CRIC

Science, Technology and Innovation Policy in Developing Economies

Fourth Draft

21st July 2000

Paper prepared for the workshop on Enterprise Competitiveness and Public Policies, Barbados 22nd – 25th November 1999,and revised following that presentation

J. S. Metcalfe

ESRC Centre for Research on Innovation and Competition University Manchester

I am grateful to Jeremy Howells, Fred Nixson, Ganashan Wignaraja, and to the participants of the Barbados workshop for helpful comments on the first draft.

THE UNIVERSITY of MANCHESTER

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

UMIST

Introduction

The central theme of this essay is the nature and role of science, technology and innovation (STI) policies in developing countries. Perhaps paradoxically, a good deal of attention is given to the formulation and implementation of innovation policies in developed, Western economies, for reasons which will become clear as we proceed. Most notably because the focus and content of STI policy has changed fundamentally in the past two decades. Three themes dominate our discussion:

- The factors influencing innovation;
- The distributed form of modern innovation processes within a division of labour between multiple kinds of knowledge and multiple organisational sources of knowledge; and,
- The elements of workable innovation policies.

The importance of this topic for the achievement of international competitiveness and industrial development should not be underestimated. Competition and development are knowledge driven processes and the conditions and contexts in which knowledge is accumulated and applied in the modern world are changing rapidly.

We must be clear from the outset, that, as a general rule, the STI policy of developing economies should not be directed at reaching the world science, technology and innovation frontier. Rather, the central concern should be with absorption and adaptation of established practice to suite local resource endowments and market prospects. As we will see these are non-trivial tasks. Even imitation and adaptation far from the technological frontier can require major investments in organisations and capabilities.

In addressing this topic we must face a number of difficulties. The first is the vast range of economic performance in developing economies. In terms of GDP per head, or the scale and composition of economic activity, or the relative contributions of the public and private sectors, or the levels of education in general and in relation to science and technology in particular, or in relation to the institutional infrastructure and business culture there are enormous differences between developing countries. Just as there are between the so-called advanced economies. At one end, we see the great success of the newly industrialised economies of South East Asia; at the other end, we observe the continual problems of many of the predominantly agrarian and mineral exporting African economies. In between is a vast range of performance. A moment's reflection is enough to establish that the nature of STI policy will differ widely across this range of developing economies. South Korea will differ from Colombia and what is appropriate for Colombia will not be appropriate to an economy such as that of Mauritius. Similarly, the appropriate science and technology policy for South Korea in the 1990s is quite different from that which was appropriate in the 1960s. Developing economies are adapting systems working within an evolving world situation and the evolution of new policy frameworks is an important part of that development process. A 'one policy fits all' for all time approach clearly will not suffice. There is consequently no best policy independent from time, place and the legacy of the past. Context is fundamental to all appropriate policy endeavour.

Secondly, the world economic system continues to develop at a rapid pace. For the past three decades in particular, we have seen world trade grow more quickly than real world GDP, and world direct foreign investment grow more quickly than world trade. Indeed between 1950 and the present, world exports have increased six-fold relative to world GDP. Alongside this we see the continual growth of integrated world supply chains for many products, from automobiles to processed foods. This internationalisation of production activity and commerce has always been reflected in an increasing internationalisation of the production and application of new scientific and technological knowledge, particularly between the advanced triad economies, Japan, USA and Western Europe (European Commission, 1998). National R&D efforts are increasingly interdependent, measured flows in the technological balance of payments are increasing as are exports of hi-tech goods, and there is widening co-operation between firms and governments in relation to techno-scientific activity. One important consequence of this is an inter-dependence, albeit little recognised, in the conduct of national science, technology and innovation policies. The continued development of information and communication technologies, and the spread of internet communications will further encourage these trends.

Thirdly, it is important to recognise that these trends follow from the restless nature of capitalist economies and that this property follows inevitably from the central role of knowledge in their operation. Production depends on the use of knowledge but in the very use of knowledge a further change in knowledge is produced so opening up new productive opportunities, a never-ending process. Economic development is open-ended because the development of knowledge is open-ended. Capitalism is never in equilibrium, if we mean by that a state of rest, and its development is necessarily uneven in respect to both space and time. Hence the ever-present problems of (uneven) economic development itself, of shifting patterns of comparative advantage and trade patterns, and of incessant structural change within and between economies. Even advanced economies do not develop in a uniform way; rural Wales, Galicia, Southern Italy all speak to the local and uneven nature of development. Indeed, it is one of the distinguishing features of economic development that it produces strong spatial patterns, concentrated around cities and their respective hinterlands.

Before proceeding some important caveats are in order. It is most important to recognise that science policy differs from technology policy which, in turn, differs from innovation policy as I shall explain below [see Box 1]. Equally, it is obvious that many other economic policies will have implications for the availability of resources to advance scientific and technological knowledge, for the incentives to do so and for the climate of innovation. A stable policy framework at macro and microeconomic level is of this first importance if innovation is to flourish. Equally, an acceptance of market processes and the rule of contract together with a supportive set of policies in relation to education and skill formation at all levels are required in any knowledge driven economy (Wignaraja, 1999). In this regard the institutions in relation to property rights, law, and public administration matter very greatly. We should also recognise that policies in relation to science, technology and innovation are investment policies in the sense of seeking to raise future levels of GDP per head and to do so in part by enhancing the international competitive ranking of national industries. Consequently they take time to work and they will not be helped by frequent changes in objectives or national commitments. Moreover, the outcomes of such investments are necessarily uncertain and unpredictable, the unintended consequences of policy are part of the process.

Finally it is clear that STI policies play an important role but a secondary role in the development process. Rarely is it the case that the objective should be to develop innovation capabilities at the world frontier. More often the problem is one of catching up which does not usually need an indigenous capability to advance frontier science and technology. But nor is the solution one of passively copying the technologies of more advanced nations. Indigenous capabilities are needed to transform and modify to suit local conditions, capabilities which can at later stages underpin the attempt to 'forge ahead', to gain technological independence. Imitation is an active, creative process, it involves adaptation not adoption. Thus for most developing economies the problem remains one of inward and adaptive technology transfer. Seen in this light one may avoid the danger of expecting too much from science and technology, particularly at the early stages of development. One can then enquire more carefully as to the proper role of government in this area and the appropriateness of different strategic views.

Let me begin by observing that development entails dissatisfaction with the status quo, economies in equilibrium, by definition, do not develop. That development involves ongoing structural change in the absolute and relative importance of different economic activities and that it is premised upon an ever more extensive division of labour, will be accepted without question. In modern capitalism these attributes appear in an extreme form. Capitalist economies are restless economies, there are always reasons to challenge established economic positions, and the primary reason for this lies in the knowledge generating system which is characteristic of capitalism. There is immense micro diversity in the sources of new knowledge. There is a highly developed division of labour in relation to this production of knowledge viewed either in terms of 'disciplines' and 'sub-disciplines' or in terms of knowledge generating institutions. Now systems based on this division of labour also depend upon co-ordination, and in capitalism this involves a blend of interacting market and non-market institutional forms. Market institutions provide the incentives for change and the also make possible adaptation to new opportunities. I shall say a great deal more about their relative importance and interdependence below, but here it suffices to summarise the developmental system which capitalism is as a complex system. It is a system in which the apparent anarchy of individual attempts at innovation is co-ordinated into the patterns of economic change that have characterised the past two hundred at fifty years of the world economy. Indeed it is this combination of micro creativity and institutional co-ordination which leads many modern scholars to recognise capitalism as an evolutionary economic system (Nelson and Winter, 1984; Mokyr, 1990.) New knowledge opens up opportunities for new activities that in turn lead to further knowledge in a self-reinforcing, autocatalytic process. As Frank Knight put it so accurately, in societies premised on the division of labour and the role of markets, economic development is a 'self-exciting' process. He might have added that the pace of 'self-excitation' depends crucially on the institutional structure of the economy. Because the growth of and application of new knowledge is vital to this evolutionary process we need to make some careful distinctions between science, technology, and what I shall call managerial or administrative knowledge. This leads us directly to the insight that there this is much more to technology than scientific knowledge and that there is much more to innovation than technology and science.

Science, Technology and Innovation: Basic Concepts.

Because the central concern of this essay is the relation between knowledge and economic development we must begin with some clarification of what these terms might mean. No one doubts that the accumulation of practically applicable knowledge is the foundation of the development process in all societies, rich and poor alike. Nor, I hope less confidently, would they doubt that the relationship is very different for societies at different levels of development and that the policy consequences vary accordingly. All economies are knowledge-based economies, they could not be anything else. What distinguishes different economies is the nature of the knowledge that underpins development at different stages and the different ways in which that knowledge is accumulated and applied to practical effect. In particular there are important differences in the strength and depth of their institutional structures for generating and applying knowledge, whether old or new. To express it at its simplest, the relation between knowledge and development is highly complex and this is so because capitalism in its many varieties is also complex. How is this complexity manifested?

Science and Technology

A wealth of recent scholarship has established that science and technology are different and mutually reinforcing bodies of knowledge, created within distinctly different communities of practitioners characterised by different institutional contexts and rules of accumulation. They have in common a dependence on imagination and creativity in the solution of problems, and on the cumulative building of knowledge upon knowledge. *But their differences are profound*. In science the focus is upon the law-like status of natural phenomena at all scales of observation. Its natural institutional context is the academic discipline, and its organisational form is the university or the private or public research laboratory. The method of knowledge accumulation is that of conjectures and experiment, of rejection or provisional acceptance of hypotheses. Moreover, the conjectures are not formulated at random but follow cumulatively from the established state of theoretical understanding. The search is for truth and truth depends on the conformance between observations and theory. Science is open, its results are diffused widely within an international culture of publication and its primary reward mechanisms are closely related to priority of publication and the breadth of impact of the discoveries. To this degree science is an international institution, following commonly accepted procedures and it increasingly involves international collaboration in its prosecution.

By contrast the world of technology is that of the law-like nature of man-made phenomena and its natural institutional context is the profession and its organisational form is the firm. Conjectures and experimentation are just as important as in science but conjecture builds on practical experience and is far less bounded by theoretical speculation. As science seeks after confirmable truth, so technology seeks after practical effect, and practical effect is embodied in products and processes, in technique. The natural outputs of technology are designs, artefacts and practices and their modes of operation, and their value is judged not by their intrinsic truthfulness but rather by their practical utility. Not, 'Is it True?' rather, 'Does it Work?', that is the question. As science is 'open' so technology is 'closed', at least relatively, with quite different dissemination cultures and a natural concern for secrecy or, where possible, patent protection. In particular, the development of technology and its reward mechanisms depend upon successful exploitation in the economic and social sphere, and the formation of technological conjectures is strongly shaped by those practical experiences. Indeed, the complexity of technology frequently takes its operation beyond the bounds of theoretical understanding, which is one reason why 'disasters' play such an important role in shaping the development of technologies. Many of our technologies are operated in contexts in which experience is the only guide to operational validity and further development. It often is a case of learning as one goes along, producing, applying and using. Now this has a very important consequence, namely, that the development of technology cannot be separated meaningfully from the market process in which it is continually tested to meet commercial or social ends.

However, these differences must not be overdrawn, the dividing line between science and technology is often extremely difficult to draw, as it always has been for example in relation to medicine. In truth, the accumulation of knowledge defines a spectrum of activities along which the scientific and the technological merge naturally, one with the other. Modern science and technology are becoming increasingly interdependent. Wherever an understanding of the natural world is relevant to an understanding of the practical world this will be so. Thus developments in science may open up new opportunities for technology and equally, the converse is true; the demonstration of a technological effect can stimulate the search for the underpinning natural principles. This is as much true of the discovery of say iron or steel as it is of the transistor. This is one reason why a substantial number of firms engage in pure scientific research. Their competitive position depends on an understanding of relevant sciences and so they conduct science to solve their own problems, and, of equal significance, so that they can interact with and draw upon the far wider world of science beyond their own laboratories.

Understanding Innovation

The first point to note in answering this question is that innovation involves much more than knowledge of the relevant science and technology. At least since Schumpeter (1911) economists have accepted a distinction between the formulation of a working idea for a product or process (an invention) and the application of that idea to the economic process (an innovation). They distinguish the wider application of an innovation beyond its originating firm by the term diffusion. [See Box 2.]

Now innovation requires much more in the way of knowledge than science and technology. It requires a sound judgement of what potential users might demand in a product and what they would be willing to pay. It requires an ability to organise the production process, to acquire the appropriate inputs at economical prices and to manage the new activity. It requires the ability for creative conjecture well beyond that associated with the advancement of science and technology. The concept of entrepreneurship captures this well. The entrepreneurial function is to bring together market opportunities with scientific and technical opportunities. It requires an ability to combine conjectures and knowledge from these different sources, to see in them a new profit opportunity, and to carry this opportunity into practice. Without a capability to combine together these complementary kinds of knowledge innovation does not occur. This is especially so with many new technologies that draw upon information from multiple disciplines and sources. New managerial, organisational and market knowledge is also highly practical knowledge, like engineering production knowledge it accumulates on a trial and error basis and is only weakly guided by theoretical supposition. It has a much greater claim to be tacit, localised knowledge and it is certainly deeply connected with the market process.

Before proceeding further it will be helpful to summarise some of the important functions of this innovation process. First and foremost is its **unpredictability** arising naturally from the two concepts that define any innovation, change and novelty. Unpredictability implies uncertainty and an inability to predict with any accuracy either the contributing elements in the innovation process or the uses to which innovations are put. Because all innovations are business experiments within a wider process of knowledge discovery, the unexpected plays a more than usual role. Nevertheless we know a good deal about the kinds of phenomena that define the innovation process.

Innovations are not best understood as isolated events. Rather they are located in sets of innovation opportunities from which **sequences** of innovations typically emerge in a **cumulative** fashion (Utterback, 1996). Many of the innovations will be **incremental** improvements in current practise, a much smaller number will be the **radical** innovations which open up whole new fields of opportunities. Consequently one of the features one expects of any internationally competitive industry is the ability of the firms within it to sustain a trajectory of innovation, not their ability to make a single innovation. Single innovations give only transient competitive advantages, and, often, rivals who understand the significance of maintaining the momentum of innovation overtake the pioneering firms.

In assessing the factors that shape innovation it is convenient to distinguish four elements; **opportunities, incentives, resources** and managerial **capabilities**. The significance of these categories is that they become the **targets of innovation policies**.

The opportunities depend on the combination of technological and market ideas to identify a new product, process or method of organisation. The incentives depend on the expectation of profits sufficient to compensate for the risks in relation to the capital invested. The resources include not only the elements of formal R&D but also all the complementary assets required to transfer ideas into practice. The capabilities relate to the knowledge skills and organisation of firms involved in the management of the innovation process. Innovation capabilities are a distinctive type of capability, involving the management of knowledge and change, additional to the capabilities in relation to production, investment and interaction identified by Lall (1987), although, clearly, they overlap to a considerable degree. Innovation policies can be defined in relation to all for attributes as we show below.

One of the most important factors governing the generation of innovation opportunities is the fact that much of the relevant knowledge lies outside the firm either in suppliers or customers or research institutions such as universities. An ability to gain access to and absorb external knowledge into the firm is crucial in a world where even the largest firm cannot accumulate all its knowledge in-house. Innovation is more likely to occur when firms are located within a rich knowledge base and when it was developed the skills to interact with this knowledge base. Consequently, networks play a very important role in the innovation process. Some of these may be concentrated geographically, so-called clusters, others may be distributed nationally and internationally. Again we shall see below that network formation is an important dimension of innovation policy.

There has been considerable debate about whether the stimuli to innovation reflect demand-pull or science-push in the innovation process (Mowery and Rosenberg, 1973). It is now accepted that both views are mistaken, it is the interaction between push and pull which matters and this interaction is reflected in the multiple kinds of knowledge required in the innovation process. Adding to the stock of scientific knowledge, without making the complementary investments in supporting technological, managerial and market knowledge simply leads down the path of rapidly diminishing innovation returns. Some idea of the importance of these complementary activities is given in Table 1 based on a selection of OECD countries. It shows that R&D expenditures, on average, account only for one-third of total innovation expenditures, and that on average a quarter of total expenditures are incurred outside of the firm. Equally, market opportunities remain unfilled if the innovation capabilities are missing.

It follows from the above that we cannot treat the categories of invention, innovation and diffusion as a logical, temporal sequence with invention first and diffusion last. The stages interact: knowledge gained in the diffusion process stimulates further invention that stimulates additional innovation in never ending sequences. In the case of most technologies we observe streams of *multiple innovations* which are shaped by the process of application and diffusion, by the interaction between technological possibilities and market opportunities (Bell and Pavitt, 1993). Thus innovations are in practice *sequences of related improvements*, a stream of developments within a particular technological and market context. Nor is this surprising. The growth of knowledge reflects the emergence of particular problems that act as focusing devices to guide enquiry. Some of these problems are internal to the science or technology, others arise from experience in production and use of the particular devices. Either way the give rise to the *cumulative* nature of scientific and technological advance.

To make the best of these distributed forms of knowledge requires that this division of labour be co-ordinated and that the institutions needed to achieve this are in place. Secondly, the returns to investment in innovation fall off sharply if the complementary sources of knowledge are not properly co-ordinated. Thirdly, many of the important complementary types of knowledge constitute practical knowledge of market needs, of how to organise production and distribution, with little relation to science and technology as normally understood. Finally, there is an important complementarity between the two principle ways knowledge is acquired in relation to innovation, through the experience of the market process and through formal R&D programmes. *It is the bringing together of these two complex ways of learning that I define as a central problem of STI policy in developing economies.*

By way of summary, a policy for innovation cannot be reduced to a policy for science or even technology and on this misunderstanding has foundered many a promising initiative. Innovation policy is necessarily broader. It must address the availability of complementary assets and knowledge. It must address the supply of skilled labour and the supply of risk capital. It must address the ways in which those with knowledge of science and technology can be brought together with those who have organisational and market knowledge. It must address the incentives to innovate and, most fundamentally of all it must address the capabilities of firms to manufacture with new technology and to market new products.

Science, Technology and Innovation Policy: Underlying Principles.

Policies do not exist in a vacuum nor do they emerge at random, they are always grounded in a wider set of beliefs about the world: those beliefs in relation to economic activity have played an important role in shaping the practice of science, technology and innovation policy. Behind these developments are two very different accounts of market economies. One set of principles is defined by the economic theory of competitive equilibrium, it focuses upon the efficiency with which the market system allocates given resources to competing ends. In a perfectly competitive price system, the prevailing prices measure and thus equate the marginal valuations placed on commodities and resources by producers and consumers. Such a system has a quite remarkable efficiency property; neither is it possible to produce more of any commodity without sacrificing some of another commodity, nor is it possible to increase the welfare (utility) of any agent other than by reducing the welfare of some other agent. The intellectual force of this 'Pareto Principle' cannot be underestimated since it underpins many of the ideas in relation to tariff and tax policy in the world economy. However, as we shall see it also leads to strong implications in relation to the efficiency with which knowledge is produced and used in market economies.

A second contrasting set of beliefs is associated with the Austrian and evolutionary schools of economic thought. It was Hayek (1948) who put the problem of knowledge at the heart of his economic analysis and who argued that market systems have developed as solutions to two distinct but interrelated problems. The first is the idiosyncratic individual nature of knowledge, its distribution among all the actors in an economy and the impossibility of any one mind comprehending in total the knowledge of what individuals want and what they can do. Markets and the price mechanism 'solve' this problem of knowledge dispersal. The second and related problem is that of learning and the growth of knowledge. Markets provide a framework for experimentation and the trial and error formulation and testing of business hypotheses, and they provide a means of adaptation in which new events require new knowledge for their solution. In this perspective, development and the growth of knowledge are inseparable adaptive consequences of market institutions, which like all institutions are best evolved as the outcome of a trial and error process. To say that economic growth and development depend on the accumulation of knowledge is also to say that they depend upon a competitive process. The micro diversity of creative behaviours which innovation reflects has its economic impacts through market relations in the competitive process. Successful innovators develop new products and or processes that enable them to attract customers and resources from rivals. In this process growth and profitability are closely linked and the outcomes depend very much on the operation of the prevailing market institutions. We shall see below that this makes competition policy a natural complement of innovation policy (Metcalfe, 1998). Firms can compete in many ways, some of them socially unproductive. Competition policy can guide firms to compete in productive ways, of which competition through innovation is the most beneficial to economic development. The profitability of firms is not only crucial in connection with the ability to expand and attract scarce resources, it is also crucial to their ability to fund investments in knowledge creation and thus maintain a sequence of innovations. The directions in which technology advances depend very much on who is successful in this market process.

This line of thinking has become vital to the development of evolutionary accounts of market activity (Metcalfe, 1998; Nelson and Winter, 1984). Evolution depends on micro diversity of individual behaviours and the market processes that resolve that variety into patterns of economic change. In this view, markets are devices for communicating information about what is available on what terms and firms are devices for deciding what is to be produced and how. Micro diversity is in turn created by acts of innovation and acts of innovation depend upon the idiosyncratic development of knowledge. These processes will not be efficient by the canons of the Pareto Principles, for they inevitably involve elements of failure, of waste. However, they will be creative, *and it is too this creativity that evolutionary economists point in charting the rise of the Western economies* (Rosenberg and Birdzell, 1986).

Thus the dynamics of capitalism is a reflection of its creativity in generating and applying new knowledge to economic problems that are largely self generated. Capitalism is not then the particular state of affairs emphasised by equilibrium theory but rather a process of change, a process of discovery with particular properties. It is in all relevant essentials a development system. Both development and the competitive process depend on the imperfect distribution of knowledge that in turn is a reflection of the division of labour.

These different views on the nature of a market economy lead to two very different justifications for STI policy, namely, market failure and system failure. We explore each one in turn.

Market Failure

Let us turn first to the problem of knowledge in terms of the competition equilibrium theory of resource allocation. It was Kenneth Arrow, in a seminal paper (1962) who drew attention to the peculiar economics of the production and use of information. From this has come the principal modern justification for STI policy, the doctrine of *market failure*. Arrow fully recognised the fact that information is not knowledge and that the peculiar economics of information qua commodity, have deep implications for the role of the market mechanism in the generation and application of knowledge. What are these peculiarities?

First and foremost, information has the property of *a non-rival good*, the same ideas may be accessed and used any number of times by any number of people. Information is used but it is not used-up. This is true whether it is used to produce goods and services or to produce more knowledge. In this it also has properties akin to a public good and it had long been understood that market systems undervalue the true social worth of public goods. Secondly, the value of an idea is highly *uncertain* and the economic system lacks the depth of future markets to give the necessary comfort to stimulate investment in information production. Since one cannot foresee the future one cannot know which innovations will emerge or how needs will evolve, there is no basis for writing future contracts to trade commodities not known about. Here the probability calculus does not help, one cannot transform uncertainty into risk when one cannot write down all the options which will define those risks.

Thirdly, and reinforcing the first two points, it is extremely difficult to establish *secure property rights* to protect the producers of ideas. There is a natural tendency to experience spill-over information externalities, which allow individuals to benefit from the knowledge investments of others while avoiding the costs required to make those investments. The 'theft of ideas' thus undermines the incentive to produce ideas. Why sow when others will reap?

Fourthly, the production of ideas is subject to significant *indivisibility's* in terms of the investment required to generate that information, and indivisibility's give rise to scale economies in the application of knowledge. One cannot have half an innovation, all the ideas must be present for it to work. The consequences of this are profound. While the non-rival nature of information suggests that it be widely diffused at a nominal communication cost, such a pricing regime would mean that the producers of these ideas could be unable to cover their fixed costs of information production. Marginal cost pricing will not work to efficiently distribute ideas and simultaneously cover the costs of production. As many economists have understood such indivisibility gives rise to increasing returns and monopoly.

Fifthly, the production of knowledge creates *asymmetries* in what is known by buyers and sellers and asymmetries can lead to opportunistic behaviour, adverse selection and moral hazard. It is then difficult to create incentives for each side of the market to behave in an efficient way. Familiar examples of this problem are provided by the markets for commodities with unknown characteristics (the lemons problem) or by insurance markets where the seller of insurance can neither observe nor control the behaviour of the insured. Now the essential point about innovation is that it of necessity requires information asymmetries; an innovating firm knows and acts in ways different from its rivals, and the outcomes are always uncertain.

Finally, Arrow pointed to a paradox that strikes at the heart of the idea that efficient market transactions depend upon their property rights. Imagine, he suggests, that you are to sell an item of information. Quite reasonably the purchaser needs to know what the information is before she can place a value on it and decide whether or not to meet the asking price. Thus for the transaction to occur the information must be divulged in advance. But then, once divulged, why should the purchaser pay. Rather like a market in 'lemons' the transaction process seems to self-destruct.

To the extent that all economic activities require prior and continuing investments in information production and the translation of information into knowledge, the conclusion that necessarily follows from the above is that no activities can be organised in a Pareto efficient fashion (Stiglitz, 1997). At best, capitalist economies will at best be imperfectly competitive in the sense made clear by Edward Chamberlin. The normal mode of organisation in an ideas-based economy is monopolistic, and prices have to stand above production and distribution costs by at least the degree necessary to cover and reward the costs incurred in generating the underpinning knowledge as well as the normal costs of production and distribution.

If these are the principles behind market failure what are the consequences for STI policy? Consider first basic science as a type of knowledge whose areas of potential economic application are highly uncertain, and highly diffuse (Nelson, 1959). Private firms, it is argued, will not invest in producing pure science, a market solution will not work. Consequently pure science has to be funded by the state and be prosecuted in non-commercial institutions. This is broadly what we observe, basic science and basic technology is the preserve of universities and dedicated public laboratories. Moreover, the institutions of science are particularly favourable to its having the impact one would hope from the production of a non-rival, quasi-public good. Scientific awards are allocated according to priority of publication, and publication in international journals is a device to disseminate that information at a minimal, marginal communication cost. This is just as true for work in basic technological research.

Consider next the related problems of spill-over externalities and property rights in ideas. The solution here is the patent system and the copyright system. In return for public disclosure of relevant information, a patent holder is given a limited term monopoly right to use or license the information within a particular domain of application (the scope of the patent). Information is placed in the public domain and the inventor can extract a reward for her efforts. Notice though that the reward is not necessarily linked to the cost of inventing nor does it typically capture more than a fraction of the wider social value of an invention. Nor are patents the only way to protect intellectual property, secrecy or a rapid rate of innovation, or the complexity of the invention are often more than effective barriers to imitation. Thus the required degree of patent protection and the use of patents varies very greatly from sector to sector. In pharmaceuticals they are vital elements in innovation in the engineering industries they are not.

Now these institutional devices, patents and the public funding of open science, are remarkable in themselves and they reflect the sense in which the Nelson and Arrow arguments are exactly right. However, to link this to a general presumption of market failure in relation to innovation is simply a mistake. *Rather it is clear that many of the alleged sources of market failure are in fact essential for the market process to work at all.*

Here it is important to recognise again that information is not knowledge and that economic activity depends directly on the latter not the former. This has nothing to do with the less than satisfactory tendency to equate information with a flow and knowledge with a stock. Rather it reflects the much deeper point that a flow of information will reflect a certain state of knowledge in the sender and may generate a quite different state of knowledge in the recipient. It is not knowledge that flows between them but a message embodying the intended information. *While information can be public, knowledge is not naturally so*. What one learns from particular information depends on one's prior state of knowledge and this is necessarily *idiosyncratic and individual*. Thus the ability to interpret information messages is not to be taken for granted nor is it a cost-less process. To understand information one must make the necessary investments in background knowledge. This takes time and resource, and, since both are scarce, we cannot invest in everything, it follows that the emergence of specialised knowledge is a consequence of and reinforces the division of labour in society. As Rosenberg (1990) has indicated this is the reason firms in high technology activities make major investments in basic science and technology, not only to develop their knowledge internally but also to interpret the flow of external information and hold intelligent conversation with its producers in universities. That knowledge is non-rival we can agree; that it is publicly accessible at a negligible price once it is produced is a far more doubtful proposition.

Here we can see an important weakness of the Arrovian framework. Because information may be disseminated readily at negligible cost, it treats knowledge in the same way, as if it were part of the atmosphere, or, as others put it, readily available off the shelf. This assumption is very far from the reality: the substantial costs of turning information into knowledge means that knowledge is not readily available to all. *Knowledge is sticky and it* does *not flow like water to find a uniform distribution. If it did flow uniformly, it would be difficult to explain why the development paths of countries are so different.* This is true of basic science and technology just as it is of more applied knowledge. Scientists and technologists are necessarily specialists in what they know, they often have very limited abilities to claim expertise outside of their competence. Even within disciplines, access to knowledge is subject to substantial barriers, barriers which become greater the further one's knowledge is behind the frontier. If one wanted further proof of the significance of this distinction between information and knowledge one need look no further than the current complaints about information overload in modern society: more information then can possibly be translated into useful knowledge.

It does not follow from the above discussion that there cannot be *workable* markets in information. These have always existed. Books, newspapers, compact disks are all devices that embody non-rival public information in rival physical goods and make market transactions possible. Moreover, the provision of scientific and technical knowledge on a commercial basis has for at least two centuries been the basis for viable business activities. Consulting chemists and engineers, contract R&D companies, and more recently, management consultants are each examples of the market provision of specialist information. The Arrow Paradox does not destroy this market. Contractual arrangements are readily devised and problem-solving capability readily becomes a matter of reputation and trust.

These markets may not be Pareto efficient, the information providers may act as limited monopolists but that this is surely better than having no information markets at all.

The thrust of the argument thus for is that market failure can only be part of the rationale for policy. Moreover, it is clear that uncertainty and information asymmetries are necessary for the market process to work in knowledge-based and innovation-driven economies. It is perverse, consequently, to identify them as sources of market failure.

Consider the problem of uncertainty, which all agree is the essential characteristic of the innovation process. It cannot be avoided and to suggest that this stands in the way of a fully articulated set of futures markets is simply irrelevant for the real competitive process. To eliminate uncertainty one would need to eliminate innovation – scarcely a sensible policy stance. This is also the case with asymmetries in information and knowledge. Far from being a nuisance they are, in fact, essential to the innovation process: innovation is exactly the process of creating and trading an information and knowledge difference between rival firms. These particular kinds of asymmetry cannot be labelled market failures if the market process cannot operate without them. Here we see the source of the difficulty. Market failure has been judged by the standards of equilibrium resource allocation. Innovation, however, resides in the world of market process not market equilibrium. It is essential to that competition process and indeed it is the combination of innovation and a competitive process that delivers economic development.

Consider next property rights. What is important here is the comparative weakness of the patent system: it protects against pure imitation but it does not protect against rival invention based on different principles, and rightly so. Capitalism depends for its development on the principal that every economic position is open to challenge. Thus while patents can be important, it is equally necessary that their scope not be drawn so widely as to make it too difficult to invent around an established idea. As with many domains of policy, difficult trade-offs have to be identified and exploited.

System Failure

We turn now to the second kind of rationale for STI policy. We have seen above, that a central feature of the innovation process is the division of labour in the production of innovation related knowledge. That innovation is not a relay race proceeding sequentially from science to market but that it is more like a basketball game on which all players contribute their different skills at different points in time. This leads us directly to the idea of *innovation systems and to systems failure as the rationale for STI policy*.

The central idea is straightforward. As innovation system is a set of interacting organisations charged with the production, communication and storing of all the elements of specialised knowledge required in the innovation process (Nelson, 1993; Freeman, 1987; Edquist, 1997; Carlsson, 1995; Lundvall, 1992). Because systems are formed from components and interactions between those components we can think of innovation systems failures in two ways. *An STI systems failure arises whenever access to needed knowledge is prevented either because the appropriate organisation to produce or give access to that knowledge is missing, or because the linkages to communicate ideas between the respective organisations are missing or operate defectively*. Then STI policy becomes a problem of institutional design, a problem in building the appropriate social capabilities to realise the potential for development (Abramovitz, 1989). It is this aspect of STI policy that is of particular relevance to developing economies.

Firms are obviously key players, directly, and indirectly through their roles as users of technology and suppliers of technology in the innovation process. So are universities and public and private research laboratories, professional societies and consulting firms. Indeed in any knowledge-based economy there is a rich network of organisations that contribute to innovation. Some of them are national in domain of influence some of them are specific to particular sectors of economic activity.

Now what matters for the operation of the STI system is how these different organisations interact, how the knowledge generated in one part is communicated to another part where it is combined in the process of producing yet new knowledge. The system becomes a framework for compound learning, what one organisation can learn depends in the learning ability of the other organisations in the system. In this way the system provides for the collaborative activity necessary to produce innovations from the combination of different hands of knowledge. Scholars recognise these institutional arrangements as components of the social capital or social capabilities of an economy (Edquist, 1997; Fountain, 1998). Relationships based on reputation trust and reciprocity enable the benefits to be gained from multiple sources of learning, from group problem solving and from working together for mutual gain. These relationships are based on transactions within networks and within markets and they provide the basis for the collaborative and co-operative development of innovation capability. They are an appropriate response to the increasing technological diversity and complexity of the innovation process; a reflection of the need to combine multiple kinds of knowledge created by multiple organisations. The division of labour in knowledge production reduces the society wide cost of knowledge generation, social capabilities enable this division of labour to be co-ordinated in the innovation process.

Now this co-ordination process is not easily achieved. Specialisation of purpose can result in incompatibilities in incentives and difficulties in the communication of knowledge. Knowledge is sticky, and there have to be receptive capabilities as well as transmission capabilities, or, putting it differently, intelligent users as well as intelligent producers of knowledge. This requires investment throughout the innovation system. It may also require the creation of specific bridging organisations to create, for example, the interface between firms and universities or public research laboratories.

From this system failure perspective, the role of policy in the innovation process is clear. It is the embedded nature of firms in a wider network of knowledge producing organisations which matters. While the market failure perspective focuses on lack of incentives to invest in innovation in the single firm, the systems failure perspective points to the creation of opportunities and capabilities in co-operative fashion. Firms remain the key actors in the innovation process but their knowledge generating capabilities are greatly enhanced by their being embedded in a wider matrix of knowledge generating organisations.

It is clear that on the past two decades with Europe, and to a lesser extent the USA, the balance of policy has shifted markedly in favour of the systems perspective. Indeed a recent OECD report (1999) defines a new agenda for innovation policy focused upon the development of what I called above social capabilities. This recognises the importance of an innovation culture, the need to promote networks and clusters of the relevant organisations and the opening up of the science base to new patterns of entrepreneurship.

A Framework for STI Policy Choices

We have drawn attention already to the fact of the diversity of conditions between developing economies and the implausibility of applying similar STI policies in all conditions. For low-income countries the principal policy should be one of learning via imitation, achieving inward technology transfer typically through importing the appropriate machinery, product designs and manufacturing procedures and through accepting complementary direct foreign investment. A point will be reached, however, when this passive policy is no longer appropriate and an innovation possibility threshold is passed in one or more sectors. The problem passes to a more active phase of technological learning, in which adaptation replaces adoption to build a capacity for incremental innovation not least to fit technology more closely with national market needs and the resource base. This is more likely in middle income economies when market processes are working, the public finances are sound, export markets are securely established there is a well established educational infrastructure and a well distributed and adequate level of economic competence to identify, develop and exploit business opportunities. It is in these circumstances that policy choices in relation to STI arise, and it is this case that I focus upon.

STI Policy Choices

As with many policies the primary question involves an understanding of the relative roles of the public and private sectors in the innovation process and a strategic assessment of how national activities in agriculture, industry and service activities are to be developed. Once answered, the secondary questions relate to identifying national deficiencies in relation to the opportunities to innovate, the resources to innovate, the incentives to innovate and the capabilities to innovate.

Innovation Indicators

To achieve this level of understanding requires that the policy maker have access to **appropriate indicators** of the state of the national innovative effort. A good deal of effort has been put into developing appropriate indicators in the OECD countries and a sample of the most important ones is given in Box 3. These are divided into three categories, in relation to inputs, intermediate outputs and final outputs. Input indicators cover R&D activity either in the form of expenditures, employment of qualified scientific and technical personnel, or lists of projects and programmes. Their chief limitation is in knowing the quality of the inputs, which are necessarily very idiosyncratic in the case of the people involved, and the effective organisation of research teams. At best these issues can be assessed indirectly but should include measures of public and private inputs and measures of engagement with the wider world of science and technology, for example, through attendance at seminars and conferences. Intermediate indicators include patents and scientific and technological papers. It is well recognised that the quality of patents varies enormously and that different industries place very different weights on patent activity, nonetheless they remain a tolerable, if partial, measure of inventive activity. Publication based indicators, linked either to patents or scientific and technological papers, can always be accompanied by citation analysis, due allowance being made for time-lags. Final output indicators are the least well developed, again because of quality problems. These can include lists of innovations, measures of diffusion of technology and measures of new business formation to commercialise innovations. When used with care, **benchmarking** of firms against each other and foreign rivals can provide useful information on performance gaps.

Any information system is only a prelude to analysis and action. The next step is to identify relevant technologies, singly or in combination, to decide which firms and other research organisations are to play an innovative role and whether this is to be reflected in the identification of particular innovation projects and programmes. The policies can be general or they can discriminate between sectors, technologies, firms or projects. R&D tax credits, for example, are an entirely general policy, applying in principle to all firms in all sectors. Project-based R&D support is at the other end of the spectrum, being highly specific in their application.

There is, however, a simple and useful way to categorise alternative kinds of policies. This involves distinguishing between policies that take innovation opportunities as already established and needing only to be realised, and policies that are designed to create those innovation opportunities. The two groups are, of course, complementary not mutually exclusive. The first group includes policies that deal with market failures and the second group with policies that deal with system failures. Table 2 provides a breakdown based on OECD data of support for industrial technologies. Fiscal incentives fall in our first category and infrastructure policies in the second, while mission oriented policies may fall in either group. The considerable differences between countries in policy mix is immediately noticed and without further detailed investigation it is not clear which mix would be appropriate for any individual LDC.

<u>Group 1:Policy with given Innovation Opportunities</u>

<u>R and D Subsidies</u>

The first case to consider is when the innovating firm does not have available the internal financial resources to fund the profitable projects, nor can it raise the money in the capital market for well known reasons in relation to risks, imperfect information and adverse selection. In short it cannot convince potential backers that its hopes are justified, nor can it offer sufficient collateral against the required loans. Its resources are too small relative to the options for innovation that it can identify. Here lies the case for government support, typically in the shape of a specific project grant, a fraction of the project costs (often 50%) is made available to the firm which, if successful, will be repaid in part or in full. Subsidised R&D loans from banks, and R&D tax breaks are alternative ways of achieving the same end, namely to guide more resources into innovation by reducing the marginal cost of R&D activity (Metcalfe, 1994). This type of policy is often of most importance in relation to innovation in small firms. Usually the subsidy applies directly to R&D expenditures but it can equally be directed at the employment of R&D personnel.

R&D tax breaks have a number of attractions, not least in that they do not involve government in making micro decisions on particular innovation projects. Most of these schemes involve treating R&D as an allowable expense for tax purposes and granting a tax credit on a fraction of these expenditures. What is to be included as allowable expenditure is not always transparent. A good case can be made, for example, for including market identification and development expenditures under the broad heading of R&D. While there are obvious dangers in the encouragement of creative accounting, there is some evidence that tax incentives can be effective. Although, clearly, their effectiveness depends on the efficiency of the prevailing tax administration.

Public Purchasing

A final type of policy is found in public purchasing and market developing policies more generally. Because innovations require indivisible investments in their realisation it follows that their exploitation gives rise to increasing returns. The bigger the market the lower become the average costs of innovation. The same principles lead us to more general policies in support of the demand side of the innovation process. Public purchasing can have a very effective role in supporting demonstrator projects to establish feasibility to users, and, more generally, in providing innovation products for public services such as health and utilities which have to be supplied domestically. Moreover, in relation to metrology, quality assurance services and standards the government can act as the proxy customer for what are essentially public goods. It is the same argument that holds with respect to basic science and basic technology research. On the demand side, governments have a positive role to play.

There is a related way that policy can stimulate the innovation process, namely, by export promotion policies that create awareness of and incentives to exploit foreign markets. Indeed any policy that increases penetration of foreign markets will help to encourage innovation. As pointed out above, knowledge of market possibilities is an essential component in the definition of innovation opportunities.

Group 2: Policies to Identify Innovation Opportunities

However, fiscal incentives of this kind address only one dimension of the innovation problem, namely, resources. In many other cases the lack of awareness of opportunities and managerial capabilities will be of far greater importance. It is knowing how and where to innovate that is the problem. We can interpret the negative innovation stance as a lack of economic competence in either of two dimensions. Either a firm lacks the design manufacturing and marketing capabilities, so that its projects are not profitable in the prevailing competition situation. Or, alternatively, it lacks the managerial ability to carry out innovation projects. In response to these problems, innovation subsidies of any kind are not the answer, and this is where the innovation systems perspective comes into play.

The crucial point is that the relevant capabilities or knowledge lie outside the firm because we can take it that it is not operating at the world frontier. Then the problem is how to access the necessary ideas, and here collaborative arrangements are potentially of great importance

Collaborative Innovation

We have already pointed to the multiple kinds and sources of knowledge that characterise modern innovation activities, their embeddedness in **distributed innovation processes**. The policy issues here are of two kinds. Is the STI infrastructure sufficiently well developed for current innovation needs, and, Are there appropriate academic and other research facilities for the needs of local industry? Secondly, if the infrastructure is satisfactory are the networking arrangements and incentives in place to support local innovative activities?

For developing economies these are likely to be the key issues. Investments in infrastructure need to be the prime aim of policy. But then the organisations so created need to connect with the rest of the economy in a range of collaborative activities. The following are the more important examples:

- collaborations between firms ,suppliers and customers to develop new technologies;
- collaborations between firms and local STI institutions;
- Collaborations between local STI institutions and overseas universities and laboratories, in part to promote the exchange of research staff;
- Collaborations between local firms, STI institutions and foreign multinationals to transfer capabilities in jointly executed projects.

In respect to each of these possibilities **specialist local research organisations** (SRI’s) have an important role to play by being the bridge between different contributors to innovation. They can act as focal points in the innovation process in a number of ways. By collating, codifying and disseminating knowledge on the industry's technology, so raising awareness. By providing technological and innovation management services for firms; by engaging in pre-competitive research projects and supporting the innovation projects of specific firms; and, by acting as a bridge between firms and other knowledge based institutions such as overseas universities. In particular, they can organise collaboration research projects in an industry bringing together the viewpoints of different firms and sharing the costs of innovation. Thus SRI's can act as organisers of innovation networks within supply chains and between firms and other knowledge creating organisations. They can be the most effective institutions to co-ordinate the division of labour in the innovation process. By encouraging the demand for innovation they justify expenditure on the supply of innovation.

Here we also find the importance in an innovation systems perspective of policies in relation to training, education and research. When feasible, it is obviously sensible to access the work of overseas innovation systems through secondments or joint research projects with foreign universities and research institutes and by using the R&D facilities of foreign firms that have invested locally.

Technology Infrastructure

That government has responsibility to develop a country's technological infrastructure is on of the key lessons of the innovation systems perspective on policy. This is not only a question of supporting advanced research and education activities in universities and specialist research organisations. A particularly important aspect of this is contained in the need to support an infrastructure of **metrology, testing and standards** activity. There is no area of productive activity that does not require the use of accurate measurement techniques and this dependence increases as technologies become more advanced and dependent on the interconnection of multiple components and systems. The creation of national standards, metrology and testing services is essential for economic development and this falls to government in all the advanced countries. Metrology is the classic example of information as a public good and is to be funded by the state though not necessarily managed in all its dimensions by the state. In the UK, for example, public laboratories hold the fundamental standards in relation to measurement while a network of private laboratories is accredited to provide metrology and testing services for industry.

The importance of these issues is difficult to overestimate. Accurate measurement and the ability to meet standards is essential if a country is to compete in international markets, it is essential to the design and development process for new products and processes, and it is essential to the successful conduct of R&D activity at any level. Metrology and related services are a central element in any country's innovation system. Policy must not only establish these services it must ensure that the are coupled with training activity and that procedures are in place for the effective diffusion of this information. It is no accident that the reorganisation of the service in the USA in 1988, with the creation of the National Institute of Standards and Technology, was legislated for in the Technology Competitiveness Act of that year. Competitiveness depends on standards and standards depend on metrology (Tassey, 1992).

Lessons from Different Countries.

Following this rather long discussion of the principles behind innovation policy it will be helpful to turn to several specific cases, the UK, South Korea, Colombia and Mauritius, since they provide insights on policies at different stages of development.

The UK

It will be instructive to begin with the UK since it has a well-established STI infrastructure, dating from the immediate post-war years. Yet there is a sense that this system does not contribute to innovation in the UK as well as it might and there is a continual search for policies to enhance this innovation system. In the early 1960s the UK's STI system reached the climax of its first post-war phase. This system is biult around a broad division of labour. Universities are funded from the public purse primarily to carry out basic research in science and technology. The policy missions of government departments where supported by publicly funded laboratories (with the bulk of the spend being on defence and nuclear energy). Industry funding was directed at applied research and development in support of innovation, primarily in large firms in a small number of sectors, chemicals, engineering and aerospace. In addition, it had long been recognised (from 1918 in fact) that fragmented industries, predominantly made up of smaller to medium sized firms, could benefit from co-operative research arrangements (the Industrial Research Associations) and many had been established in the 1920s and 1930s.

The Labour governments of the mid to late 1960s began a long process of change and reform, setting up the framework of Research Councils and the ill-starred Ministry of Technology. The thrust of the policy was to support key industries (computing, aerospace, nuclear power) and establish a policy of support for innovation in private firms. This framework, which lasted until the mid-1980s, and a Conservative government under Margaret Thatcher, provided innovation grants to UK companies in support of innovation. Support was project-based and single firm based and required firms to provide 50% collateral funding for their projects. The rationale for these schemes was pure market-failure, as explained previously, and co-funding was designed to suppress any tendencies to exploit opportunities for moral hazard at the public expense. It is clear that these policies simultaneously provided firms with resources to innovate and increased their incentives to spend more of their own resources on innovation.

In the 1980s this framework for innovation support came under increasing scrutiny. Despite its commitment to the free market, the realities of innovation in the UK meant that an active role was maintained for government. The stimulus for change was the observed policy of the Japanese government where major investments were being made in the development of new enabling technologies through joint public/private funding. The UK response was the adoption of collaborative research programmes focused on pre-competitive research. In this model, public funding was provided to groups of research collaborators, firms and universities, provided the research was not deemed to be ‘near to market’. The idea of generic, enabling knowledge that could be exploited in many different ways by different firms was central to this approach. At first these principles were adopted in a major programme of collaborative research and development in computing and information technology, the Alvey programme, which treated the UK industry and university system as a distributed research laboratory. However, the principles were soon extended more widely. The idea of single company support for innovation was progressively abandoned from the late 1980s onward and confined to very limited programmes in relation to innovation in SMEs. By 1993, the last vestiges of single, large company funding support, the Advanced Technology Programmes, had been terminated. This transition is extremely important for it signalled the beginning of a systems failure perspective on STI policy. At the same time the development of a European Community policy on cross-country collaborative research began to shape the thinking of policy makers.

Together these developments amounted to a shift towards a systems failure perspective on policy that was endorsed by the 1998 White paper, ‘Our Competitive Future: Building the Knowledge Driven Economy’. The new policy is driven by three considerations, stimulating competition, developing innovative capabilities by encouraging entrepreneurs and developing skills throughout the workforce, and by encouraging collaboration in the innovation process. This policy is now firmly entrenched, and an indication of the current types of innovation policy instruments, as managed by the Department of Trade and Industry (DTI), is shown in Box 4. Of all these schemes only the SMART programme provides innovation subsidies for single company projects. These are directed at small firms and the purpose is to enable them to develop an innovation to the stage where it can attract venture capital support. The LINK programme is the major initiative that funds projects and programmes on a collaborative basis between firms and the science base. A total of 75 have been funded since the acceptance of the scheme although the overall scale of funding is limited. These collaborative programmes provide 50% co-funding of pre-competitive research programmes. Eureka and the Fifth Framework are programmes of collaborative work within Europe.

All of the other schemes are examples of policy directed at creating connections within the innovation system. The ISI scheme is directed at the encouragement of the widespread adoption and effective use of information technology in small firms. Business Excellence is devoted to networking and the promotion of best practice in industry, and ITS is a scheme to enable UK companies to access foreign technologies. The TCS is a very important scheme that links graduate study in Universities to projects that are of strategic significance to the companies concerned. In 1997, industry committed £35m to the scheme with 222new projects involving 356 graduates. Large companies pay 60% of the costs a figure reduced to 30% for small firms.

However, perhaps the most significant policy development of the 1990s, at least from a system's failure viewpoint, has been the Foresight Programme.

Technology Foresight

There is no more appropriate indication of the switch in policy from matters of resources and incentives to matters of opportunities and capabilities than the adoption of a Technology Foresight Programme by the UK Government and indeed other governments (Laat and Laredo, 1998). Foresight activities have been defined as:

> ‘a systematic means of assessing those scientific and technological developments which could have a strong impact on industrial competitiveness, wealth creation and the quality of life’ (Georghiou, 1996).

and they appear to have been applied on a most consistent, long term basis within the Japanese science and technology system (Freeman 1987). The process involved in conducting a large-scale foresight programme is precisely a matter of bridging and connectivity within a nation’s science and technology base and between that base and its areas of application. In particular, the crucial point about foresight proper is its inclusion of knowledge about demand and market developments in its activity. Foresight activities of this kind are necessarily broadly defined to explore the social and economic constraints and opportunities in relation to the development of scientific and technological knowledge.

The process involved the creation of fifteen sectoral panels of ‘experts’ that consult on a wide basis with the relevant communities in industry, academia and government through regional workshops, a major delphi survey and numerous other activities. Panels covered fields as diverse as transport, biotechnology and the service economy. Each panel produced a report indicating the main forces for change and the policy issues which flow from the analysis as well as identifying the likely constraints on change. It is without question the most extensive consultation of industrial and scientific opinion that has ever occurred in the UK. It is the fact that the development of modern technology is so heterogeneous with respect to its discipline base and institutional context that makes the sounding of opinion in the broadest possible fashion extremely important.

One way to interpret foresight activity is in terms of Weinberg’s (1967) careful enunciation of external criteria for the support of science. Despite strong objections from the pure science lobby, the use of external criteria does not imply that pure science is to be transmuted into applied science. Rather what is at stake is the differential focusing of basic scientific work in relation to non-scientific objectives. Here the crucial point is that the principal lasting benefit of the exercise lies in the process of building the science base into the national innovation system. It is what the process does to the formation of commercial and academic *strategies* to promote innovation; to the creation of lasting *networks* between industry, government and the science and technology community; and, to the emergence of coherent *visions* within their communities on *complementary developments* in science and technology. By a coherent vision is definitely not meant a consensus view about specific technologies or routes to innovation but rather an understanding of the breadth and interdependence between the uncertain opportunities open to a particular sector.

Thus the policy aim has the stimulation of the technology support systems of particular groups of firms; and, bridging between those formal and informal institutions which interact in a specific technological area for the purpose of generating, diffusing and utilising technology (Carlsson and Stankiewicz, 1991; Carlsson, 1995). The latest example of this can be found in the renewed concern for industry-university links and the encouragement of university spin-off companies. To create effective webs the policy maker must know the relevant communities of scientists and practitioners, and understand the rival technologies. The sequences of innovations that emerge, and the firms which are successful, are the outcomes of the process and are not a specific concern of the policy maker. Winners emerge, they are not pre-chosen and they cannot be predicted in advance.

The basic principles behind all these system building policies are network formation and the creation of operational innovation systems. Since, many kinds of knowledge play a role in the innovation process, the different providers have to be co-ordinated appropriately. When basic science and technology are involved then public funding is provided in recognition of the diffuse and uncertain benefits of this work. Responsibility for the final steps to innovation lies firmly with the private sector. Thus the central policy question has become 'How do firms gain access to the necessary external knowledge to support their internal innovation activities?'.

South Korea

The case of South Korea provides an instructive example of the role of science and technology policy in a regime of rapid industrialisation. After hostilities ended in 1953, Korea was heavily dependent on inflows of military and other aid from the United States and it was not until 1961 that rapid economic development began. This experience well illustrates the different stages of development of a policy for technology acquisition. In the first stage there was no demand to develop technology on a stand alone Korean basis, and the central purpose was the acquisition of overseas technology and the internal diffusion of that technology largely through internal labour mobility. Only in the subsequent stages did an indigenous innovation stance emerge. In the 1960s the focus was on light industry (for example, Textiles, Plywood), moving on in the 1970s to heavy industry (for example, Ships, Steel, Construction). By the 1990s Korea was at the leading edge of the next generation of electronic products on areas such as multi-media and HDTV. Three aspects of the general environment are important to understanding the Korean case: the extremely high levels of educational attainment; the emphasis on strong internal competitive pressure; and the role of the large industrial conglomerates (chaebol) as the vehicle for industrial organisation (Kim, 1997). The later are unique to the Korean experience and placed it on a quite different path of development from close rivals such as Taiwan, where industry was in the hands of a multiplicity of small and medium enterprises (Hobday, 1995).

In the first stage, foreign technology was acquired through capital goods imports and the purchase of turn-key plants, supported by the posting of nationals overseas and a policy of reverse engineering. At this stage neither foreign licensing nor FDI played a significant role. The emphasis was on catching-up in mature technologies, taking advantage of lower national wages to support a vigorous export policy while protecting the home market through high rates of effective protection. As development proceeded successfully in the 1960s and 1970s the natural consequences was a rise in real wages that began to erode Korea's competitive advantage in advanced county markets.

It was at this stage in the 1980s that the need arose to develop indigenous innovation capabilities and this resulted in new approaches to STI including an increasingly important position for the Ministry of Science and Technology. What Korean experience indicates is that there is little point in developing an elaborate supply infrastructure for science and technology if the demand to use the knowledge generated does not exist. From about 1984 onwards a concerted group of policies were put in place including public procurement policies to encourage the development of domestic technological capabilities, the management of inward direct foreign investment and the establishment of technology transfer and sectorally specialized public R&D institutes. During the 1980s the transition to greater technological independence was achieved through the development of strong OEM relationships with foreign companies in Japan, the USA and Europe. These relations provided a powerful framework within which to learn new capabilities and provide access to established distribution channels in overseas markets. As the 1980s progressed so did the ability of Korean firms to develop their own independent design and development capabilities (Hobday, 1995). In support of these advances, a total of 46 industrial research co-operatives had been established by 1989. The public banking system provided preferential financing arrangements for technology projects, which were supported by tax credits for R&D and human capital investment, and the provision of accelerated depreciation for R&D facilities. This combination of infrastructure development and technology incentives provided a powerful stimulus to the R&D expenditures of private firms that increased from 12.3 million won in 1975 to 6,903 million won in 1995. More tellingly this represented an increase in the fraction of GDP devoted to R&D from 0.42% to 2.69% over the same period, with over 80% of the total spend accounted for by private firms, compared to some 10% in 1965 (Hobday, 1995). These figures exceed the proportionate spend of many more advanced countries. In the UK, for example, the comparative figure for business R&D from the 1980s on is less than 1% of GDP. Similarly the number of corporate R&D laboratories increased from 12 to 2,270. Kim (1997) has documented accurately the nature of this remarkable technological transition that transformed Korea from an agrarian society to an advanced industrial country in three decades. GDP per head rose over this period from $87 per annum in 1962 to $10,000 per annum in 1995. It was a transition from technological imitation, through a more sophisticated stage of reverse engineering and development of relatively mature technologies, to, finally, the development of an indigenous R&D capability including basic research. The strong export orientation and the competition pressure this produced have clearly been crucial, and so has the underpinning of a well-educated population. But from the point of view of accumulating capabilities the key lessons are three in number. First the development of a first rate higher education system and research base focused on technology, mathematics and computing as a necessary element in communicating with and learning from the external world of knowledge at the science and technology frontier. A policy encouraging international mobility of national scientists and technologists is an important element in this communication process. Secondly, in order to develop beyond a role of technology dependence, it is essential to develop a national innovation infrastructure, and in this the State has a crucial role in providing the foundations for the development of firm capabilities in R&D. In Korea's case it took responsibility for the training of researchers and for the establishment of key public research institutions. Thirdly, the supply capabilities of this infrastructure need to be matched by the development of demand-side capabilities and a supporting policy of R&D incentives. Korean firms achieved this through the formation of strong OEM relationships with foreign technological leaders which they used these to frame technological learning. They also benefited from subsidised loans to develop new technology and the ability of the large Chaebol to cross subsidise R&D investments. Clearly the Chaebol where a key element in this particular path of development, indicating the importance of specific idiosyncrasies in any nation's development. What the Korean experience so clearly indicates is the shifting balance of public and private support for innovation in conditions of rapid development.

<u>Colombia</u>

The experience of Colombia provides a fascinating case study of the evolution of science, technology and innovation policy towards a national system of innovation perspective (Unctad, 1999). From the mid 1950s to the mid 1970s Colombia experienced positive if modest rates of GDP growth per head based on a policy of domestic protection and export promotion combined with restrictions on inward foreign investment. In 1991 this policy was abandoned dramatically with a programme of tariff cuts in agriculture and manufacturing and a switch to the encouragement of direct foreign investment. By the mid 1990s Colombia had established itself as a middle income country with a GDP per capital of $2,300. From 1973 to 1994 it enjoyed the fastest growth rate of all the Latin American economies. The 'Apertura' of 1991 is the key event that ushered in new approaches to STI policy. Colombian officials describe the period 1957-74 as one with a 'Defensive Technology Policy' in which initiatives supported the pattern of protection. Public funds supported scientific research in the universities but little attempt was made to connect this work with industrial needs. From 1974 onwards a technology policy began to be developed and this has developed rapidly after the move to trade liberalisation. The overarching aim of policy was to support the competitive development of Colombian economic activity through innovation. The government plan of 1994-98 sits out the following objectives in support of this:

- to activate the National System of Innovation;
- to strengthen the research, training and technological services infrastructure;
- to support technological innovation in business;
- to generate an entrepreneurial business culture based on creativity, knowledge and a long term view;
- to encourage innovation at regional level in order to foster balanced social development; and,

- to provide financial and other incentives to private investment and research and development.

These are ambitious aims and what is important about them is the recognition of the central role of new R&D organisations and the connections between them. As the UNCTAD report points out (p. 9) 'the capability to learn and build new competencies depends on how well the parts fit together and on the strength of their connections'.

The central purpose of the new policies is thus the creation of networks of interacting research organisations, many of these newly created. In total 29 Centres for Technological Development (CDT's) have been created to act as 'virtual' structures, whose function is to co-ordinate the supply with the demand for new technologies while operating with the existing structures of universities, enterprises and test laboratories. Eight of the CDT's are in industry, 10 in agriculture and livestock, 7 in new technologies and 4 in the mining- energy sector. Several broad kinds of organisation are involved. Sectoral Technology Centres whose aim is to give a better definition of the technological requirements of business, in industries which are perceived to face strong foreign competition (for example, plastics, textiles, shoes and papers). Secondly, there are technology centres focused on new technologies, biotechnology, optics, electronics, software and automation. In addition to these, a number of research and technology incubator units have been formed. The new CDTs are meant to reinforce the links and connections between sectoral and regional technology organisations including those that provide support services in relation to quality and standards, training and technical assistance. They have four functions: to perform R&D, to provide technical extensive services, to co-ordinate with the internal and overseas R&D communities, and to support collaborative innovation between firms in supply chains.

<u>Mauritius</u>

A final case of a very different character is provided by Mauritius, a small late industrialising economy, that has concentrated on the textile industry for its present stage of development. Over 80% of its exports come from the garment industry leaving the economy over-specialised in relation to foreign competition (Lall and Wignaraja, 1998). The development of new capabilities in sectors such as consumer electronics is central to its future but this presents it with major challenges. The economy is too small to fund the necessary R&D programmes to put it at the leading edge of these industries, so it must acquire established mature technology and rely on inherent cost advantages. In turn this requires the requisite level of skills and capabilities and a technology policy to develop them. Mauritius has tackled these problems in a number of ways, primarily to build its technological infrastructure. Central among these was the creation of the Mauritius Bureau of Standards in 1975. This body is responsible for the development of standards that are recognised internationally, for the provision of metrology and testing services and for the certification of firms for quality assurance purposes. In regard to each of these it performs a major educative role and its services are vital for firms that wish to develop new export markets. Another important policy instrument has been the Technology Diffusion Scheme, this provided grants for firms to buy consultancy services to raise competitiveness and productivity. An evaluation indicates a very high return measured in terms of additional export revenues, indicating the benefits obtained from the intelligent use of relatively simple managerial and market knowledge. Other programmes have been implemented to improve design and product development skills and to carry out limited collaborative R&D projects.

Clearly Mauritius is very different from Korea and Colombia yet technology and innovation policy play an important role in its pattern of development. Relevant knowledge is not necessarily or normally high-tech knowledge.

A Brief Evaluation

An evaluation of these different national experiences is clearly premature but several observations are in order. The effectiveness of any innovation system depends on an appropriate matching of demand for innovation with its supply. *Technology push from universities and public laboratories generally does not work and the major issue becomes the innovative stance of domestic firms and their absorption capacities.* If firms cannot identify benefits to product or process innovation then little of substance is likely to happen. Thus a first function of this new system is not to produce a list of innovations per se but rather to build the capacity to absorb new technology. Furthermore, it is important that the infrastructure of STI institutions be appropriate to the stage of development of the economy, and that this infrastructure can adapt as development proceeds. Failure so to do may act as a severe brake on a nation's development.

Lessons for STI Policy

In this final section we can draw together some of the lessons that can derived from the previous analysis. At the outset it is important to reiterate the point that that no single policy stance is appropriate for all developing economies, nor will an appropriate policy remain unchanged over time. Nonetheless some general policy principles can be identified. The focus of these principles is the creation of a working innovation system. They are not concerned primarily with the scale of expenditure on R&D.

The most important principle of all is the need to put innovation first and recognise that the proper role of science and technology is to support innovation. In turn, innovation is concerned with enhancing national productivity and national competitive performance. Many different kinds of knowledge are required for firms to innovate, and knowledge of market possibilities and the organisation of production and distribution are as important as more formal science and technology. Appropriate knowledge need not be sophisticated, formal knowledge. What innovation requires is practically useful knowledge and much of this can only come from experience. Thus, the studies by Best and Forrant (1994) of the Jamaican furniture industry, and by Wignaraja and O'Neill (1999) of the Mauritian textile industry each make the point that 'simple' managerial knowledge is what is needed to make those industries more competitive. To put it more precisely, it is the ability to combine different kinds of knowledge and skill that is the essential factor in the innovation process. However, the ability to combine knowledge applies in two other ways. First in relation to linking the results of R&D programmes with the knowledge that is generated through practical experience. Secondly, in linking with the international world of science and technology which is becoming increasingly integrated.

The second principle requires the State to take a strategic view of the sectors where sustainable competitive positions can be established: positions that reflect the domestic resource base and the nature of international competition. This does not require the national efforts to be best practice in world terms, it only requires that they be better than prevailing worst practice, that is to say, they are viable at world prices. Thus a view has to be established of the countries strategic location behind the technological frontier and with regard to the complexity of the relevant technologies (Bell and Albu, 1999). Again, the matter is a practical one, the choices must reflect the time needed to build the necessary capabilities and the fact that the external situation will also advance over time. Moreover, STI strategy is not a detailed recipe, a plan for individual innovations. It is a framework of commitment within which the sets of innovating actors can work, confident in the durability of the strategic aims. *If a policy is to have lasting impact it must be adaptable to the changes that are a necessary element of the competitive process.*

The third principle concerns the need to establish an innovation system infrastructure appropriate to these strategic choices. We have seen that innovation systems consist of sets of organisations and their interactions, and that the principal route to interaction is through a wide variety of collaborative arrangements. A key role in this is played by lead actors whose role it is to co-ordinate the division of labour in the innovation process. In many developing country's this role will be associated with specialist research institutions either partly or totally funded by the State that sit at the centre of the appropriate, sectoral, innovation networks. Among these, those related to metrology and standards have a particularly important function. Their role is defined in relation to the use and the generation of knowledge (Bell and Albu, 1999). Their main activities can be listed as follows:

- The training and formation of a skilled labour force, including management,
- The provision of metrology services,
- The linking together of firms with their suppliers and customers in pursuit of innovation,
- The generation of collaborative R&D projects and programmes,
- The oversight of standards in the various sectors,
- Interaction with foreign universities and relevant technology institutes to keep a watching brief on world developments in a sector,
- Linkage of foreign firms into the national innovation structure.

One way to interpret this innovation system is to view it as a broadcasting system with transmitters and receivers of information, remembering that information is not knowledge. The capability of the receivers matters as much as the capability of the transmitters and barriers to their interaction may come from misaligned incentives and the 'not invented here' attitude. One of the major difficulties facing research institutes on this model has always been that of keeping their R&D and training activities relevant to the needs of the sector. By far the best way to do this is to have industrial partners as collaborators in these activities not as distant and indirect customers for its services. This requires in turn that the firms in question have the capabilities to interact with the SRIs.

Within the innovation system universities and science policy have an important role to play. They have a training function in relation to advanced research and experimental capabilities, they supply bridging knowledge between pure science and its applications, and, they provide a natural focus for links with overseas research programmes. But this role remains secondary to the main task of raising the technological and innovative performance of local firms.

Finally, it is important to recognise that innovation is not to be equated solely with hi-tech sectors. New knowledge can just as well open up significant innovation opportunities in established sectors. The essential point about innovation is that it is concerned with change and transformation not with newness in a narrow sense.

Concluding remarks

Innovation presents the policy maker with many paradoxes. It is the driving force in the development of capitalism, yet it remains unpredictable in its content and field of application. Its importance reflects the restless, discovery based nature of capitalism in which the accumulation of knowledge is embedded in market processes. It cannot readily be managed let alone accounted for. A world of innovation is in policy terms rather uncomfortable. However, in terms of economic development it is clear that innovation policy matters. I have suggested that what matters for STI policy is the creation of an innovation system and an associated innovation culture. Its role is not to innovate at the world frontier but rather to adapt and develop available technologies to meet the needs of local markets and resources. This is challenge enough.

Box 1

Science, Technology and Innovation Policies

Science Policy

To manage and fund the accumulation of knowledge in relation to natural phenomenon by creation and support of appropriate organizations - research laboratories and universities.

Technology Policy

To manage and fund the accumulation and application of practical knowledge needed for particular productive activities, including transfer of technology from overseas and the transfer of scientific knowledge into wealth creation. Appropriate organizations are research laboratories, universities and firms.

Innovation Policy

To encourage the transfer of science and technology knowledge into application by ensuring that necessary complementary resources (eg. capital finance) and knowledge are available, by supporting entrepreneurship and by protecting intellectual property.

Box 2

Invention, Innovation and Diffusion

Invention

The conception and realisation of a working design for a product or process, or an improvement to a product or process. If sufficiently novel can be patented.

Innovation

The application of invention to economic activity, that is to say, the economic use of an invention. Normally restricted to the first example of economic use.

Diffusion

The spread within the economy of an innovation, the process by which innovations gain economic significance. Diffusion invariably leads to the modification and development of an innovation. Sometimes equated with imitation, the process of copying ideas from application to another.

Radical vs Incremental Innovations

Radical innovations open up new design spaces in the innovation process. Usually involve new principles behind the product or process. Incremental innovations explore this design space with "small" step changes in working principles or design performance.

Box 3

Innovation Indicators

Inputs

R&D Expenditures	a) Annual rates
	b) Cumulated expenditures net of depreciation
Qualified Scientists and Engineers	a) Working in R&D
	b) Working in production and marketing

Intermediate Outputs

Counts of Scientific Papers
Number of Patents
Number of Expenditure on Collaborative Innovation Projects
Number of Public and Private R&D Laboratories in Operation
Citation Analyses of Patents and Papers

Outputs

Productivity Growth Statistics for Firms and Sectors
New Product Launches
Stock Market Valuation of Intangible R&D-related Assets
Fraction of Sales from Products Launched in the Past "X" Years
Diffusion Measures of the Use of New Technologies

Box 4

UK Innovation Policies Administered by the Department of Trade and Industry

Aims	*Scheme*
1. Enhance the capabilities of firms	Teaching Company Scheme SMART University for Industry
2. Collaborative Innovation	LINK Foresight EUREKA EU Framework
3. Diffusion of Best Practice	Innovation Unit Business Excellence Information Society Initiative International Technology Services

Table 1: Breakdown of Innovation Expenditure

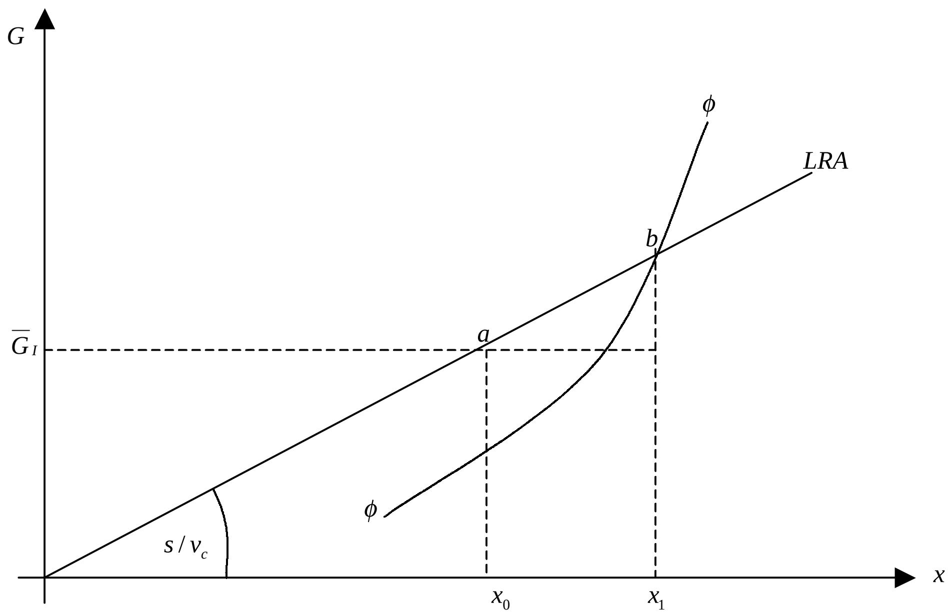
	Percentage Share				
	R&D	**Patents and Licences**	**Product Design**	**Market Analysis**	**External Spending**
Australia	35.1	4.1	..	7.6	..
Belgium	44.7	1.5	11.3	6.6	21.2
Denmark	40.1	5.3	15.8	8.2	9.0
Germany	27.1	3.4	27.8	6.1	29.2
Greece	50.6	6.4	..	13.2	11.7
Ireland	22.2	4.3	22.0	38.5	20.4
Italy[1]	35.8	1.2	7.4	1.6	47.2
Luxembourg	29.3	8.9	8.4	4.3	26.4
Netherlands	45.6	6.1	7.6	19.8	20.2
Norway	32.8	4.2	14.2	5.5	17.6
Portugal	22.9	4.1	24.5	5.4	16.8
Spain	36.4	8.0	..	8.8	6.3
United Kingdom	32.6	2.7	28.4	8.9	15.9
Average	**33.5**	**4.6**	**24.0**	**6.6**	**22.4**

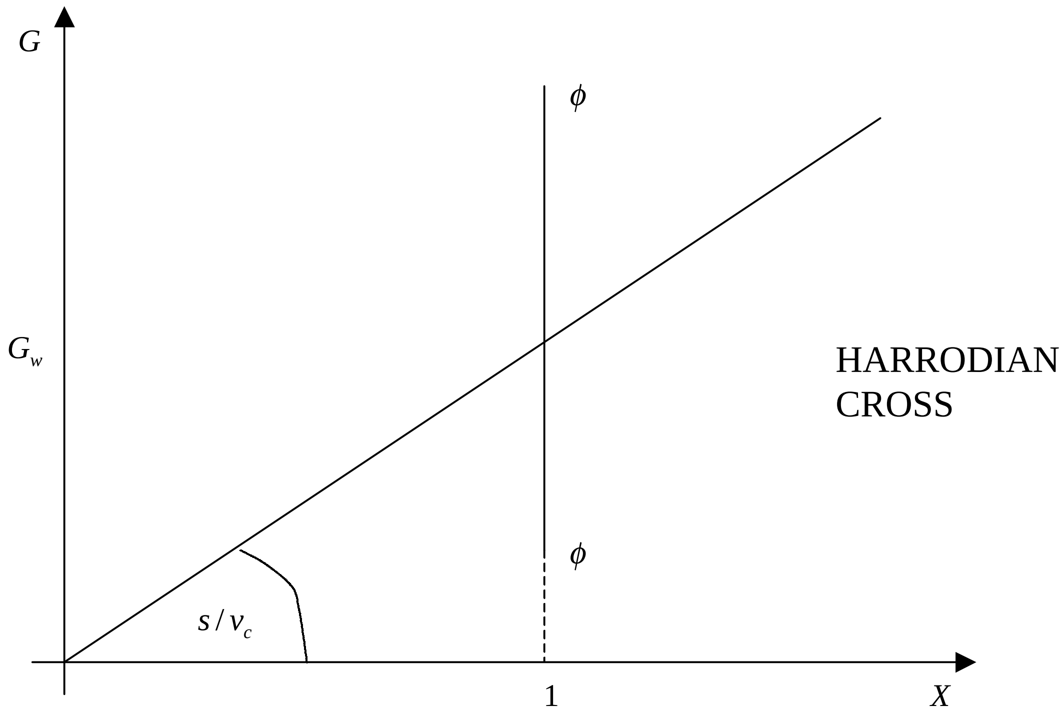
1. Adjusted according to ISTAT. Data do not total 100%, as “other expenditures” are not included in the table.

Source: Bosworth et al, 1996; Community Innovation Survey Data; ISTAT, 1995; Australian Bureau of Statistics, 1994.

Table 2: Government Support for Industrial Technology by Type, 1995

	Australia 1993	Canada 1995	Finland 1996	France 1995	Germany 1993	Japan 1995	Mexico 1995	Nether-lands 1995	U.K. 1995	United States 1995
Fiscal incentives										
Fiscal incentives	38.9	46.9	0.0	8.8	0.0	1.8	0.0	25.0	0.0	6.2
Grants and forgiven loans	14.1	9.7	42.7	14.6	28.0	1.2	2.3	12.0	4.9	15.5
Other	0.0	0.4	2.7	0.0	0.0	1.3	0.0	0.0	0.0	0.0
Total	**53.0**	**57.0**	**45.4**	**23.4**	**28.0**	**4.3**	**2.3**	**37.0**	**4.9**	**21.6**
Mission-oriented Contracts and Procurement										
Defence	9.7	4.7	0.0	35.6	19.5	8.3	..	7.4	61.2	58.8
Space	0.2	9.8	7.4	19.4	11.2	7.5	..	12.3	4.5	8.7
Other	0.0	14.8	0.0	4.3	1.8	10.9	..	1.7	7.3	9.4
Total	**10.0**	**29.3**	**7.4**	**59.4**	**32.5**	**26.6**	**..**	**21.3**	**73.1**	**76.9**
S&T Infrastructure										
Technology institutes, etc.	28.8	5.6	34.7	0.9	13.7	21.6	14.3	11.0	2.6	0.5
Academic engineering	0.2	0.0	0.0	0.0	1.6	0.0	..	0.9	6.3	0.0
Other	8.0	8.1	12.5	16.4	24.3	47.5	83.4	29.7	13.2	0.9
Total	**37.0**	**13.7**	**47.2**	**17.2**	**39.5**	**69.1**	**97.7**	**41.7**	**22.1**	**1.4**
Grand Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**


G
ϕ
LRA
b
a
$\overline{G}_1$
ϕ
s/v_c
x
x_0
x_1


G
G_w
ϕ
ϕ
s / v_c
1
X
HARRODIAN
CROSS

Source: OECD calculations based on R&D database, PSI database and information supplied by Member countries, March 1998.

REFERENCES

Abramovitz, M., 1989, Thinking about Growth, Cambridge University Press.

Arrow, K., 1962, 'Economic Welfare and the Allocation of Resources to Invention', in Nelson, R., (ed), The Rate and Direction of Inventive Activity, NBER, New York.

Bell, M. and Albu, M., 1999, 'Knowledge Systems and Technological Dynamism in Industrial clusters in Developing Countries', World Development, Vol.27, pp. 1715-1734.

Bell, M. and Pavitt, K., 1993, 'Technological Accumulation and Industrial Growth: Contrasts between Developed and Developing Countries', Industrial and Corporate Change, Vol.2, pp.157-20.

Best, M.N. and Forrant, R., 1994, 'Production in Jamaica: Transforming Industrial Enterprises', in, P. Lewis (ed), Preparing for the Twenty-first Century; Jamaica 30th Anniversary Symposium, Ian Randle, London.

Carlsson, B., 1995, Technological Systems and Economic Performance: The Case of Factory Automation, Kluwer Academic, Dordrecht.

Carlsson, B. and Stankiewicz, 1991, 'On the Nature, Function and Composition of Technological Systems', Journal of Evolutionary Economics, Vol. 1, pp.93-118.

Edquist, C. (ed), 1997, Systems of Innovation: Technologies, Institutions and Organisations, Pinter, London.

European Commission, 1998, Internationalisation of Research and Technology, Brussels.

Fountain, J.E., 1998, 'Social Capital: A Key Enabler of Innovation' in L.M. Branscomb and J.H. Keller, *op cit.*

Freeman, C., 1987, Technology Policy and Economic Performance, Pinter, London.

Georghiou, L., 1996, 'The United Kingdom Foresight Programme', Futures, Vol.28, pp. 359-377.

Hayek, F., 1948, Individualism and Economic Order, Chicago University Press.

Hobday, M., 1995, Innovation in East Asia, Edward Elgar, London.

HMSO White Paper, 1998, Our Competitive Future: Building the Knowledge Driven Economy, HMSO, London

Kim, L., 1997, From Imitation to Innovation: The Dynamics of Korea's Technological Learning, Harvard Business School Press.

deLaat, B. and Laredo, P., 1998, 'Foresight for Research and Technology Policies: From Innovation Studies to Scenario Configuration', in R. Coombs, K. Green, A. Richards and V. Walsh (eds) Technological Change and Organisation, Edward Elgar.

Lall, S., 1987, Learning to Industrialise: The Acquisition of Technological Capability by Developing Economies, MacMillan, London.

Lall, S. and Wignaraja, G., 1998, 'Mauritius: Dynamising Export Competitiveness', Commonwealth Secretariate, London.

Lundvall, B.A., 1992, National Systems of Innovation: Towards a theory of Innovation and Interactive Learning, Pinter, London.

Marshall, A., 1919, Industry and Trade, Macmillan, London.

Metcalfe, J.S., 1994, 'The Economic Foundations of Technology Policy', in P. Stoneman, (ed), Handbook of the Economics of Innovation and Technological Change, Blackwell, London.

Metcalfe, J.S., 1998, Evolutionary Economics and Creative Destruction, Routledge, London.

Mokyr, J., 1990, The Lever of Riches, Oxford University Press

Mowery, D.C. and Rosenberg, N., 1979, 'The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies', Research Policy, Vol. 8, pp.102-153.

Mowery, D.C., and Rosenberg, N., 1998, Paths of Innovation, Cambridge University Press.

Nelson, R.R., 1959, 'The Simple Economics of Basic Scientific Research' Journal of Political Economy, Vol. 67, pp.351-364.

Nelson, R.R. (ed), 1993, National Innovation Systems: a Comparative Analysis, Oxford University Press.

Nelson, R.R. and Winter, S., 1984, An Evolutionary Theory of Economic Change, Belknap Press, Harvard.

OECD, 1999, Managing National Innovation Systems, OECD, Paris.

Rosenberg, N., 1990. 'Why Firms do Basic Research (with Their Own Money), Research Policy, Vol.19, pp. 165-174.

Rosenberg, N. and Birdzell, L.E., 1986, How the West Grew Rich, Basic Books, New York.

Schumpeter, J.A.,1911, The Theory of Economic Development, Oxford University Press, (1938 edition)

Stiglitz, J.E., 1997, Whither Socialism, MIT Press, London. .

Tassey, G., 1992, Technology Infrastructure and Competitive Position, Kluwer Academic, Dordrecht.

UNCTAD, 1999, The Science, Technology and Innovation Policy Review, Colombia, United Nations, Geneva.

Utterback, J., 1996, Mastering the Dynamics of Innovation, Harvard University Press.

Wignaraja, G., 1999, Tackling National Competitiveness in a Borderless World, Commonwealth Business Council, London.

Wignaraja, G. and O'Neill, P., 1999, SME Exports and Public Policies in Mauritius, Commonwealth Trade and Enterprise Paper, No 1. Commonwealth Secretariat, London.

Weinberg, A.M., 1967, Reflections on Big Science, Pergamon, London.