Bessant[14] in the light of research on learning and capabilities. For the purposes of this paper we shall discuss specific policy measures using a simple approach which distinguishes between the two broad camps of policies:

- assisting firms to exploit their existing innovation possibilities more intensively, and;
- creating or enhancing innovation possibilities by adding to the firm's knowledge and capabilities such that the same effort produces greater innovative outputs.

These characteristics are concerned with the effects of policies and hence may co-exist within a single policy measure. Nonetheless, we shall argue that the trend in European innovation policy has been from the first to the second of these categories. Considering then some of the main policy measures:

1) Provision of finance for innovation

Traditionally this policy is treated as having two major variants, provision of **direct** support through grants or loans for individual projects and **indirect** support through fiscal

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[12] Gibbons M., Limoges C., Nowotny H., Schwartzman S., Scott P. and Trow M., The New Production of Knowledge, London:Sage (1994) [BACK]

[13] Rothwell R. and Zegveld W., *Industrial Innovation and Public Policy*, London: Frances Pinter, 1981 [BACK]

[14] Dodgson M. and Bessant J., Effective Innovation Policy: A New Approach, London:International Thomson Business Press, (1996) [BACK]

concessions for R&D or other innovative activities (though in Germany there is also a concept of 'indirect-specific' support, whereby all eligible applications for grants are accepted until the budget is exhausted). The argument for these policies rests largely upon the familiar market failure rationale, essentially that left to themselves firms will under-invest in innovative activities because of their inability to appropriate all of the benefits arising from these. When social returns are taken into account, the argument goes, public provision of resources is justified. A key aspect of these measures is the question of additionality, that is the extent to which the subsidy given to firms represents additional expenditure rather than substitution for expenditure which would be made anyway. Fiscal incentives tend to concentrate on rewarding incremental expenditure, while direct support is normally accompanied by appraisal procedures which examine each project in these as well as other terms.

During the 1970s direct financial support for innovation projects was relatively common. The trend towards more conservative policies in the 1980s moved away from single company support and tended to restrict financial aid to inter-firm and academic-industrial collaborative programmes (except for SMEs as described below). The rationale here was that collaboration offered many benefits (cost and risk-sharing, complementarity, development of standards, strategic learning[15]) but that collaborative research was more expensive, particularly to newcomers, and therefore financial assistance was justified. It was also argued that collaborative research was inherently more "leaky" and hence that appropriability arguments applied *a fortiori*. Collaborative R&D could also be reconciled more easily with conservative ideology by arguing that firms would only willingly collaborate on "pre-competitive" projects, from which they would subsequently exploit the results separately and in competition with each other.

Collaborative R&D has been a feature of national programmes in Europe but has achieved its greatest prominence as the principal instrument of the European Commission's Framework Programme's and of a separate, nearer to the market scheme, the EUREKA Initiative. In both of these cases, the arguments above are reinforced by a desire to use R&D as an instrument of European integration. Rather paradoxically, while the availability of finance has been an

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[15] Georghiou L. and Barker K., Management of International Collaboration, in Swann J.P. (ed), New Technologies and the Firm, London: Routledge, 1992 [BACK]

important motivation for firms to enter these programmes, evaluations have shown that their most durable effects have been in terms of the behavioural changes they have induced in participating firms in terms of developing strategic linkages (termed "behavioural additionality")[16]. Not surprisingly, the least fertile ground for this type of effect is one which meets the original "pre-competitive" criteria by bringing together competitors. Firms have tended to avoid such projects except in unusual circumstances (pre-normative research for standards development or competitively peripheral activities such as safety) in favour of projects which are structured upon vertical collaborations between suppliers and customers, with additional participation from academics[17]. As the programmes have moved into new areas such as biotechnology research, concern from industry about protection of intellectual property is leading to pressure for projects which have only one firm involved (along with academic collaborators)[18].

At a national level there has been a gradual move away from support for industrial collaborative R&D, partly because this is already being catered for by the European schemes (though this is problematic for EUREKA which does not have a dedicated budget, relying on each participating government to fund its own nationals through domestic schemes - many EUREKA participants do not receive public funding). The national focus is upon providing finance for R&D and innovation for SMEs, often through reinforcement of venture capital schemes. Thus Sweden has the Swedish Industry Fund (a government controlled foundation) which operates a risk capital operation targeted at small innovative firms in their early development stages; similar funds in Finland subsidise R&D in SMEs in the form of equity-based development loans; in France substantial funds are available to promote the uptake of Key Technologies by SMEs; Germany is launching a programme of support for patent applications by SMEs, covering the legal and associated registration costs of patenting; the UK operates competitive awards for SMEs in its SMART and SPUR schemes. For the first time a European equivalent to NASDAQ (EASDAQ) has become a reality.

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[16] Buisseret T., Cameron H.and Georghiou L., "What difference does it make?", International Journal of Technology Management, 10, 1995, pp 587-600 [BACK]
[17] Ormala E. *et al*, Evaluation of EUREKA Economic and Industrial Effects, Brussels: EUREKA Secretariat, 1993 [BACK]
[18] Commission of the European Communities Evaluation of the Biotechnology Programme, 1997 [BACK]

2) Support for Networking

Policies to promote networking have focused principally upon improving the relationships between firms on the one hand and public sector laboratories and universities on the other. Perhaps the strongest expression of this is in the UK where the 1993 White Paper on Science, Engineering and Technology (the first since the 1960s) redefined the role of all publicly funded research as being to support wealth creation and quality of life. Apart from giving research councils mission statements which link them to specific user sectors, the effect of this injunction has been for grantholders to be expected to demonstrate user interest even for basic research. Increasingly, funding has been concentrated upon researchers who are able to raise industrial contributions, the argument being that this will mean that exploitable research is performed. Virtually every European country has schemes to promote networking: the Swedish innovation agency NUTEK has invited businesses to form local groups with a joint purpose to support the use of new technology in order to build networks between firms, technology advisers and universities; the Dutch Ministry of Economic Affairs has rationalised its collaborative schemes into a single instrument aiming to increase co-operation between businesses and between the private sector and research institutes in a range of technology fields; Spain operates a network of research transfer offices (OTRIs); Greek universities and research centres receive funding to create industrial liaison offices; Germany is strengthening its already impressive infrastructure with a new programme of “innovations-kollegs” in which university-based research teams drawn from academic and private sector sources will be half-funded for a period of five years. Industry-only networks are also a growing phenomenon, often with the aim of using benchmarking to stimulate performance improvements.

Policy measures in this category are clearly intended to enhance opportunities for firms: in linear mode they can be seen as bringing firms into contact with exploitable results and thus turning knowledge into opportunities. If an interactive perspective on innovation is applied, the resulting relationships appear more complex but nonetheless valuable. A typical pattern of collaborative innovation places the main thrust of development with the company while the partners in the science base raise the technological level, solve problems and test and evaluate the outcomes. In less developed regions and for SMEs there is also a resource factor in that the external research input is one they could not perform for themselves and probably could not afford to pay for on full commercial terms. For large companies the motivation is different - they see the benefits of networking with the science base as providing them with a window on the latest developments in their fields. This has led to a policy dichotomy for the Framework Programme, with large firms currently pressing for the next iteration to place the emphasis on longer term strategic research, while small firms lobby for an instrument which supports work much closer to the market.

3) Advice, Information and Infrastructure

A strong growth area in innovation policy has been the provision of information to companies. This is not necessarily a distinct category from the other policy measures discussed in that advice is often intended to guide firms towards suitable partners or to assist them to acquire funding from public or private sources. Other forms of advice are directed at assisting firms to make decisions about the acquisition of technology (as knowledge, skill or artefact), to improve their capabilities to manage innovation or to guide them through regulatory issues. In this mode government (or its agents) become brokers rather than providers.

In the UK at least, the rationale for a strong shift of emphasis away from national schemes to support collaborative R&D in high technology sectors and towards information-based support has been based upon analyses which demonstrated that aid was mainly going to a small group of large firms in a narrow range of sectors. The great majority of firms, SMEs and those in traditional sectors were largely excluded. In these sectors solutions would more typically involve acquisition of technology developed elsewhere (including outside the country). A new infrastructure has been developed to deliver these measures, based upon a network of “Business Links”, so-called one-stop shops in most cities and towns where firms are directed by specialist counsellors towards the source of expertise which an initial diagnosis indicates they require. A cynic might remark that these policies have the attraction of being considerably cheaper than direct project support, especially as most services have to be paid for, albeit at subsidised rates. It is too early to judge the success of the shift in UK policy (which coincided with the White Paper) but earlier experiments with this type of approach have shown that the principal difficulty is likely to be in persuading firms to become used to paying for this type of information.

Other countries are also developing activities in this direction. In France a new measure allows organisations to be accredited as a "Centre de Resources Technologies" and provide technological services to SMEs. Several countries have sectoral schemes, notably to promote the development of the "Information Society" through the uptake of relevant technologies and services. Another trend in this direction lies in the supporting infrastructure, whereby science and technology parks are increasingly providing a range of accompanying services to incubate start-up firms. The European Commission has been active in this sphere, using its SPRINT and INNOVATION programmes to provide a transnational dimension to these networks and to facilitate transfer of expertise.

Broader infrastructural issues affect innovation directly or indirectly. The Green Paper pointed out educational deficiencies, barriers to mobility and cumbersome administrative procedures involved in establishing new companies. More directly connected to the innovation system are regulations governing intellectual property and standards.

4) Foresight and Critical Technologies

Perhaps the most prominent of the new innovation policies has been the rise of technology foresight programmes in Europe during the 1990s. Some countries, notably France, had a tradition of planning and prospective studies but Foresight has also taken root in countries without such a tradition, notably Germany, the UK and the Netherlands. In some cases the aim of Foresight has been to establish priorities for funding of technological research. France ran a panel-based exercise to identify "Key Technologies"[19]; these now provide the basis for measures to promote their uptake and are being used to guide research priorities more generally. In the UK, the Technology Foresight Programme had two aims, to establish priorities for public expenditure on R&D and to promote networking between industry and the science base[20]. Fifteen panels were supported by widespread consultation, including a Delphi survey. The resulting priorities have been applied to strategic research across government and the research councils, while a specific follow-up scheme supports academic-

[19] Ministere de L'industrie (1995), Les technologies cles pour l'industrie française: a l'horizon 2000. [BACK]
[20] Office of Science and Technology (1995), Progress through Partnership - Report from the Steering Committee of the Technology Foresight Programme [BACK]

industrial collaborative projects aligned with Foresight priority themes. Dutch Foresight activity has stressed the networking aspects rather than priorities, while in Germany large-scale Delphi surveys undertaken in collaboration with Japan aim to inform rather than direct policy.

It has been argued that the rise of foresight activity, and in particular the enthusiasm with which it has been embraced by industry, can be explained in terms of the transformation of the innovation system[21]. The development of the network economy, described above, means that innovations are now frequently undertaken in collaborative mode and almost always involve external interactions with customers, suppliers, regulators, knowledge providers etc. This is particularly the case for the type of complex systems discussed in Section 2 of this paper. In these respects, part of the strategy-making process which was previously internal to the innovating firm is now in a semi-public domain. Foresight provides an arena in which a common strategy can be formed, restoring some stability to the firm's environment. In this respect the key element of Foresight is not its ability to predict accurately the future (no-one can do that) but rather to inform participants what their collaborators (and competitors) believe the future will be. Thus informed, all concerned are likely to be in a better position to exploit opportunities when they emerge.

3. TECHNOLOGY POLICY MAKING IN A COMPLEX EVOLUTIONARY WORLD

The developments outlined above can be summarised in the following broad terms. The traditional policy approach of taking the innovation opportunities of firms as given and using policy instruments to encourage the more effective exploitation of these given relationships has been augmented by a policy focus aimed at improving the opportunities which firms face and their capability to exploit them. This broad shift from a "grants and subsidies" based approach to an "infrastructure building" approach has been particularly noticeable in the UK but the trend is more general (Kash and Rycroft, 1993; Galli and Teubal, 1996; Sulzinko, 1997). It is naturally systemic in outlook. While the role of market failure in the rationale for technology policy is still accepted the policy maker is no longer seen as a surrogate for a perfectly informed social planner: correcting imperfect market signals to guide private decisions toward more desirable outcomes. Recognition of the complex systems

characteristics of the innovation process takes us to a different rationale for policy, a rationale which recognises the ambiguity and uncertainty of the policy environment and the futility of picking winners as distinct from encouraging winners to emerge by strengthening
the innovation process in general. The primary concern of the new policy focus is to promote the generation of novelty and to do this by the principle of connectivity, the bridging together more effectively of the different actions and institutions involved in the innovation process. It is about innovation infrastructure and not directly about specific innovation outcomes. Consequently, a prime task for the policy maker is to map and appraise the particular innovation systems and communities of practitioners through which policy initiatives are to have their influence.

From an evolutionary systems perspective the policy maker needs to ask a number of questions to identify the institutions involved and the mechanisms which bridge between them. The key question is where do the capabilities for knowledge generation lie? It is widely accepted that firms have to look beyond their own boundaries for the solution of innovation related problems. Establishing such connections can involve a number of mechanisms ranging from the passive, general dissemination of information in an unfocused way, to the development of joint programmes in which the knowledge generating activities of the participating institutions are co-ordinated. In between will be more formal attempts to transfer technology often involving the transfer of people across different institutions within the system. If these connecting mechanisms are weak the plans of the different institutions will be uncoordinated and the ability of an institution to improve the innovative contribution of another may reduce to happenstance - something which is not necessarily to be dismissed lightly, but which of itself is unlikely to bear much fruit. The policy question is whether unfocused, random bridging can be improved upon, and the answer to this clearly appears to be in the affirmative, as recent European experience indicates. This is not a task achieved easily. The different internal communication patterns and incentive structures of different, independent institutions do not help when institutions as diverse as universities and private firms seek to align their innovative activity across their different kinds of knowledge generating activities. Moreover, only non-proprietary knowledge can be shared effectively in such circumstances which puts a premium on the development of generic knowledge, knowledge which is not the defining element in the generation of competitive advantage. As

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[21] Georghiou L., The UK Technology Foresight Programme, *Futures*, Vol. 28, No. 4, May 1996, pp.359-378. [BACK]

many authors have recognised there are natural limits to collaboration between competing organizations, not only rival firms.

The attempt to shape the research agenda of universities, for example, by introducing external criteria in the research funding process is bound to create friction especially when the overall volume of public funding for research is in decline. It may be that the alignment of behaviour can only be achieved by creating specialist bridging institutions, linked to the academic base but otherwise setting their agenda separately. Notice carefully that such institutions may still do fundamental work but it is fundamental work chosen in relation to wider objectives. The trend to collaborative work, Foresight analysis, and the creation of specialist bridging institutions are all supportive of our systems perspective.

There is, of course, a drawback to this emphasis on joint learning, in that while it may speed advance along agreed, established lines it may also be very conservative with respect to major shifts in innovative direction. Since knowledge accumulation is a positive feedback process there is always a danger of "lock-in" to specific design configurations. Inertia is a fundamental evolutionary constraint and the issue becomes one of trading off the support for established lines of technological advance against the open-ended encouragement of new and potentially competing lines of development. Innovation infrastructures are likely to be good at incremental innovation, less good with radical innovation unless this is explicitly encouraged. Of course, this raises particularly interesting questions about innovation systems for newly emerging technologies and how those new institutional structures emerge.

The second aspect of the policy shift to be emphasised is the implicit change from the optimising policy maker to the adaptive policy maker. Policy is no longer about correcting imperfect incentives for private agents it is rather about facilitating the emergence of new opportunities by building innovation infrastructure. Here the emphasis is upon the co-ordination of actions leading to innovation by non-market methods recognising that once innovations occur they will be co-ordinated by the market process.

In a world of immense micro complexity, the adaptive policy maker can make no claim to superior knowledge, operating rather within the constraints of localised, imperfect knowledge just as do the firms and individuals that are trying to innovate. What the policy maker does enjoy is superior co-ordinating ability across a diverse range of institutions. Policy may not work just as complex strategy may not work and the concern is how will the policy maker learn and adapt in the light of experience. The agenda for the adaptive policy is a demanding one since it can only be formed and implemented in the light of judgements about the working of the system as a whole. From the system perspective, it follows that individual firms are unlikely to be the focus of policy, rather the emphasis will be, as we have seen, upon all the co-operating groups of institutions defining a particular innovation system.

Finally, one may sum this up by saying that technology policies, like innovations are trial and error experiments. Hence if the policy maker is to learn and adapt, considerable emphasis must be given to policy trials and their evaluation. In most parts of Europe evaluation of technology policy has been institutionalised since the 1980s, albeit in diverse ways which reflect the different administrative cultures[22]. It also seems clear that learning is a strong motivation for evaluation; evaluation resources have clustered around new policy instruments. Thus collaborative R&D programmes were for several years a major focus for evaluation but, as this instrument has become better understood, there has been a tendency to routinise evaluation, reverting to a monitoring mode and with an increasing use of performance indicators. The emergence of the new innovation policies discussed in this paper is likely to create a new demand for innovative and detailed evaluations which in turn allow the policymaker to learn and adapt.

In Summing Up

In summing up we simply draw attention to the principal themes of the evolutionary and systemic perspectives on technology and innovation policy. We list them seriatim:

- While policy may usefully distinguish between the promotion of innovation and the spread of innovation, in reality the two are closely intertwined such that feedback from the diffusion process shapes considerably the development of a technology.

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[22] Georghiou L. Research Evaluation in European National Science and Technology Systems, *Research Evaluation* Vol.5(1) April 1995. [BACK]

- Technologies typically develop through sequences of related innovations in which a major stimulus is often the extension of the technological principles to new market applications. Market conjectures are at least as important as knowledge conjectures. Consequently, intelligent users are as important as intelligent, innovating suppliers in the innovation process: if users learn slowly this must limit the rate at which suppliers can innovate profitability. Technology and innovation policy should not privilege the supply side to the detriment of the demand side of the innovation process.

- Policy can influence the development of novel devices and concepts either through subsidizing the pay-offs to innovation or through enhancing these pay-offs. This latter has been a noticeable feature of recent policy initiatives which emphasize innovation infrastructure and an innovation systems perspective. The issue here is building connections between firms and their wider knowledge base.

- Important dimension of innovation systems will be inherently sectoral in focus and likely to spillover natural boundaries through the operation of transnational companies and user-supplier linkages. This being so a question of co-ordination of different national policies will arise together with the intriguing question of transnational bridging institutions.

- Difficult questions for policy makers relate to whether their policies are to be general in terms of firms and technologies or specific. If so which firms and which technologies, the posing of which comes uncomfortably close to picking winners.

- Policy will have its impact by changing the behaviour of firms which are constrained by the relevant innovation system. This raises the matter of whether the "design" of the system should itself be a matter for policy initiative. In the case of newly emerging technologies, or existing technologies experiencing rapid change it may well be that different institutional components are neither being created nor reacting appropriately to the new opportunities.

- Evolutionary processes are inherently wasteful ex-post and involve considerable degrees of trial and error. Any policy to promote the generation of novelty on a broad front is then open to obvious objection. However, it is not at all obvious in a complex world that we can do better.

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