Some New Ideas About Research for Development

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1. Introduction

This is a background paper, provided to the Commission on Development Related Research in Denmark. Its purpose is to inform the Commission about current thinking relevant to the funding of research for development. Our approach is to consider theory and policy from a global perspective, and to derive conclusions for development funding, rather than to consider developing country research in isolation.

Research funding is a potentially important component of development aid because of the central role played by technological change – in the wide sense of the improvement and use of knowledge in production – in socio-economic development. 'Research' in this sense is to be construed widely, not as 'basic research' – whose relevance in isolation to development processes is minimal. In this paper, we will use 'R&D' as a short hand for this wide definition – though we will also show that the required concept is wider even than conventionally defined R&D.

Nations need to devote some of their income to R&D in order to put externally-generated improvements in knowledge to use, be competitive, make good policy and strategy decisions, especially as the technological content of governmental decisions increases.

R&D has two 'faces' – a knowledge generating face, and a learning or knowledge using face. The knowledge-using face is quantitatively more important in developed than in developing countries, because it deals with the huge *stock* of knowledge that is exploited in productive activity. The knowledge-generating face is qualitatively important because it provides additions to that stock. Technology-using organisations including farms, healthcare institutions and industrial firms need R&D to help acquire and absorb the existing stock, as well as occasionally to make additions to it. Governments increasingly need R&D to enable them to regulate the acquisition and absorption of technology and in order to improve their own activities. For example, issues such as regulating the use of genetically modified crops and the environmental implications of changes in agriculture require considerable technological sophistication. Government, too, is the chief provider of people and knowledge to society through the higher education and research system. It is much more important in this respect than as a provider of new technologies. Under certain circumstances, it makes sense to use government R&D to develop completely new knowledge – 'research' in the traditional sense – but this is by no means always a high priority.

Companies in capitalist economies, at all levels of development, under-invest in knowledge production. The state usually tries to compensate for this, by making long-term investments, which should yield social benefits (externalities). Donors can support this by providing resources, which can be invested away from short-term budgetary pressures but under the strategic control of the recipients. The object of such donations must be to support the performance of R&D and innovative activities and the creation of knowledge infrastructures to support the economic and social structures and problems of particular recipient nations. While local knowledges must exist to tackle specific problems, most of the knowledge required is globally generated and globally valid. The required knowledge is 'world class.' Just as 'appropriate technology' tends to be uncompetitive, so bad science is not science at all. But the required knowledge mostly does not reside within public research institutions. Rather, it needs to exist right across the economy and society – in firms, on farms and in hospitals as much as in the universities.

In this paper, we first discuss a number of important new ideas about research, technology and development. We place these in the wider context of national systems of innovation and production, and consider lessons – particularly from the way the 'Tiger' Newly Industrialising Countries in SE Asia have developed – for knowledge management. We contrast these with the development of research capacities and the role of donors in less developed countries before arriving at conclusions about new requirements for donor policies concerning research for development.

If desired, section 5.2 can be read as a summary of this paper.

2. Some New Ideas about Research, Technology and Development

Important elements of the 'mental model' with which Western policy makers have approached research and economic development policy since the Second World War have been shaped by a number of ideas which we now see as misconceived. These ideas have promoted the design and deployment of counter-productive policies, both in the context of funding research for development and in research policy more generally. Such misleading ideas include:

- The idea that invention, rather than imitation, is the major source of innovation and economic development. In fact, 'creative imitation' and exploitation of the existing stock of knowledge accounts for most economic development
- The idea that basic science is the ultimate source of innovation and therefore of economic development (the so-called 'linear model' of innovation). In fact, the relation between basic science and the innovation process as a whole most resembles the 'parallel play' of two-year-olds. From the perspective of economic innovation, science is generally more interesting as a source of trained people than as a source of new and commercially relevant knowledge
- The neo-classical model of the firm as a well-informed, rational robot. Real firms are fallible, have variable capabilities, lack information and make progress through learning
- Market failure as the only (or chief) justification for state (and, therefore, donor) intervention in research. The new understanding of real firms suggests a broader role for the state in *enabling* companies, farms and other technology-using institutions to function well.

In this section, we describe the transition in thinking in each of these areas, as a basis for defining better donor policy for funding research for development.

2.1 Creative Imitation and the Dynamics of Capitalist Development

The role of technological change as a driving force in capitalist economic development has for a long time been understood. Adam Smith wrote[1] of improvements in production and the division of labour being driven by "philosophers or men of speculation whose trade it is not to do anything but to observe everything; and who, upon that account, are often capable of combining together the powers of the most distant and dissimilar objects." Marx placed the transformation of social relations and of technology at the centre of his analysis of capitalism, while Schumpeter connected technology with the "gale of creative destruction" that drove capitalist progress.

While economists have awarded the central role in economic development to technological progress, they mean something rather broader than hardware and software: namely 'a new combination of the factors of production.' This *may* involve using results of scientific or technological research. However, it can also involve much

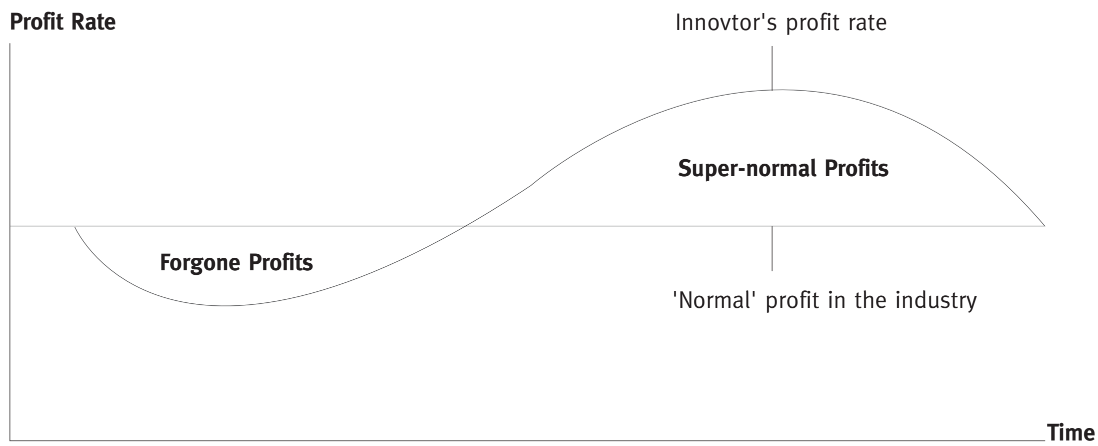
1) *Adam Smith, The Wealth of Nations, 1776; reprinted, Harmondsworth: Penguin, 1974, p. 115.*

more mundane things such as laying out the machines on the factory floor in a better order, changing the design of the product packaging or copying ideas from a producer in a distant market in order to create a local advantage. These things may be 'new to the firm' as opposed to 'new to the world,' yet still give rise to competitive advantage. A key observation, however, is that innovation is a fundamentally economic process, in which technology may play a greater or a lesser role.

The reason economists see technical change as being such an important driver of economic development is that it involves *imitation.* By creating a temporary advantage, an innovator forces competitors to react – often in creative ways involving improvements and 'innovating around' the first innovator's design, rather than through simple copying. In this way, innovations give rise to changes in the economy, which may be several times larger than the effect on the original innovator.

Exhibit 1 shows the conventional representation of the effects of successful innovation on the entrepreneur's profit rate. Initially, profits drop below the industry norm, as the entrepreneur pays the investment costs of innovation. Success of the innovation allows the entrepreneur to earn super-normal profits for a period when she effectively monopolises the innovation. These profits are then competed away by the innovative and imitative activities of other entrepreneurs. Often, these competitors use much of the same knowledge stock as the original innovator.[2]

Exhibit 1
Innovation and Profits



In is often only in this kind of simple theoretical exposition that a difference between original and imitative innovation is clear. A normal pattern is for an industry to experience a continuous sequence of innovations – as in the succession of models offered by competitors in the car industry. Whether we describe these as innovations or – recognising their common but developing knowledge base – creative imitations matters only in so far as 'imitation' has a bad press.

2) R Brainard, C Leedman and J Lumbers, Science and Technology Policy Outlook, Paris: OECD, 1988.

If we go on to consider where the 'original' innovator obtained the knowledge used, most of that will also come from the existing stock. In so far, then, as every innovation is based on a lot of existing knowledge mixed in with a little new thinking, the distinction between innovation and imitation in economic terms breaks down. All innovation is in this sense imitation. There are, of course, differences in the degree of novelty involved and the extent to which innovations can be appropriated. The terminology of 'innovation' contra 'imitation' with its connotation of 'superior' contra 'inferior' serves the interests of those who do research to create new knowledge by enabling them to claim high status. But, in terms of economics and development, its connotations are inaccurate and counter-productive. Imitation is perhaps *the* central fact about innovation and economic development under capitalism.

2.2 New Models of Innovation

The mental models we carry around with us shape the way policy is made. In relation to innovation, the predominant popular mental model – the so-called 'linear model' – suggests that basic science *leads to* applied science, which causes innovation and wealth. This 'technology push' or 'science push' idea is mistaken. Policies based on this model tend therefore to be counter-productive.

For most of historical time, no one worried much about a distinction between basic science and technology. Theory-building and technological development went along in parallel: sometimes apart; sometimes together. Indeed, the early Industrial Revolution in England had little to do with formal science and a great deal to do with practical experimentation and work by 'mechanics' in a pattern of imitation and incremental improvement. An often-quoted example of the relationship in practice is the impetus given to thermodynamics in the Nineteenth Century by the development of the steam engine. Over time, theoretical developments first began to explain why steam engines worked and only later to provide a basis for improving their design.

The startling achievements of physics during the Second World War had made clear the immense power of science, reinforcing belief in science as a force for social change. The manifesto for the new view of science was Vannevar Bush's 1945 report[3] *Science: The Endless Frontier,* which successfully argued the case for a US National Science Foundation and paved the way for the massive expansion of higher education and research since the war. Bush had spent the war doing a mixture of applied and use-inspired research to underpin weapons development. Yet his manifesto for post-war science was *basic* science and he argued that increasing science funding would automatically increase product and process innovation and therefore national competitiveness as well as military preparedness. It seems odd to those of us who have lived with the term all our lives, but the idea of 'basic research' is therefore rather new and rather artificial – "a rhetorical creation on the part of scientists anxious to justify their social position."[4] The high (almost religious)[5] status, which the basic science establishment has managed to achieve has made it hard to question the allocation of resources to it.

3) *Science The Endless Frontier, A Report to the President by Vannevar Bush, Director of the Office of Scientific Research and Development, Washington DC: United States Government Printing Office, July 1945.*
4) *Ibid.*
5) *Paul Feyerabend, Against Method, London: NLB, 1975.*

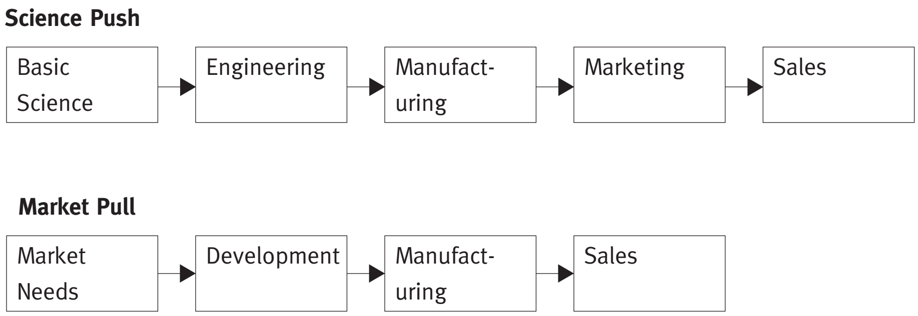
The 1950s and 1960s saw significant efforts in many OECD countries to build up their university systems and, often, dedicated research institutions. There were many reasons for this, including an increasingly democratic view of education as well as a belief that this growth would hasten economic reconstruction and development. But in economic terms, underlying these efforts was the now-traditional 'linear' view of the innovation process as being essentially 'pushed' by science. The policy implication of the linear model is simple: if you want more innovation (and therefore economic development), you fund more science.

With hindsight, we can see how easy it was to take the scientific achievements of the War out of context. In fact, they made a huge impact for at least two reasons:

- First, the now-famous projects like Manhattan Project, which developed the atomic bomb, often responded to clear military requirements (powerful munitions, detection of enemy aircraft); in other words, they were in a strong sense *user-oriented*
- Second, they did not happen in the context of peacetime markets but in wartime – that is, in command economies, where it is possible to *force* a direct connection between technological advance and economic production.

During the 1950s, the science-push model of innovation dominated.[6] While there was some limited research support for this view in the 1950s, in its crude form it does not stand up to much scientific scrutiny. It is perhaps better thought of as part of the ideological superstructure of the post War expansion of science, rather than as a theory of innovation. Soon, thanks to the empirical work of those such as Carter and Williams,[7] Schmookler[8] and Myers and Marquis,[9] more emphasis came to be placed on the role of the marketplace in innovation. This led to market-pull or need-pull models of the innovation process. *Exhibit 2* is a schematic of the two linear models.

Exhibit 2
Traditional (Linear) Models of Innovation

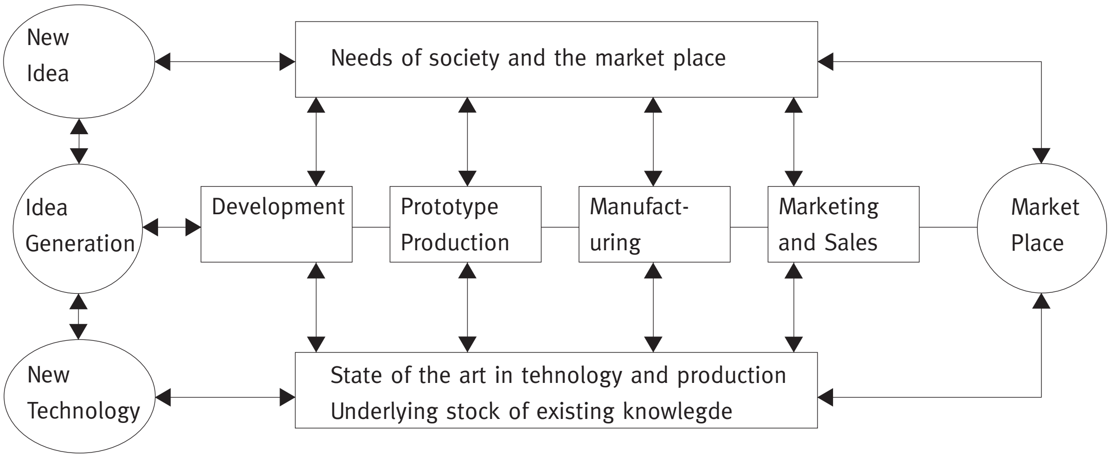


6) *This account of successive generations of innovation model is partly based on Roy Rothwell, 'Successful Industrial Innovation: Critical Factors for the 1990s', R&D Management,: 3, p. 221-239, 1992.*
7) *Carter, C. and Williams, B., Industry and Technical Progress, Oxford University Press, 1957.*
8) *Schmookler, J., Invention and economic growth, Harvard University press, 1966.*
9) *Myers, S. and Marquis, D.G., Successful Industrial Innovation, National Science Foundation, 1969.*

A key weakness of the linear models is a failure to conceptualise how the links between successive stages of innovation are supposed to work. Such links are, in fact, very difficult to achieve in a managed way, except inside a single company. Typically, different people do the activities conducted at each stage in different places and often in different institutions. They tend to have different motivations and incentives and to operate in different interpersonal networks. *A priori,* one would expect it to be very hard to create the kind of chain-links between them, which are depicted in the linear models.

By the late 1970s, Mowery and Rosenberg[10] largely laid the intellectual argument between push and pull to rest by stressing the importance of *coupling* between science, technology and the marketplace. Their coupling model constituted a more or less sequential process linking science with the marketplace (via engineering, technological development, manufacturing, marketing and sales), but with the addition of a number of feed-back loops and variations over time in the primacy of 'push' and 'pull' mechanisms. This is shown schematically in *Exhibit 3.*

Exhibit 3
Modern 'Coupling' Model of Innovation



The preoccupation of the earlier generations of innovation model is with the link between the *flow* of new knowledge and economic innovation. However, this ignores the huge importance of the *stock* of existing knowledge indicated at the bottom of *Exhibit 3.* The vast majority of the knowledge used in any innovation comes out of this stock, and is not created afresh in the project that gives rise to the innovation. Important parts of the knowledge stock can be very old, as was shown in the TRACES and HINDSIGHT[11] projects, which tracked the movement of knowledge elements respectively from applied and basic research into industrial practice across very long periods of time.

10) *Mowery, D.C. and Rosenberg, N., 'The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies', Research Policy, April 1978.*
11) *Illinois Institute of Technology, 1969, Technology in Retrospect and Critical Events in Science (TRACES: A report to the National Science Foundation), NSF Contract C535; Office of the Director of Defense Research and Engineering, Project Hindsight – Final Report, National Technical Information Service, 1967.*

Working with and reworking the *stock* of knowledge is the dominant activity in innovation – a fact which is readily obscured by the focus on novelty in the linear models and in the values of the *research* (as opposed to the R&D) community. Countless surveys of OECD firms show that their main sources of technology are internal knowledge and other firms. Public sector research accounts for a vanishingly small share of their knowledge inputs. In product development, considerable efforts are devoted to monitoring competitors' products and to reverse engineering – both as a source of ideas and in order to benchmark the company's own processes. For example, car companies routinely buy each others' new models and disassemble them. We are aware of at least one case in the USA where the same was done with a railway locomotive.

Innovation theory has moved on to consider increasingly complex 'systems' refinements of Mowery and Rosenberg's model. However, the simple linear model retains a strong grasp on the popular and political imagination, and continues therefore to be an important driver of policy and practice. Its empirical credentials may be dubious, but it helps justify the position of the scientific élite. At least as bad, by diverting attention from the fact that most R&D involves working with existing knowledge it obscures the central role of creative imitation in OECD practice.

2.3 Reconceptualising the Firm

The past twenty or so years have seen a radical re-thinking in innovation theory about the firm, improving significantly our understanding. Conventional, neo-classical economics viewed firms, in effect, as autonomous and rational robots using perfect information. Much of the traditional, neo-classical framework has been overturned during the 1990s, through a convergence of evolutionary economics, with its stress on firms as 'learning organisations,' and research on the innovation process. The new National Innovation Systems[12] approach stresses the idea that firms and other economic actors have 'bounded rationality' and this makes knowledge, learning and institutions key to overall economic performance. In the new view, economic actors are no longer autonomous robots, but are deeply interwoven into the economic fabric. The performance of the individual firm or institution and the system as a whole are inter-related. The unit of analysis is no longer only the individual firm but also the 'system' of networks within which firms operate. National economic performance is explained as the performance of this total system.

A second key idea, which stems from the central role attributed to learning, is that of historical path dependence. What a company or institution can do today depends upon what it could do yesterday[13] and what it has learnt in the meantime. "Often, the elements of the system of innovation either reinforce each other in promoting processes of learning and innovation or, conversely, combine into blocking such processes.

12) *See Christopher Freeman, Technology Policy and Economic Performance: Lessons from Japan, London: Frances Pinter, 1987; Bengt-Åke Lundvall, National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, London: Pinter, 1992; RR Nelson, National Innovation Systems, New York: Oxford University Press, 1993.*
13) *Nathan Rosenberg, Perspectives on Technology, Cambridge University Press, 1976.*

Cumulative causation, and virtuous and vicious circles, are characteristics of systems and sub-systems of innovation."[14]

2.4 Market Failure

The new view of firms, and therefore of markets, leads to new and different rationales for government policy and for funder activity.

The idea of 'market failure' leading to under-investment in research has been the principal rationale for state funding of R&D[15] in the post-War period. Of course, governments had been funding research long before the economics profession produced a reason. Arrow is generally credited with describing the three major sources of market failure which – from a neo-classical perspective – make it useful for government to fund research:

- *Indivisibility,* because of the existence of minimum efficient scale
- *Inappropriability* of the profit stream from research, leading to a divergence between public and private returns on investment. This results from two essential (and economically efficient) freedoms that scientific researchers have: namely to publish and to change jobs
- *Uncertainty,* namely divergences in the riskiness of research respectively for private and public actors.

Arrow's argument was particularly relevant to more 'basic' (and, by implication, generally applicable) forms of knowledge because capitalists' inability to monopolise the results of such research meant they would be least likely to invest in it. His argument is, however, conceptually flawed. It simply *assumes* that there is under-investment in basic research compared to an imagined welfare-economic optimum. It makes this assumption because it implicitly accepts the 'linear model' account of the role of science in economics and development. In fact, no one has observed or calculated what such an optimum would look like.

Relying on the neo-classical model of the firm, the market failure approach assumes away key deficiencies of real companies, not least what we have elsewhere called 'capability failures.[16]' The new approach to the firm suggests that there are other important failures affecting economic performance. These include failures in infrastructural provision and investment; 'transition failures'; lock-in failures; and institutional failures.[17] These failures justify state intervention not only through the

14) *Bengt Åke Lundvall (ed), National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, London: Pinter, 1992.*
15) *Ken Arrow, 'Economic Welfare and the Allocation of Resources for Invention,' in Richard Nelson (Ed.) The Rate and Direction of Inventive Activity, Princeton University Press, 1962; see also Richard Nelson, 'The simple economics of basic scientific research,' Journal of Political Economy, 1959, vol 67, pp. 297-306.*
16) *Erik Arnold and Ken Guy, 'Diffusion policies for IT: the way forward,' OECD/ICCP Expert group on the economic implications of Information Technologies, Paris: OECD, 1991.*
17) *see Keith Smith, Systems Approaches to Innovation: Some Policy Issues, TSER 3.1.1, Oslo: STEP Group 1996.*

funding of basic science, but more widely in ensuring that the Innovation System performs as a whole.

While this makes a huge difference in theory, it involves less of a change in the practice of OECD and many NIC governments, which have long assumed wide responsibilities in education, developing infrastructures, assisting companies in developing capabilities and so on. Their practice is in stark contrast to many recommendations and requirements of the World Bank, through which they forbid to developing countries the policy mechanisms they use at home. If the new view of the firm is correct, then donor and lender willingness to promote the use of these more active forms of intervention is key to effective development.

3. Innovation Systems – A Radically Changed View of Knowledge and Production

Over the past ten years or so, there has been a revolution – a 'paradigm shift' – in the way we understand the relationship between research, innovation and socio-economic development. In a number of areas, policy practice had moved ahead of theory, but theoretical development means that we now have in some countries greater harmony between theory and practice than was the case in 1990.

3.1 National Innovation Systems

As one would expect with such a new concept, a precise definition of a 'National Innovation System' is still emerging. Nelson and Rosenberg[18] use a rather narrow definition, namely the "set of institutions whose interaction determine the innovative performance of national firms." Metcalfe says:

A system of innovation is that set of distinct institutions which jointly and individually contributes to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies.[19]

Based on what the NIS literature actually says about the way innovations happen, we prefer an *inclusive* definition. *Exhibit 4* sketches what *we* mean by a 'National Innovation System': namely, all the actors and activities in the economy which are necessary for industrial and commercial innovation to take place and to lead to economic development. As we indicated earlier, those who do research on research and innovation have given up attempts to understand successful innovation through single-factor explanations (such as technology push or demand pull) as inconsistent with the data. Instead, the current orthodoxy is that economic well-being is founded on a well-functioning National Innovation System, in which not only the actors shown in *Exhibit 4,* but also the links between them, perform well. The NIS is in this sense similar to Lall's notion of national technological capability:

National technological capability is the complex of skills, experience, and effort that enables a country's enterprises to efficiently buy, use, adapt, improve and create technologies. While the individual enterprise remains the fundamental unit of technological activity, national capability is more than the sum of individual firm capabilities. It comprises the non-market network of inter-firm networking and linkages, ways of doing business, and the web of supporting institutions.

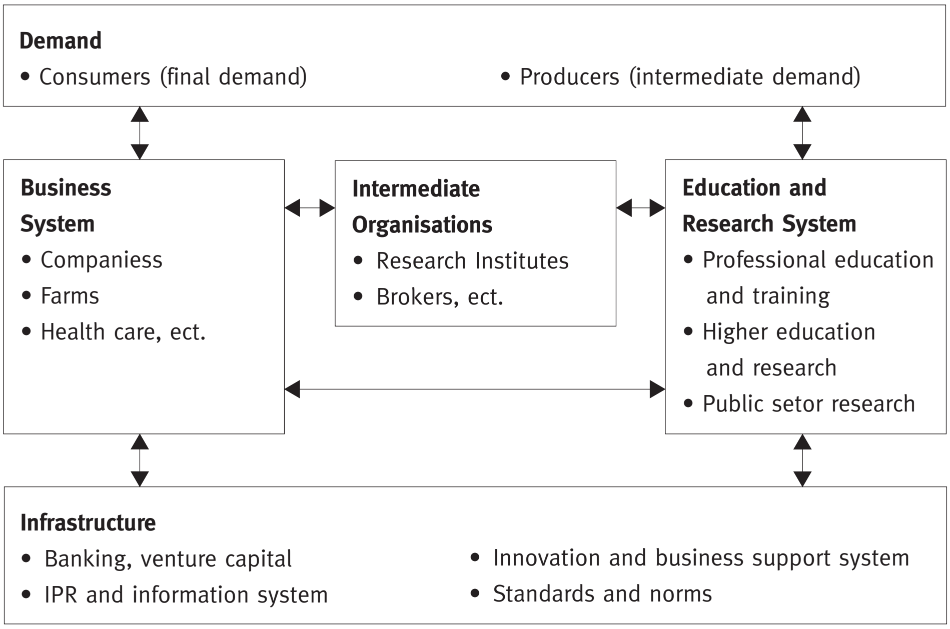
18) *R R Nelson and N Rosenberg, 'Technical innovations and national systems,' in R R Nelson (ed), National Innovation Systems: A Comparative Analysis, Oxford Univerisity Press, 1983.*

19) *Metcalfe, J., The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives; Stoneman, P., (ed.) Handbook of the Economics of Innovation and Technology Change, Oxford: Blackwell.*

These affect significantly how firms interact with each other and the efficacy with which they exchange the information needed to co-ordinate their activities and to benefit from collective learning.[20]

Exhibit 4
Major Components of a National Innovation System

Framework Conditions
- Financial environment
- Taxation and incentives
- Propensity to innovation and entrepreneurship
- Trust
- Mobility
- Education, literacy



20) *Sanjaya Lall, 'Technological change and industrialisation in the Asian newly industrialising economies: achievements and challenges,' in Linsu Kim and Richard R Nelson (eds.) Technology, Learning and Innovation: Experiences of Newly Industrialising Economies, Cambridge University Press, 2000.*

In contrast to earlier views focusing on entrepreneurs as individual heroes, innovation and learning are now seen more as *network* activities.

As Edqvist argues[21] "the notion of optimality is absent from the systems of innovation approaches. Hence comparisons between an existing system and an ideal system are not possible." The NIS approach is nonetheless normative, in the sense that it claims that certain system characteristics – such as strong network links between actors – are likely to improve performance.[22]

3.2 The Business System

The 'business system'[23] shown in *Exhibit 4* is of particular importance. This is where knowledge is translated into goods and services, so it is where wealth is created. Companies are therefore among the most important institutions in this sector – and increasingly so as levels of development rise. Almost all the knowledge (technology) used in this system is generated within it. For example, the commonest sources of a company's technology are its own stock of knowledge or another company. To the extent that innovation happens in networks, these are very often supply-chain networks. At this level, the direct contribution of the R&D infrastructure to economic development is small. That infrastructure plays a much greater role in providing trained manpower, learning and service provision than in new creating knowledge, which is applied directly in innovations.

Because of bounded rationality, the notion of 'absorptive capacity' is also key to our understanding of learning and the development process. Crudely, it says that the ability of companies to learn depends on their internal capabilities, and that these capabilities can often be represented by the number and level of scientifically and technologically qualified staff in an organisation. Callon points out[24] that substantial absorptive capacity is needed, in the form of complementary skills and investments, to make use of much 'public' science. He questions the claim that such results are 'public goods' in any meaningful sense.

Altering the balance of R&D (and, more generally, innovation) expenditure and effort between the business system and the state is one of the key phenomena in economic development. In most OECD countries, the great majority of R&D is financed and performed within the business[25] sector. We now understand that R&D has two 'faces':

21) *Charles Edqvist (ed), Systems of Innovation, London: Frances Pinter, 1997.*

22) *Rodrigo Arocena and Judith Stutz, 'Looking at national systems of innovation from the South,' Industry and Innovation, Vol 7, No 1, June 2000, pp. 55-75.*

23) *This term is slightly unusual. We use it to indicate that, while a major component is companies, other organisations, such as farms and hospitals, which create and use technology in the production of goods and services need to be included. In developing countries, the agriculturale component tends to be high, while in OECD countries this system is dominated by industrial companies.*

24) *Michel Callon, 'Is Science a Public Good?' Science, Technology and Human Values, Vol 19, pp. 395-424.*

25) *Given the important proviso that state-owned companies are well managed and run on quasi-private lines, it need not matter for this purpose whether parts of the company sector are owned by the state.*

The learning face, which acquires and absorbs technology; and the innovative face, which seeks and applies new knowledge.[26] This means that the company sector is securing the bulk of its technological needs through its own efforts and that it is doing enough R&D to be economically dynamic. It has the 'absorptive capacity'[27] to conduct a professional dialogue with the state research sector and other external sources of knowledge. It is, in many cases, working close enough to the technological frontier that it *needs* to turn to such external sources, as opposed to adopting and adapting existing technologies.

This situation contrasts sharply with that in many developing countries, where the company sector's investment in R&D is extremely low. In most cases, it is massively overshadowed by the small amount of resources the state devotes to research. A ratio of 80:20 between government and business expenditure on R&D is common in developing countries. In stark contrast, among OECD countries R&D expenditure and performance are dominated by the business system, which performs 60-70 per cent of national R&D. Where its own expenditure on R&D and innovative activities is low, the business system is often unable to make use of results from the research sector and elsewhere – notably other companies' stock of knowledge – and may have difficulty even in absorbing research-trained manpower. Crucially, it may be unable to *specify* its research and technology needs, and it can therefore be difficult to involve it in the governance of research – a device used extensively in OECD countries[28] to ensure the economic relevance of state funding of research and research-trained manpower.

With the replacement in theory of the neo-classical robot by a more realistic view of the firm as having bounded rationality – and therefore limited abilities to learn and adapt – it becomes obvious that companies' technological capabilities are major determinants of performance.

Technological capabilities can also be considered as belonging to two separate (but often complementary) types.

Some elements of the knowledge system tend to be more concerned with using, replicating and re-circulating knowledge that is already established within the production system, whereas other elements are more involved in acquiring, creating, processing and accumulating new knowledge, so that it can be brought into play in the system. The ***knowledge-using*** *elements are involved, for example, in maintaining or expanding capacity using given modes of production; training workers in established operating procedures, or within a cluster context, the imitation of the production techniques used by neighbouring firms. The* ***knowledge-changing*** *elements are involved, for example, in the management of innovation processes; in product design and development; or in the search for, selection, adaptation and assimilation of new product or process technology.*[29]

26) *W Cohen and D Levinthal, 'Innovation and learning; the two faces of R&D,' Economic Journal, Vol 99, 1989, pp. 569-596.*
27) *W Cohen and D Levinthal, 'Absorptive capacity: a new perspective on learning and innovation,' Administrative Science Quarterly, No 35, 1990, pp. 128-152.*
28) *For example, even in the very small countries of Norway and Sweden, the main technology-funding agencies (respectively, RCN and NUTEK) each boast external networks of 1000-1100 people drawn from industry and academia, who play active roles in defining and steering R&D programmes.*
29) *Martin Bell and Michael Albu, 'Knowledge systems and technological dynamism in industrial clusters in developing countries,' World Development, No 9, 1999, pp. 1715-1734.*

The meanings of 'technological capability' are not yet well mapped. *Exhibit 5* is a non-exhaustive list of what the concept includes, in relation to companies. We would expect the needs of others in the business system – farms, hospitals and so forth – to be broadly similar. OECD countries and the more successful NICs tend to devote significant state resources to fostering these capabilities, which form the needed foundation for technological dynamism, R&D performance and success in the company sector. In the absence of significant technological capability in that sector, state R&D expenditures bring few economic benefits.[30]

Exhibit 5
Company Technological Capabilities

Strategic

- Search for market opportunities
- Understand and manage the fit between the firm's capabilities and market needs

Internal

Tangible technology

- Products
- R&D facilities
- Appropriate plant and equipment

Develop and manage appropriate intangible resources

- Codified intellectual capital
- Qualification and skills profile adapted to the needs of the firm
- Tacit knowledge

Create needed organisation

- Technology management capabilities
- Change-management capabilities
- Coordination among internal 'owners' of capabilities

Networking Capabilities

Access external knowledge

- Science
- Technology, techniques
- Artifacts, practices
- Know-how, tacit knowledge
- Information resources

Manage producer/user relations

Access partners with needed complementary assets

- Complementary knowledge
- Complementary production
- Complementary supply-chain role

Source: Erik Arnold and Ben Thuriaux, Developing Firms' Technological Capabilities, report to OECD, Brighton: Technopolis, 1997

OECD countries have a huge repertoire of state extension, education and other programmes aimed at improving these technological capabilities.

30) *An important reservation here is the agricultural sector, where geography-specific and local-adaptation R&D in state institutions can bring important benefits – provided they are accompanied by an extension service or other mechanism which actively transfers results to farmers.*

3.3 Demand and Framework Conditions

In addition to the company sector, the state is in most countries an important 'customer' for research. The quality and quantity of the state's demand for R&D can be an important factor shaping the quality and overall relevance of the research sector. On the one hand, the state can over-demand research in particular areas, skewing national research capabilities into directions which have limited socio-economic value. A conspicuous example is the extreme importance of 'defence' R&D in the USA, UK and France, which appears[31] to have had a negative influence on economic performance. On the other hand, the state can under-demand R&D support, owing to inadequate understanding of its usefulness, or to lack of appropriate mechanisms – such as an absence of research budgets in ministries.

A further important side-side influence on the innovation system is the sophistication of consumers' and companies' demand. The more demanding customers are of high quality and performance standards, the more strongly motivated is national industry to meet these standards. In the absence of an exacting demand side, the national market affords at least temporary shelter from global norms, reducing the incentive for companies to perform to international levels.

Other 'framework' conditions are important in shaping the performance of national innovation systems. Obviously, fiscal and taxation policies are important, but so too are levels of trust (and the absence of corruption) in business dealings, levels of education and literacy, and the national propensity to entrepreneurship. Several of these factors are closely linked to culture. All can be influenced by appropriate policies.

3.4 The Research Sector

As regards the research sector, performance standards are set by global science, just as in the business system quality standards are set in international competition. In so far as research communities are international, this means that researchers must be capable of publishing internationally, training and examining PhDs at a standard which is internationally recognised and otherwise be members of the global 'invisible colleges'[32] or networks which define the scientific community.

The type of research community that is needed differs at different stages of development. There is clear consensus among the OECD countries that a basic science component is important in advanced industrial economies, even if there is a degree of variation among them in the relative allocation of resources between basic and other types of research. Kim and others[33] argue – in our view convincingly – that the pattern of research needs to be smaller-scale and much more applied at 'earlier' development stages.

The role of 'intermediate institutions' such as applied research institutes and research associations is frequently under-estimated or misunderstood. These typically have low status compared with universities and basic science institutes. They perform applied R&D and technical support activities, which are in principle relevant to the business

32) Derek de Solla Price, Little Science, Big Science, New York: Columbia UP, 1963

33) Kim and Nelson, Op Cit, 2000.

system. They typically survive on a mixture of core state funding and contract work for industry. They are rarely 'intermediaries,' in the sense of brokering knowledge produced in science. Rather, they work within and help develop knowledges within applied paradigms. Intellectually, they live their own lives, in the good cases in close collaboration with industrial customers. Traditionally, the intermediary institutions provide a large share of their services as extra-mural R&D for medium-large companies. Increasingly, governments are paying them also to work with smaller companies, typically in a way, which includes an element of subsidy.

3.5 Linkages in the NIS

It is not just the actors in the 'boxes' in *Exhibit 4* that need to perform well, however. The linkages among the boxes (and between actors *within* each box) are also very important – not least those between the business system and the other research-performing sectors.

If information were the only result of basic science, then there would be no incentive for individual governments to fund it. Instead, they could act as 'free riders': using the information published as a result of other countries' investments in science, rather than themselves contributing to the costs of science. This free-rider behaviour would be contained if the time from scientific discovery to market exploitation were an important factor in competition. This seems to be the case in parts of molecular biology and pharmaceuticals. But there need to be other benefits from funding science if individual states are to be dissuaded from free riding.

Pavitt points out that "Contrary to common belief, the main economic benefits of basic research are not knowledge directly applicable in a narrow range of sectors, but background knowledge, research skills, instruments and methods that yield economic benefits over a much broader range of sectors."[34] Valorising this background knowledge and skills therefore requires extensive contact – *networking* in today's jargon – between basic researchers and others. It can not be achieved by putting basic research in an Ivory Tower. Equally, industry cannot make use of basic science if it lacks the capabilities to handle these types of resources.

Case studies and surveys provide an interesting – but essentially unquantified – list of economic benefits resulting from basic research:

- New, useful information
- New instrumentation and methodologies
- Skills, especially skilled graduates
- Access to networks of experts and information
- Solving complex technological problems
- 'Spin-off' companies.[35]

34) *Keith Pavitt, 'The national usefulness of the research base,' paper presented to the Advisory Board of the Research Councils, Brighton: SPRU, 16 April 1991.*

35) *for an excellent review, see Ben Martin, Ammon Salter et al, The Relationship Between Publicly. Funded Basic Research and Economic Performance, report to HM Treasury, Brighton: Science Policy Research Unit, 1996.*

The research literature in this area, however, comes almost entirely from large OECD countries, notably the USA. Our evaluation of the Basic Research Grants Scheme in Ireland[36] identified a seventh link: sharing access to specialised equipment and informal trading in samples and consumables. We largely validated Martin and Salter's findings for the case of Irish universities, at a point where Ireland had clearly moved from NIC to OECD income levels. However, it is not clear from the literature how many of these links operate at earlier stages of development or how effective they are at those points.

In so far as intermediary organisations are easier for companies to deal with, their links with the business system tend to be wider than the links of the university scientists. Their out-reach in OECD countries can be very good among companies which lack the technological capability to deal with science. Equally, in the absence of incentives for them actively to reach out to and serve the business system, they readily prioritise internal over external goals. There are many examples of well-functioning Research and Technology Organisations (RTOs) in both developed and developing countries, which help develop both the knowledge-using and knowledge-creating capabilities of their industrial clientele. They may serve as 'knowledge gatekeepers' for a cluster of firms, in addition to providing more direct services.[37] As one example among many, CITER in the textile district of Carpi, Italy brings the cluster both access to new technologies such as computer-aided design and cutting but also intelligence about fashion trends and business process improvements.[38] The potential importance of RTOs in development depends partly on industrial structure. Thus, in the context of Taiwan's and Hong Kong's SME-dominated economies, RTOs appear to have paid a useful role in support of company development, while in the context of Korea's development focus on the major Chaebol, RTOs have been less significant and the development of company-internal capabilities have been more important.[39]

The critical requirements for such RTOs to be successful appear to be a degree of receptiveness and minimum capability on the part of firms, and RTO management highly attuned to the needs of the customers. A fascination with research per se is a recurrent factor among RTOs, but one that tends to promote failure in the industrial mission.[40]

More generally, it is clear that, while the levels of capability and absorptive capacity needed may vary among the components shown in *Exhibit 4,* it is clear that few (if any) can operate in the absence of such capacities. The Stockholm Technology Bridge Foundation, which has a mission to promote links between the Universities in the City and other socio-economic actors, especially firms, points out that a bridge needs a foundation at each end. It works, therefore, both to develop companies' absorptive capacity and to encourage change in the culture and incentive systems of the universities themselves, in order to create reasons for the academics to work with the outside world.

36) *Erik Arnold and Ben Thuriaux, The Basic Research Grants Scheme: An Evaluation, Dublin: Forfás, 1998.*
37) *Bell and Albu, Op Cit.*
38) *Howard Rush, Michael Hobday, John Bessant, Erik Arnold and Robin Murray, Technology Institutes: Strategies for Best Practice, London: International Thomson Business Press, 1996.*
39) *Ibid; Kim and Nelson, Op Cit.*
40) *Rush et al, Op Cit.*

4. Research, Innovation and Catching Up

The experience of various newly industrialising countries in catching up towards OECD levels of income and development provides useful clues about development needs and tactics. This section aims to capture some of this experience and to relate it to the wider problem of funding development. Since the experience considered is of industrialisation, it is strongly coloured by the needs of industrial firms. In so far as the agricultural and health care sectors – like firms – are predominantly technology-using, industrial experience should also have relevance for them.[41]

Post-war thinking on research for development has polarised around two views.[42] One was that which gave rise to the 'technology gap' approach: namely, the idea that the technology stock of the developed world could simply be transferred to developing countries. This overlooked the reality that some of this technology was skill- and capital-intensive, complex and inappropriate to factor prices and availabilities outside the developed world. It also completely missed the point that an active R&D or innovation function is a necessity for absorbing and developing externally generated technology.

The alternative view was that developing countries needed autonomously to develop their own science and technology 'base' more or less from scratch. This was partly to avoid dependence on the developed world, and therefore to avoid a kind of neo-colonialism. It was often also seen as a necessary complement to import-substituting industrialisation policies – bolstered by the linear-model idea that research would necessarily lead to innovation. This view was also partly a reaction to colonial history. In many countries colonialists had encouraged the development only of the new knowledge needed for colonial exploitation, such as specific medical, climatic and agricultural knowledge. Colonialists varied in the extent to which the needed knowledges were generated in the colonies or at home, but had generally little interest in fostering more complete research systems in the colonies.[43]

4.1 The Catching Up Process

Especially since 1950, there has been a clear pattern of convergence among the developed economies in total factor productivity and in labour productivity.[44] This is generally ascribed to their ability to operate at or near the scientific and technological

41) *A caveat is that, to the extent that these sectors deal with unique local problems, the opportunities for creative-imitation-based strategies may be more limited.*
42) *Howard Pack, 'Research and development in the industrial development process,' in Linsu Kim and Richard R Nelson (eds), Technology, Learning and Innovation: Experiences of Newly Industrialising Countries, Cambridge University Press, 2000.*
43) *For a series of accounts of the development and functioning of scientific communities, see Jacques Gaillard, V V Krishna and Roland Waast (eds), Scientific Communities in the Developing World, New Dehli: Sage Publications, 1997.*
44) *E. Woolf, 'Technology, capital accumulation and long-run growth,' in J Fagerberg, B Verspagen and N von Tunzelmann (eds), The Dynamics of Technology, Trade and Growth, Aldershot: Edward Elgar: 1994.*

frontier. There is more to this than R&D, because these economies' spend on R&D/GDP varies by two or so percentage points. But there is a huge gap in both absolute and relative spending on R&D between these countries and developing nations, as well as in factor productivity and per capita incomes. Closing this gap is not a passive process.[45] Among other things, this depends on the rate of investment in R&D activities by the follower countries.[46]

The Industrial Revolution in England, which started in the late Eighteenth Century, was not based on science but on the development of pragmatic engineering capabilities, with science later on filling in and formalising gaps in knowledge.[47] Not until the late Nineteenth Century did science-based industry (chemicals and to some degree the electrical sector) play a major role in the economy. Catching up today similarly depends more on developing and deploying technological capabilities in the business system than on formal research. Since the required technological trajectories have already been identified through the activities of 'leader' firms and nations, a major part of the catch-up effort needs to be devoted to creative imitation.

Until the late 1960s, there was little interest among development economists in the role of research and technology in the development process. It was assumed that technology was developed in the advanced countries and 'transferred' between countries in the form of capital goods. In the neo-classical approach, technology transfers are assumed to be smooth and costless – essentially because technology is not theorised in neo-classical economics. Technology would therefore automatically be acquired in the course of capital accumulation. Subsequently, a substantial literature has grown up which describes the realities of technology transfer. It points out: the role of learning; the fact that any particular technology embodies assumptions about the environment in which it will be used; and shows that considerable innovative activity is required in order to make use of transferred technology. The sharp distinction between invention and imitation assumed in the neo-classical approach is, in fact, an illusion. The imitation process involves a great deal of innovation – in the sense of implementing products and processes which are new to the firm – and this, in turn, requires a industrial skill set very similar to that for invention.[48]

Starting with the neo-classical idea of simple technology transfer, a separate tradition of 'technology gap' analysis has arisen to investigate the differences between 'leader' and 'follower' nations. The idea is that in leader economies the growth of output depends on the rate at which the scientific/technological frontier moves. In follower economies, it is determined by the speed at which they adopt and adapt technologies developed by the leaders. In this tradition, too, the complexity of technology transfer has increasingly been understood and the roles of learning and R&D investigated.

Catching up is, in important respects, easier than moving ahead of other developed nations. In the catching up process, the 'gap' with the state of technology in leader countries helps define the capabilities that are needed and the directions in which

45) *Bell & Albu, Op Cit.*

46) *Jan Fagerberg, 'A technology-gap approach to why growth rates differ,' in Christopher Freeman (ed) Output Measurement in Science and Technology, Amsterdam: Elsevier, 1987.*

47) *David Landes, The Unbound Prometheus: Technological Change and Industrial Development in Western Europe, Cambridge University Press, 1969.*

48) *Arnold and Thuriaux, Op Cit, 1997; Bell & Albu, Op Cit.*

resources should be allocated. Successful strategies for closing the gap have focused on creating technological capabilities in industry. The approach taken in the SE Asian 'Tiger' economies in the 1960s and 1970s was to combine massive capital investment with deliberate 'reverse engineering' and experimentation in selected branches of industry. While the research and education systems were important producers of qualified personnel, they do not appear to have played a direct role in industrial development.[49] The Mercosur countries provide a stark contrast. While they also made significant investments in foreign technology during the same period as the 'Tigers,' a similar investment in using R&D for learning was not made, and the contribution made by foreign technology to development was correspondingly lower.[50]

Since the development of technological capabilities during catch-up is a learning process, we would expect there to be stages or levels of learning. For example, Schnarr[51] has proposed a staged description of imitative product development at the firm level:

- Duplicative imitations, of two kinds:
  - Counterfeits – illegal copies branded as the original products
  - Knockoffs – (generally) legal copies which make no pretence of being the original, but which sell under their own brands at lower prices
- Design copies – mimic the style of the brand leader, but introduce unique engineering specifications
- Creative adaptations – are inspired by existing products, but differ from them
- Technological leapfrogging – where a latecomer uses more recent or more appropriate technology to improve on the original product concept
- Adaptation to another industry – where technology from one branch is reapplied in another.

The interest of Schnaar's description is that it focuses on the use of existing products and processes as a 'school' in building up technological and business capabilities. The firm's internal development and design capabilities grow as it moves between successive stages, but there is no role for research. On the basis of the East Asian experience, at least, successful firms may go through a kind of 'reverse product cycle.[52]' They begin with simple assembly processes but gradually and systematically accumulate the capability to modify, design and build their own product and process technologies. Customers play a major part in this cycle, which proceeds through successively higher value-added forms of production.

At the national level, Nelson and Pack have argued that the success of the 'Tiger' economies[53] was the outcome of several inter-related features, including:

- Their openness to foreign knowledge and their ability and willingness to tap international markets

49) *Kim & Nelson, Op Cit, 2000.*
50) *José Eduardo Cassiolato and Helene Maria Martins Lastres, 'Local systems of innovation in Mercosur countries,' Industry and Innovation, Vol 7 No 1, 2000, pp. 33-53.*
51) *Stephen P. Schnaar, Managing imitation strategy: How later entrants seize markets from pioneers, New York: Free Press, 1994.*
52) *Michael G Hobday, 'Export-led technology development in the four Dragons: the case of electronics,' Development and Change, Vol 25 No 2, 1994.*
53) *Hong Kong, Korea, Singapore and Taiwan.*

- The pressures brought to bear on firms to increase their productivity to continue to increase exports rather than to use the knowledge obtained to extract rents from the domestic economy, thus creating a demand for foreign technology
- The high productivity of foreign technology as its dissemination and successful use were enhanced by an educated domestic labour force.[54]

Pack[55] describes two stages in the development of the 'Tigers.' In the first stage of 'early industrial development,' they focused on exporting labour-intensive products, under intense national and international competitive pressure and using imported production technology. There was a strong policy focus on providing universal primary education, allowing these technology inflows and the use of the technology acquired. There was limited interest in educating high-level research or R&D staff. At this stage, the probability of domestic R&D producing viable innovations was very low.

The second stage of 'more complex industrial development' involved building a more advanced local education and skills base in order to enable learning and to allow local evolution of foreign technology. Technical changes and innovations continued, however, to be generated firmly within companies. Universities and the large RTOs such as ITRI continued to contribute few product and process innovations. However, they did play increasingly important roles as educators of qualified manpower.

An important omission from the available accounts of catch-up development is the creation and role of 'mid-level' craft and technician skills, which are crucial to the absorption and use of production technologies and to a great deal of innovative activity not classed as formal R&D. A further key omission concerns the need to develop *design* capabilities.[56]

During the catch-up process, then, research plays a limited role. Major, unfocused investment in the basic research and scientific system risks creating capabilities disconnected from the economy and society, which are unlikely to have developed the absorptive capacity to make use of such investments. Given the limited resources available for research, they also risk being below critical mass unless they are highly focused. Investments in research institutions do not produce returns in the form of innovations, but may be useful sources of the technology-literate people needed by the business system. Given the long lead times involved in creating sustainable research communities, the rate at which it makes sense to invest in national *research* (as opposed to broader R&D) capabilities is a matter of delicate balance. It is very easy to over-invest, in anticipation of an industrial demand for linkage which then fails to materialise.

Once at the scientific/technological frontier, the way forward is no longer so clear. Huge amounts of effort are devoted to R&D in the developed economies, and a very large proportion of this is 'wasted' – in the sense that it does not result in a commercialised product or process innovation. Well over half of all R&D projects in leading US

54) *Richard R Nelson and Howard Pack, 'The Asian growth miracle and modern growth theory,' The Economic Journal, Vol 109, 1999, pp 46-436.*

55) *Howard Pack, 'Research and development in the industrial development process,' in Kim and Nelson, Op Cit.*

56) *Bell & Albu, Op Cit; Wield, Op Cit.*

technology-based companies are cancelled.[57] Of completed innovation activities, very few are highly profitable. Modern product life cycle theory builds on the idea of competing attempts to define a 'dominant design'[58] or 'product recipe'[59] early in the life of a new product. Inherently, the effort devoted to failed designs is 'wasted,' even if the overall process is immensely powerful. In contrast with this searching and experimentation, the targets for 'catching up' are relatively clear because much of the searching and experimentation have already been done by others.

While it is clear that there is scope for widely different national patterns of resource allocation to R&D (based, in no small part, on the differences in industrial structure among the 'leader' nations), catching up involves a structural change in the importance of R&D. This change needs first to take place in the business system, with R&D functions operating as organisations' 'learning department'. The extent to which the state can act as midwife in this process depends somewhat on the industrial structure. RTOs and extension services can be important where the structure is fragmented. However, the nature of the R&D *function* changes as countries catch up.

Research is critical both to advancing the technological frontier in fields dependent on formal research, like biotechnology and semiconductors, and as one of technology's 'well springs'. However … research tends to be much less firm-specific than product development, and proprietary innovation within the firm may well depend on knowledge added to the pool through research elsewhere. This points to a limited role for research in technology followers. … One might conclude that technology followers should not do R&D. There are, however, at least four reasons why followers should do R&D. First, formal R&D effort can usefully complement process thrown-back-from-the-work innovation. Second, R&D teams can play a crucial role as the firm's 'learners' of knowledge produced elsewhere. Third, doing R&D can have intangible spin-off benefits for the rest of the organisation. Fourth … moving up the value chain to more attractive markets depends on a firm's ability to develop proprietary product designs.[60]

There is also an emerging pattern among rapidly-industrialising OECD countries[61] moving to the technology frontier, where national priorities for research funding shift to become more inclusive of strategic and basic research. Norway and Finland, for example, are resource-based economies, which have in the past focused heavily on applied and industrial research funding, often via massive (compared with the size of these small countries) RTOs such as SINTEF and VTT. Having reached the technology frontier in key industries ranging from petroleum extraction through industrialised

57) *D Leonard-Barton and J Doyle, 'Commercialising technology: Imaginative understanding of user needs,' in R Rosenbloom and W Spencer (eds), Engines of Innovation: US Industrial Research at the End of an Era, Boston: Harvard Business School Press, 1996.*
58) *William J Abernathy and James M Utterback, 'Patterns of industrial innovation,' Technology Review, No 80, 1978.*
59) *Erik Arnold, Competition and Technological Change in the Television Industry, London: Macmillan, 1986.*
60) *N Forbes and D Wield, 'Managing R&D in technology followers,' Research Policy, Vol 29, No 9, 2000, pp. 1095-1110.*
61) *It should be recalled that among the countries discussed here, Norway, Finland and Ireland were among the most impoverished in Europe before the Second World War, with very low absolute levels of income.*

primary production (eg aquaculture) to electronics, raising the overall spend on R&D assumes national priority. Norway is currently aiming to match the OECD's average investment of R&D/GDP, while Finland is even more aggressively aiming to spend 3 per cent of GDP on R&D. Basic science is an important beneficiary in both cases, even if the bulk of the increase is expected to come from the business system.

Ireland has recently gone through a dramatic policy change. 'National Science Foundation'-style funding for basic research and postgraduate training had been running at well under £I 5m (Euro 6.5m) until the end of the decade. Then, the government decided to invest £I 2.2 billion over 5 years in a massive upgrade to the university research infrastructure and the pursuit of strategic research in IT and biotechnology. Japan went through a rhetorically similar period in the early 1980s, when both government and industry increased investments in basic (generally strategic) research.

None of these policy transformations is total. Countries whose development has been shaped by imitation, catch-up and applied R&D do not change their entire pattern of expenditure overnight. However, the fact that the deliberate shift towards a higher basic or strategic research content in state funding takes place as these countries establish themselves firmly among the developed nations supports the idea that it is at the stage of reaching the technology frontier that such investment makes most sense.

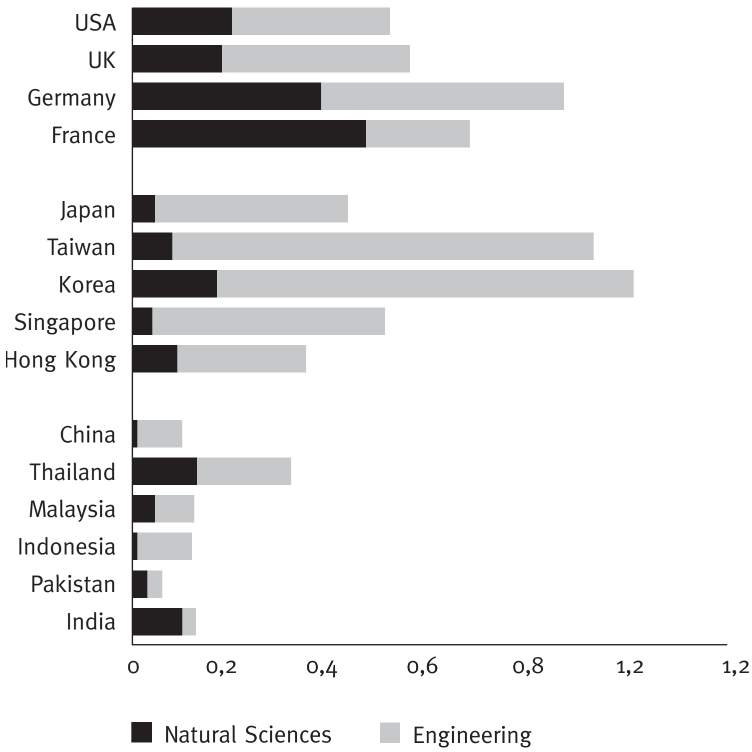
4.2 Skills, Brain Drain and the Diaspora

The pattern of tertiary education across countries partly reflects national judgements about the needed balance of effort among disciplines, and confirms this impression of a shift towards the sciences at a comparatively late stage of development. *Exhibit 6* shows data assembled by Sanjaya Lall about the proportions of the population studying natural sciences and engineering in selected countries. There are three clear patterns visible. It is striking that while the OECD countries and the Tigers have similar proportions[62] of their population in technical tertiary education. The OECD countries put a comparatively high degree of effort into the natural sciences and less into engineering. This is the pattern we would expect to see in countries operating at or near the science/technology frontier in many branches. In contrast, the Tigers' educational efforts focus strongly on engineering. Despite talk of reorientation towards basic science in Japan, the educational pattern remains more similar to the Tigers than to the OECD. The Chinese pattern is similar to that of the Tigers, but with a lower proportion of the population participating in tertiary science and engineering education. (Obviously, in absolute terms, the Chinese educational effort in these areas is nonetheless massive.) Thailand follows the OECD pattern but at lower scale, while India has a unique focus on natural sciences. Important institutional distortions lead to these misallocations of resources and help impede both the effective use of personnel and reforms to shift the national efforts towards engineering. The other countries' overall efforts are modest.

62) *Note that there is a systematic bias here. OECD countries have ageing populations, so dividing students by population tends to understate the absolute scale of the OECD effort.*

Exhibit 6

Proportions of Populations in Tertiary Science and Engineering Education 1994/5



Source: Reworking of data presented by Sanjaya Lall, 'Technological change and industrialisation,' in Kim and Nelson, Op Cit, 2000. The original data come from UNESCO Statistical Yearbook 1995, Taiwan Statistical Yearbook 1994, and the Ministry of Education in Singapore.

Since the 1960s, there has been concern about 'brain drain,' in the sense of a one-way flow of scientific and professional talent from the South to the North, but also within the North – especially towards the USA. This appears to comprise several elements

- Some degree of economic migration
- A confusion, where a movement of students and post-doctoral researchers to the North is interpreted as an intention to emigrate permanently
- 'Delayed return' – as, in recent years, has been the case with a large number of Chinese who were abroad as students during the Tienanmen Square incident, and who do not want to return home until there is a change of government
- 'Overflow,' where there is an over-supply of scientific or professional people compared with the ability of the home economy to absorb them.[63]

63) *an early discussion, see G B Baldwin, 'Brain drain or overflow?' Foreign Affairs, Vol 48, No 2, 1970, pp. 358-372.*

A mid-1970s study of 6 500 students in 11 countries showed that:

- Students who stayed in their country of study on completion of their courses nonetheless intended to return to their home country
- Most of the students who had returned to their home country intended to stay there
- It was not necessarily the brightest students who stayed in the country of study[64]

Of course, the longer people stay abroad, the greater is the tendency for them to get 'stuck' in their new location, but it does appear that the 1960s concern about brain drain was over-blown. International mobility is increasingly understood as a normal part of scientific activity, and is actively fostered within the European Union by European Commission subsidies, in an effort to strengthen international research links. In the development context, the International Organisation for Migration and the UNDP, through its TOKTEN programme, have been fostering the return of trained migrants to their home countries.

South Korea and Taiwan had policies for the systematic reintegration of returning migrants from the 1960s onwards. In the case of Korea, it was not until the 1980s that large numbers of US-based Korean scientists and engineers decided to return home. By that time, the level of development and job opportunity in Korea was already making the country more attractive, and the government abandoned its programmes to attract returning migrants in the 1990s, in the belief that the country had by that time become sufficiently attractive for return to be spontaneous.

Especially since the growth of the Internet, a growing number of national scientific and professional diaspora have been organising – sometimes with the aid of resources form the home country. These do not always aim to encourage repatriation, but they do provide receptive international milieux, within which a circulation of students and post-docs can take place, and through which the interaction between national and international science can be fostered. However, both the high Korean return rate and the very low return rates experienced in India lead to the same conclusion. Migrants return when there are opportunities and when it becomes attractive to do so. In the case of research personnel, this largely depends on the state of development of the NIS.

4.3 The Multinationals

Many developing countries – and especially those historically concerned about 'dependence' – are rightly cautious in their dealings with multinational companies (MNCs). Policy with respect to inward MNC investment in industry is seen as having two related, though distinct, components. One is concerned with the initial investment in *production* activities. The other is concerned with the extent and 'depth' of associated *technology development* activities during the subsequent lifetime of the production facility.

64) *W A Glaser and G C Habers, The Brain Drain: Emigration and Return, UNITAR Research Report, Oxford: Pergamon Press, 1978; cited from Jacques Gaillard and Anne Marie Gaillard, 'The international mobility of brains: exodus or circulation?' Science, Technology and Society Vol 2, No 2, 1997, pp. 195-228.*

While there may be initial signs of a trend to seek R&D manpower globally, most of the evidence points to a 'Triadisation' rather than globalisation of multinationals' R&D efforts.[65] Studies of Multinational R&D location consistently point to the choice of locations where there already is a strongly-developed NIS, which provides a rich environment of geographically local network interactions to the company. MNC plant which benefit from such an environment and conduct R&D are less 'footloose' than

those which do not do R&D. In the Irish case, at least, it has been shown that the greater the technology-intensity of the plant, the lower the probability that it will be closed.[66]

Some major international companies also locate a handful of R&D outposts on or near research campuses. The main driver is the presence of globally leading, excellent scientific research. Few are in a position to offer such presence, so this type of R&D relationship with multinationals is both rare and rather focused in the most advanced countries.

Nonetheless, adaptation R&D and R&D/technical support are needed at plant level. These provide important ways to 'embed' footloose foreign investment and strengthen the hand of local MNC managers in global intra-firm competition for resources and tasks. In Ireland, the research infrastructure has been able to provide some such support to local managers, as well as to use the MNCs as 'training schools', enabling it to increase the quality and relevance of national industrial extension services.[67] The MNCs act as demanding buyers, raising levels of quality and innovation among their local suppliers. In the Irish case, again, the presence of a number of foreign electronics multinationals has fostered the development of a large number of niche electronics and software suppliers, and the growth of a significant indigenous software, electronics and telecommunications sector.

The flow of knowledge embodied in people moving between firms also seems to be very important. In industrialising countries, subsidiaries and joint-venture partners of MNCs often seem to play a particularly important role in generating such flows. For instance, a 1987 study in Taiwan examined the role of former MNC employees in a sample of 161 firms. It found that these ex-MNC personnel had made significant contributions to strengthening management, product design and marketing capabilities. Some 96% of the surveyed firms considered this was so with respect to managerial technology; 85% with respect to the improvement of product design; and 76% with respect to marketing

65) *Keith Pavitt and Pari Patel, 'Global corporations and national systems ofinnovation: Who dominates whom?' in D Archibugi, J Howells and J Michie (eds) Innovation Systems in a Global Economy, Cambridge University Press, 1998; Brechje Albert, Paul Beije, Patries Boekholt, Maureen Lankhuizen and Rob van Tulder, Interactive Innovation: Multinationals and Systems of Innovation – Towards an Internatiuonal Interactive Perspective, report to EU TSER Programme, Erasmus University, October 2000.*

66) *Allan Kearns and Frances Ruane, 'The tangible contribution of R&D-spending foreign-owned plants to a host region: a plant-level study of the Irish manufacturing sector (1980-1996),' Research Policy, Vol 30, 2001, pp. 227-244.*

67) *Erik Arnold and Ken Guy, AMT Ireland: A Mid-term Evaluation, Dublin: Forfás, 1993; Erik Arnold and Norman Waterman, Materials Ireland: An Evaluation, Dublin, Forfás, 1994.*

technology.[68] More recently in the Malaysian electronics industry, flows of people who had acquired product design and process engineering experience in MNCs appear to

have contributed important knowledge inputs to the development of technology in supplier and other firms.[69]

Multinationals, then, are very important sources of learning and can be helpful motors of development. Successful policies involve strategies to embed MNCs within the local economy, and to support their local efforts to raise their technological level as far as possible – not least because in doing so they will drag local suppliers with them. It is important to recognise that MNCs, like other companies, are in business for money and behave accordingly. But we find that the desire in some places to foster development autonomously from the MNCs involves missing important opportunities and is ultimately counter-productive. On the contrary, there are opportunities to integrate the multinationals better into development strategy.

4.4 Aid Funding of Research

Donors increasingly see research funding as an important component of overall development aid, aiming both to build research capabilities in developing countries and to produce needed knowledge. However, much funding has been channelled into building scientific capabilities, as opposed to those needed for catching up, and – despite the best of intentions – this has turned out to hinder, not to help, development. The research funding pattern needs to be adapted to reflect the R&D and innovation needs of the recipient National Innovation System. These needs are likely to vary from field to field, depending on distance from the science/technology frontier, and from country to country. Money needs to be invested more widely across the innovation system in order to meet these needs, and to be used not only in public sector research institutions but also in RTOs and in the business system, including private companies.

A striking feature of research communities in many poorer developing countries is how small they are, in absolute terms, and therefore how fragile. Research communities that may take many years to establish are easy to destroy.[70] Often lacking critical mass, with poor links to global scientific networks and being at a disadvantage in publishing in the 'high impact' (predominantly English-language) international journals, many developing country research communities face an uphill struggle. Normal aspects of group behaviour in the interpersonal networks that make up the 'invisible colleges' of global science militate against newcomers and outsiders, making it hard for developing country researchers to break into the 'charmed circle' of those who dominate the invisible colleges. Publication and citation practices and the routines of those who generate bibliometric databases militate against the inclusion and recognition of

68) *C-M Hou and S Gee, 'National systems supporting technical advance in industry: the case of Taiwan,' in R R Nelson (ed), National Innovation Systems: A Comparative Analysis, Oxfod University Press, 1993.*
69) *Results from an ongoing SPRU DPhil study by Norlela Ariffin.*
70) *For examples including Algeria, Kenya and Senegal, see Jacques Gaillard, V V Krishna and Roland Waast, Scientific Communities in the developing World, NewDelhi: Sage Publications, 1997.*

developing country contributions to the growth of knowledge.[71] These factors may be compounded by genuine problems of quality. It is difficult for small, isolated, under-funded research groups to work at the leading edge of research, precisely because science is a social activity[72)] – and a global activity, at that.

Often, it is difficult to make research a 'policy subject' in the South.[73] Science as a practice may conflict with aspects of established value systems, and its promotion by donors can even be considered as a form of cultural imperialism. It can be difficult for developing country governments to see the value in prioritising research activities whose benefits are uncertain and hard to visualise, especially in the context of other pressing, short-term needs. There is therefore a tendency for developing country research systems to become locked into historical patterns, such as research relating to the production of existing agricultural commodities and/or the priorities of former colonialists. As a result, they may be locked out of newer and more economically promising areas.[74]

As part of the post-War enthusiasm for science, a burst of development enthusiasm in the 1960s included an initial belief that the stock of technological knowledge in the more industrially advanced countries could easily be transferred to developing countries. Thus, the 1963 UN conference on the Application of Science and Technology for Development was organised to 'display' the technological wares of the North and Southern countries were urged to 'shop wisely'. There was some discussion at that conference about establishing local S&T capabilities in the South, but the main emphasis was on knowledge *transfer.* It was therefore seen as unproblematic that much research for development was carried out in the developed countries, rather than the developing world. Examples of institutions involved include the Tropical Products Research Institute and the Anti Locust Research Centre in the UK, with most of the research undertaken by British scientists in British institutions. The 1970 World Plan of Action on Science and Technology for Development, prepared by the UN Advisory Committee on Science and Technology (ACAST) suggested that 5 per cent of R&D expenditures *in the rich countries* should be focused on problems of the poorer nations. (Unsurprisingly, the suggestion has not been taken up.)[75]

Canada founded IDRC in 1970, and Sweden followed with SAREC (now the research division of SIDA) shortly afterwards. These, and a number of subsequent funding initiatives, responded to a growing perception of need for research 'capacity development' *within developing countries.* In many cases, however, the types of capacity which donors have sought to build have been unhelpful. There was emphasis in the 1960s and 1970s on trying to establish 'world class' research institutions in the developing world. Much donor effort was oriented towards science, rather than towards its application. There was a tendency to try to 'seed' new initiatives rather than to fund them over long periods of time. There was often greater interest in funding individuals than institutions. This frequently involved the individuals undertaking research training and research in the North, reinforcing the tendency to 'brain drain' among developing country researchers. At the time, these tendencies were seen as unproblematic – not least because they were

71) *Jean-Jacques Salomon, Francisco R Sagasti and Céline Sachs-Jeantet eds, The Uncertain Quest: Science, Technology and Development, New York: United Nations University Press, 1994; W Wayt Gibbs, 'Lost science in the Third World,' Scientific American, August 1995.*

72) *T S Kuhn, The Structure of Scientific Revolutions, 2nd edn. University of Chicago Press, 1970.*

73) *Arocena and Stutz, Op Cit, 2000.*

74) *Enos, 1995.*

75) *This account of events is based on a personal communication from Geoffrey Oldham.*

consistent with the 'linear model.' But the results of these funding investments have generally been very disappointing.

Thus, Enos' analysis of structural adjustment programmes and scientific research in sub-Saharan Africa led him to paint a depressing picture:

- Under Structural Adjustment Programmes, domestic expenditures on advancing science and technology fluctuate from year to year, with a slight upward trend
- Total expenditures, counting both local and foreign, are likely to rise at a considerably higher rate
- Within the total, different areas of endeavour have considerably varying fortunes
- Which areas prosper, and which do not, are increasingly determined by foreigners …
- The choice of areas to be pursued is currently based upon the benefits of such choice for the developed countries, to the detriment of the developing countries.[76]

Since they do not want for ever to be locked into individual commitments, donors tend to be attracted to funding one-time costs, such as investments. They are reluctant to pay for wages, equipment maintenance and renewal or consumables, yet without these the research enterprise cannot function.[77] Donor interventions can therefore result in the creation of research communities or institutions that are not only irrelevant to recipients but also unsustainable over time.

Donors now tend to fund research for two reasons:

- To support research-capacity building in developing countries (the capacity objective)
- To support research with the purpose of producing results relevant for developing countries (the results objective).

Donors naturally feel most confidence is supporting public sector R&D. In so far as the 'right' level of public and private R&D investment are interdependent, this risks pushing the national innovation system out of balance, unless there are complementary mechanisms leading to increases in private-sector R&D. If the linear model were correct, of course, the increased science would lead to increased activity in the business systems. In an innovation systems world, however, increased science funding on its own leads only to an increase in science. Excess funding to educate researchers who cannot be absorbed into the National Innovation System also encourages 'brain drain.'

There are arguments for funding basic research for cultural and nation-building purposes – for example, to help (re)build a national identity through studies in history and anthropology. However, our analysis suggests there is limited direct economic value

76) J L Enos, In Pursuit of Science and Technology in Sub-Saharan Africa: The Impact of Structural Adjustment Programmes, UNU/INTECH Studies in New Technology and Development, London: RKP, 1995.

77) Jesper Carlsson and Lennart Wohlgemuth, Capacity Building and Networking: A meta-evaluation of African regional research networks, Department for Evaluation and Internal Audit, 96/45 Stockholm: Sida, 1966.

78) See Erik Arnold and Ben Thuriaux, Developing Firms' Technological Capabilities, report to OECD, Brighton: Technopolis, 1997. This may be downloaded from www.technopolis-group.com.

to be gained by many developing countries from major investment in basic research. In certain fields, it is likely that individual developing countries are – and need to be – close to the science/technology frontier. Such fields probably cluster in agriculture and health care, where problems may be specific to a country or a region. In these cases, there are few opportunities to learn from others, and there are good reasons for donors to fund scientific research, in addition to supporting the application of knowledge. In most cases, however, the biggest development effects are likely to come from various forms of 'creative imitation.' As we have shown in previous sections of this paper, for 'creative imitation' to have an effect, it must take place primarily in the business system – sometimes with the support of RTOs.

OECD countries also have a need to foster 'creative imitation' and capability building among SMEs and others such as small farmers, whose capabilities lag both the science/technology frontier and many aspects of best practice. They therefore have a vast repertoire of programmes to address these problems[78] – primarily by encouraging and subsidising capability creation within the private sector. Many of these programmes are expensive to run and are designed to operate within rich innovation systems and infrastructures. As with technology, they cannot always simply be copied and put directly to good use. They do represent a significant stock of knowledge and experience, which can be exploited via 'creative policy imitation.' Doing so requires both the willingness and the ability on the part of donors to work with a greater part of recipients' NIS. In some countries there will also be a need to overcome the vested interests of the scientific élites fostered by earlier advice and through donations inspired by the 'linear model.'

78) See Erik Arnold and Ben Thuriaux, Developing Firms' Technological Capabilities, report to OECD, Brighton: Technopolis, 1997. This may be downloaded from www.technopolis-group.com.

5. Policy and Funding Implications

In this final section, we discuss innovation policy trends and the considerable innovation policy repertoire of the OECD countries, and draw conclusions from the whole of the paper for funding research for development. We suggest both that a significant Gestalt shift is needed in thinking about funding research for development, and that this should in turn lead to significant increase in the proportion of resources devoted to creative imitation in the business system.

5.1 Policy Changes and Trends

The rate of innovation in R&D and innovation policy instruments in OECD countries has been very high in recent years, resulting in a rich flora of actions. These include:

- Building company capabilities. This involves a large range of supports including training in management and marketing, help in preparing for quality certification, technology and business audits to identify improvement opportunities
- Typically, OECD systems also provide advisory support – and sometimes finance – to start-up firms, especially where these are technology based. Many countries have adopted schemes to subsidise the recruitment of a first engineer by companies, aiming to set off a virtuous circle of technological learning.
- Innovations in smaller firms are often eligible for support – either through grants or through more or less soft loans. Support may also come in the form of a subsidy to pay for external innovation help, for example from an industry research institute.
- Network support includes programmes of supplier development, aiming to increase the capabilities of local firms providing inputs to large buyers (such as multinationals' branch plant), partner search activities to find co-producers, sub-contractors or distributors, as well as more general support to the creation of inter-company networks. Once initiated, company networks in turn provide mutual support to in a range of activities from purchasing through marketing to sharing good practices and facilities.

In the spirit of the NIS model, increasing effort has been devoted to inter-linking different parts of the innovation system, and especially in building links to the research system. Activities cover institutional linkage mechanisms, such as science parks and the use of industrial liaison officers to define and exploit institutions' intellectual property. New linkage institutions, have been created such as the Swedish 'Technology Bridge Foundations,' whose job is to foster the use of university resources and capabilities in other parts of society.

For the past 20 years or so, increased efforts have been put into encouraging the research and business sectors to work together. This can be via collaborative R&D schemes, 'Competence centres' or industrial centres of excellence where a consortium from the business system located R&D activity within a university or research campus. The long-established idea of Research Associations – where, typically, a branch-specific user group 'owns' in some way an applied research institute – has been supplemented with R&D networks, where a company networks work do R&D or technology transfer activities with a range of institutional suppliers. This introduces flexibility of supply, and encourages research institutes to work in a user-focused way.

Other kinds of measures to link demand with innovators have been developed. These include developmental procurement, where the state provides an assured initial market for innovations meeting its needs – for example, improved hospital equipment. Variations of this principle involve identifying and connecting private demand with potential innovative solutions.[79]

A further strand of innovation support promotes mobility, exchanging industry and research workers in order to provide them with insights into their external partners' needs. In the European Union, a several thousand people per year receive funding to spend periods in other EU states, for example to undertake post-doctoral research, in an attempt to build European scientific communities.

There have been various initiatives aiming to link research activity to the needs of the demand side. At the aggregated level, this has involved national consultation exercises such as Technology Foresight programmes. These aim to provide comparatively wide consultation about the future priorities for R&D funding. Increased separation between those who buy and those who perform state-funded R&D has in creased pressures for clear specification of tasks and output measures. Other more specific measures have also collectively had a rather significant effect on the customer orientation of the research infrastructure. These include:

- Reduced funding and/or increased commercial earnings requirements for RTOs and other state-funded research performers
- R&D tax credits
- Vouchers or 'cheques' to be used by firms in purchasing services form the research sector or RTOs
- Redirection of money intended to pay for industrially relevant R&D away from the research sectors and towards firms. In this way, companies in effect buy services from the research sector, as opposed to being offered that which the researchers choose to offer.

Cutting across all this diversity in innovation support measures are three broad common features of policy development in recent years in many industrialised countries.

Within the overall array of policy measures concerned with industrial technology development, a very large part is concerned with supporting and facilitating action *by firms themselves.* Measures to support technology institutions are an important component of the policy system. But at least over the last ten years or so, a major emphasis in policy development has been given to mechanisms that assist and empower forms to make use of each other and those institutions, in order to support their own technology development activities and to strengthen their own technological

79) Examples include the IFU programme in Norway and the Environment Technology Delegation in Sweden. See Johan Hauknes, Marianne Broch og Keith Smith, SND og Bedrifsutvikling – Rolle, Virkemidler og Effekter, Delrapport 1 i evaluering av Statens nærings- og distriktutviklingsfond gjennomført av Technopolis Group, STEP og Albatross Consulting, Oslo: STEP, 2000. Erik Arnold, Andreas Wulff and Ken Guy, Miljötekdelegationen: An Evaluation, Stockholm: Miljöteknikdelegationen, 1999.

capabilities. In effect, policy development has focused heavily on mechanisms that will strengthen demand-driven technology development systems, rather than continuing the earlier often exclusive emphasis on supporting technology institutions within supply-driven systems.

Within that firm-centred approach to policy, increasing emphasis has been given to stimulating and facilitating various forms of *collective activity involving groups of firms.* These groups may be established industry association, but they may also be less formally structured groups organised around (segments of) value chains, and/or regional clusters of firms in related industries.

A large and growing proportion of these firm-centred policy mechanisms have been concerned with stimulating forms of technology development that draw primarily on *existing knowledge and practice.* Obviously, very large volumes of public resources are committed to supporting the development of new knowledge and original innovations at the international frontier. However, over the last ten years or so greatly increased emphasis has been given to measures that support firms in acquiring, using, incrementally developing and applying existing knowledge and practices.

The resurgence of a concern with the social control and the 'relevance' of science to society, together with – in the 1990s – increasing efforts to implement a 'new public management' driven by measurable objectives, has led to a battle for control of R&D. In many OECD countries, this is manifest as a bureaucratic tussle between Ministries of Education and Industry, in which the 'relevance' faction has slowly become dominant. The past two or three years have seen a turning of the tide in several countries, with changes in budgets and governance increasingly favouring a 'neutral' basic science.

To the extent that this represents a resurgence of the linear model, we find this trend disturbing. A policy, which focuses on basic science and ignores the innovation process, will result in more science, not more wealth. To the extent that the resurgence of basic research (and infrastructure) funding in some OECD countries may actually represent a rebalancing to compensate for the pendulum having moved too far towards 'relevance' to maintain a stable R&D infrastructure, we are less concerned. But the 'balance' can only be set at the national level – based on the specific structures and needs of the individual economy and society. Different resource bases, problems, opportunities and national levels of development imply that a single formula will not be appropriate in all countries and at all times.

That said, one relatively clear development trajectory available to some countries is to focus heavily on applied research and intermediary institutions, before putting a more serious effort into basic research. Ireland is a case in point (see Appendix). Japan and Norway have arguably followed a similar strategy. In contrast, Thailand and Morocco have historically built up the science base without paying much attention to linkage – as a result of which, industrial development is either largely autonomous of the national R&D infrastructure or weak. The choice of strategy is closely linked to the *governance* of research and research funding. To the extent that the scientific and technological elite itself captures the mechanisms of governance, it is likely to fund its own activities rather than to pay a great deal of attention to social and industrial needs, thereby isolating the R&D infrastructure from the development process.

5.2 Conclusions and Recommendations for Funding Research for Development

Based on research and theory about the role of knowledge in economic development, we draw a somewhat radical conclusion. While the creation and flow of new knowledge traditionally has high status, attracts policy attention and funding, the working and reworking of the stock of knowledge is much more important for economic development. Since technological change and economic innovation drive the capitalist economy, *creative imitation is **the** central process in capitalist economic development.* In economic terms, science is much more significant as a source of trained people than as a generator of new knowledge, inventions and innovations.

This conclusion will be unpalatable to many. It runs directly counter to the career structure, incentives and culture of the higher education and research sector, where the creation of new knowledge is an over-riding value. It implies an end to the comparatively 'hands off,' project-based funding policies so far pursued by many donors in the area of research for development, to be replaced by closer engagement with the innovation system as a whole. And it suggests a need for both funders and national policy makers to get to grips with R&D and innovation activities in the private sector, not just in public institutions.

While the 'business system' is the producer of growth, jobs and money in the National Innovation System, its constituent organisations (firms, farms, hospitals, and so on) have 'bounded rationality.' They develop by learning, and they learn in interaction with each other and other parts of the National Innovation System. Helping to make sure the National Innovation System works well is a legitimate function of the state. This requires that research and innovation be on the 'policy agenda' and that the state takes a view of its responsibilities, which goes beyond tackling traditional 'market failure.' Supporting the build-up and application of technological capabilities – including, but not only, the ability to do R&D – in the business system is a key element. OECD countries have a vast repertoire of policy instruments to build capabilities among their smaller and less technologically capable firms. This provides an opportunity to use creative imitation to exploit this knowledge base in a manner adapted to individual developing country needs.

An important target is that the business system should grow quantitatively to dominate the overall national R&D effort. While there is a need to invest in public-sector education and research, their main functions are the supply of qualified people and, in the case of Research and Technology Organisations, to act as gatekeepers and enablers of the business system's own innovation activities. As long as countries are 'catching up' and lag the science/technology frontier, the need for new knowledge from the national research sector is limited because the technological trajectories to be followed are rather clear. R&D is mostly about learning, rather than about creating new knowledge. Once at the frontier, the links to a strengthened research sector and, especially, a significant increase in intra-business system R&D become more important, and it is a rational to spend much more on science and public research than is the case for 'catch-up' countries.

With the aid of donor funding, it is all too easy to over-invest in research in the South. This tends to be poorly linked to the business system and can promote an 'overflow brain drain.' Management of the diaspora offers a prospect of encouraging well-qualified expatriates to return home once demand for their skills picks up and the quality of the National Innovation System improves.

Funding decisions need to be taken in the context of a systems view of the recipient National Innovation System (NIS). Different countries' systems have different needs. A generic funding recipe will cause inappropriate investments, therefore time and money are needed for mapping recipient NIS's – and also for projects, such as Technology Foresight, which identify problems, propose strategies and encourage self-activation. A national research policy is part of this picture, which may be a useful object for aid aiming to secure development.

The priorities of donor countries may not be the same as those of recipients. Mechanisms are needed which help test needs, rather than relying on donor desires and guesses. It can be worth considering placing investments at the level of national funding institutions (eg a national science and technology agency) rather than at the project level, in order to secure a fit with recipient needs. However, in a number of cases, this will need to be accompanied by investments in administrative reform processes.

In most countries, the most important part of the NIS for securing economic development is private industry. Programmes, which increase capabilities/absorptive capacity here, should have high priority, otherwise there will be no economic use for investments in the R&D infrastructure. This may be difficult to live with in the context of corruption prevalent in certain developing countries, and in the context of hardening international rules on state aids, but the issue nonetheless has to be faced.

Correspondingly, investments in developing countries which focus only on the research infrastructure – especially that for basic science – may have some educational pay-off (and that is important), but will otherwise have limited economic impact. Important exceptions are cases where the national effort in R&D is already at or close to the science/technology frontier. Typically, these cases involve tackling specific local problems in health care or agriculture. Investments in research facilities and groups need to take account of the needs for international linkages into the relevant global research communities, and the ongoing costs of maintaining a research capability (for example, in the maintenance and renewal of equipment, travel, etc). Quality standards in science and technology are set at the world level. Investments unlikely to attain these standards are a waste of money.

While there is some increase in MNCs' willingness to conduct R&D outside their headquarters economies, these wider R&D locations continue to be mostly in the Triad countries. MNCs will locate small R&D groups close to publicly funded research groups – but only if these conduct excellent, world class research. The idea that an R&D infrastructure investment will attract MNCs to a developing country is – in most cases – naïve, and needs to be treated with appropriate caution.

We suspect that making use of these conclusions and recommendations will require rather radical rethinking and reform of the role of donor agencies in research for development. Without such rethinking, we anticipate that the development returns to donor investment in research for development will continue to be poor.