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Innovation and Research Strategy for Growth

DECEMBER 2011

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Keith Smith

Agnès Estibals

The Innovation and Research Strategy for Growth policy paper and related documents can be found at: http://bis.gov.uk/innovatingforgrowth

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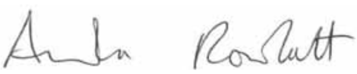
Foreword

Innovation is central to long term economic growth. There has been much fresh analytical thinking on the drivers of innovation, as the dynamic of business activity has evolved in recent years. This paper aims to bring together this new analysis in a single place and derive conclusions for public policy: it is the economic thinking underlying the new Innovation and Research Strategy for the UK.

Business innovation is a broad concept, encompassing performance improvements in products, services, processes, and systems. Competition between firms provides incentives for firms to invest in innovation, whether this involves spending on research, or skills, or simply better management. However innovation is also spurred through relationships and networks – with innovations building on previous innovations, and drawing on knowledge and lessons from a wide range of sources. This paper also demonstrates the important role of Government in this: it provides critical infrastructure, is a significant purchaser of goods and services, and can facilitate the sharing of knowledge and strengthening relationships.

The Department of Business, Innovation and Skills (BIS) was designed to bring together policy on the processes of knowledge creation, innovation, business investment and education. This Economics Paper is part of that effort. It has itself involved wide ranging collaboration: between analysts across the Department and outside it, between analysts and policy makers, and with very valuable input from the Minister for Science and Education. As with the innovation process itself, this wide collaboration has produced a stronger document – one that helps us understand the processes of innovation, and through this to have a clearer perspective on which policies are most important for innovation and how they should be structured. I recommend it to you.



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Overview and policy implications

The UK, and the world economy generally, continue to confront serious challenges. Europe as a whole is threatened by financial instability, and countries face risks and trade offs as they seek to accelerate recovery. Against this background, the UK Government aims not only to raise potential output but to generate sustained growth. This is necessary not only to tackle the effects of the recession, but also to remove longer-term weaknesses in UK development. These include sectoral imbalances, high household debt, weak investment, persistent trade deficits and constrained public spending. Growth is the connecting thread as we seek to solve these problems. The only viable way to build a strong, sustainable and balanced economy is to develop new sources of growth. Innovation in all its forms is at the heart of this.

Innovation is the engine of long-term economic development because it is the channel through which improved knowledge is applied to economic processes. This paper opens by showing that economic growth theories and models converge in giving a central role to innovation. Growth rests ultimately on innovating firms. Empirical research shows that innovation, in the form of performance improvements in products, processes, services and systems, is a core condition for both for business competitiveness and the wider growth of the economy. Innovation is not costless: it requires investment and resource commitment. Investments in tangible and intangible innovation assets – such as research, design, training and skills, intellectual property, organisational and managerial abilities etc. – are needed to underpin the productivity growth that drives both GDP growth and wider welfare. A central component of this is investment by government in scientific and informational infrastructures, in education and training, and in public procurement.

Rethinking innovation

This paper stresses the need to understand the real characteristics of innovation as a precondition for developing policy options. We have two basic resources in seeking to understand the nature of innovation. On the one hand there are extensive academic research results and evidence as a basis for policy analysis.[1] On the other, there is a platform of previous policy analyses and data.[2] These enable us to delve further into the innovation process to better capture its complexity and dynamics.

1 For a recent overview of innovation studies, see Fagerberg, J., Mowery, D. and Nelson, R. (2004) *The Oxford Handbook of Innovation* (Oxford: UOP).

2 Lord Sainsbury of Turville (2007) *The Race to the Top: A Review of Government's Science and Innovation Policies*; DIUS London (2008); *Innovation Nation: Unlocking Talent*; Dyson, J (2010) *Ingenious Britain: Making the UK the leading high tech exporter in Europe*; OECD (2010) *Innovation Strategy: Getting a Head Start on Tomorrow*; Paris: OECD; European Commission (2011), *Innovation Union Competitiveness Report*, EUR 24211, Brussels.

Innovation for growth takes two basic forms. Firstly, there is innovation that creates entirely new products, based usually on some form of breakthrough knowledge creation. This type of innovation often rests on scientific outcomes and it is often (though not always) central to technological breakthroughs. It sometimes gives rise to new industries and activities. The computing and communications industries emerging from semiconductor and microelectronics breakthroughs are examples of this. Secondly, there is innovative upgrading of existing products. This takes the form of persistent incremental improvement that transform existing industries from within. In this case, the industry stays the same (at least in name) but its characteristics may change dramatically over time. For example, innovation in vehicles has produced substantial transformations in fuel economy, mechanical reliability, materials use, assembly costs, and so on for cars. These two modes of innovation – radical novelty versus incremental change – differ significantly in how they happen, but each is important to growth performance. Each poses major challenges for policy.

What does modern research teach us about innovation? Some central robust conclusions are that innovation activity is pervasive across industries, collective in character (involving interactions of many actors), cumulative over time, risky and uncertain, and often rests on national and regional specialisations. Clusters of knowledge and innovation hotspots have emerged in a wide variety of studies as a prevalent feature of competitive advantage. Above all, innovation performance rests not simply on entrepreneurial actors but is powerfully shaped by the *innovation system*, which is the connected set or organisations (firms, universities, financial actors) and institutions (such as laws, regulations, and infrastructures) that shape the environment within which firms and other actors innovate and produce. *The structure and functioning of the innovation system is a central challenge for policymakers*.

Although we need to be careful about exaggerated claims of change, this analytical review argues that the nature of innovation has broadened across several dimensions:

- **Across borders** – scientific researchers have been globally connected for a long time. But innovators are also connected internationally, through networks, trade, foreign investment, and global value chains. Although most firms retain strong connections to their home bases, both firms and high-skilled individuals are globally mobile. Firms can and do locate where knowledge assets are to be found. Therefore advanced economies are reassessing their innovative assets with a view to boost their competitiveness. Emerging economies are creating major scientific and innovative capabilities and are directing resources towards these activities. But how well countries do in the new global context continues to depend heavily on the character of their domestic innovation systems and how these systems adapt to an interconnected world of rapid technological and economic change.

- **Across institutions** – innovation capabilities extend well beyond the innovating firm. They involve interactions between a wide range of private and public actors. Innovation is a joint process between businesses, universities and research labs, and other public organisations that produce knowledge The administrative and regulatory context can play a central role in shaping the innovative dynamism of the economy. What we refer to as the 'knowledge infrastructure' is central to the innovation system. It has two basic elements: the science infrastructure, of universities and research labs, and what we call the innovation information infrastructure. The latter consists of organisations generating and distributing framework knowledge – such as measurement techniques, geophysical information, design principles, or intellectual property rules. All countries possess and maintain such systems, though they take widely different forms and can operate in many different ways, with differing functionalities. The institutional framework for these organisations has changed and is continuing to change. Its effectiveness and functioning is an important issue for public policy.
- **Across processes** – innovation processes are changing. Digitalisation permits new forms of visualisation, simulation and experiment; modularity permits new forms of collaboration; and new materials change the ways in which products can be designed and constructed. This is changing the collaborative environment for corporate actors, with important implications for competition policy, intellectual property regulation, and skills.
- **Across industries and sectors** – all industries and sectors innovate but they do so in different ways. High-tech industries are important because they are major investors in research and development and they commercialise new technological tools. However, innovation emerges not only from high-tech, research-based industries but also from the (large and growing) services sector and from low tech enterprises, which may do little or no research (although they draw on the outputs of research organisations). Both high growth firms and highly innovating firms are spread across all sectors of the economy. Investing in innovation usually involves fixed capital investments, but also increasingly encompasses investing in intangible assets, ranging from research and human skills (often firm-specific) to organisational development, design, marketing, and managerial capability. These investments are the defining feature of the knowledge economy and central to the competitiveness of advanced economies. Systems of regulation and corporate governance that affect the abilities of managers to direct resources to such activities have a powerful impact on innovation performance.

- **Across public organisations** – Innovation is not the exclusive realm of the private sector. The public sector strongly influences the innovation performance of the economy as a whole. It does this in four main ways. First, it plays a major role in shaping the innovation environment, especially through producing essential intangible inputs (such as a literate, numerate, skilled workforce) or physical and knowledge infrastructures that are used by all industries. Secondly, the public sector supports innovation through procurement of goods and services (and often by being an early consumer). Thirdly, it directly produces innovations related to its own activities, such as defence technologies or energy innovations. It can frequently foster new technologies and thereby tap into new sources of growth. Finally, the public sector creates new forms of public service delivery, in health, education, transport, as well as in the functions of government itself.

Rethinking the policy approach

A coherent innovation strategy has to keep abreast of change in a differentiated global environment where economic gains lie both in developing new technologies and new organisational forms, and in adapting and using them to produce new goods and services across the whole spectrum of existing economic and social activities.

The UK innovation system has distinctive characteristics that are actual or potential sources of competitive advantages. These include (1) a genuinely world-leading science base and information infrastructure, (2) a major financial sector that can be better directed to support firm growth, (3) a strong supply of high-level skills and access to globally mobile skills, and (4) strong business performance in the creation of intangible assets. The government has a strategic role to play in order to build on these assets and leverage the innovative potential of the economy.

The highest performing innovation systems in the world, such as the USA, Japan, Germany and Sweden, are characterised by their ability to generate public and private long term investment, at scale, in uncertain new ideas though intensively networked innovation systems. Within these systems Government takes an active leadership role. This entails fostering groundbreaking scientific and technological breakthrough through public investment in the research base, strengthening connections between actors in the innovation system, supporting those who identify business innovation opportunities and marshalling investment resources to help business respond to global innovation challenges. Successful innovation policies have to strengthen the coherence of the UK innovation system to improve significantly its overall effectiveness in respect of these functions.

Out of the analysis which follows, four priority areas for policy emerge:

1. The need to facilitate collaboration between organisations in the private, public and third sector at every geographical level – from international to local – to generate and apply new knowledge. Innovation is an interactive process within the innovation system, and new modes of innovation draw on 'openness'. Increasingly, complementary bodies of knowledge derive from many sources. The ability to share knowledge whilst giving creators incentives to invest is a vital basis for further growth. Chapter 3 points to the **need to strengthen the sharing and dissemination of knowledge within the innovation system.**

2. The need to maintain and develop a full scale knowledge infrastructure – the university science system, research labs and organisations, and information agencies working in design, intellectual property, quality assurance and specialist support. These organisations are frequently autonomous or semi-autonomous but they are also closely related to the public sector. Innovation rests on this knowledge infrastructure: it solves scientific and technical problems, creates knowledge, trains skilled people and develops specialised innovation capabilities. These are essential intangible assets used as inputs for value creation across most economic activities. Chapter 4 emphasises that **innovation performance increasingly rests on creating and using a more coherent research and innovation infrastructure.**

3. The need to incentivise businesses across the economy to undertake the tangible and intangible investments that drive innovation. High tech sectors and companies are important, and they are performing well in the UK, but they are a relatively small part of the overall economic picture. The growth of the UK economy crucially depends on the innovation performance of the rapidly evolving service sector, and of large medium and low tech industries industries in manufacturing, construction, energy supply etc. Innovating in part means increasing the extent to which businesses in all sectors adopt high-tech inputs, but it also means developing strategic inputs for value creation such as human resources, organisational structures and interactive capabilities. Innovation in non-high tech sectors such as agri-food or energy is a national priority not simply because of their scale but because it will allow the British people access to stable and affordable food and energy supplies. Chapter 5 argues the **importance of driving business innovation in all sectors of the economy, in high-tech but also in our large service sector, and in low and medium-tech activities.**

4. The need to improve the innovative capacity of the public sector, meaning central and local governments and their delivery bodies. User-led innovation is an increasing feature of the knowledge economy, and key users include government. Government-led innovation has the potential to make more of an impact on the performance of the innovation system as a whole, but particularly in such very large sectors such as health, transport and urban development. Demand-side policies that foster innovation are a challenging

area that requires more economic research. In times of constrained public finances in most advanced economies it is becoming paramount to address this research gap. There are opportunities too for the development of new technologies to address long term social demand such as green growth, and through public service delivery activities. Chapter 6 stresses the **potential for transforming the public sector into a major driver of innovation** whilst recognising that the complexity and culture of the public sector create operational barriers towards this aim.

Innovation is a key driver of competitiveness and economic growth, but nurturing it is a challenging task for policy because it involves multiple and constantly changing actors, linkages and dynamics. The over-arching objective of the Innovation and Research Strategy for Growth is to create a coherent framework within which we can improve how well the UK innovation system identifies opportunities, builds capabilities and infrastructures, allocates financial and skilled resources and coordinates across relevant actors. The stakes in this effort are very high.

Innovation as a Key Driver of Economic Growth

The economic challenges facing the UK – of rebalancing, employment and fiscal consolidation – can be resolved only by sustained growth. Successful growth requires in turn transformation of products, processes and organisations. In other words sustained growth rests on innovation.

This Chapter overviews the role of sciences, research and innovation in theories of economic growth, then uses data analysis to explore the links between innovation performance and long-run growth. The main conclusions are:

- There are diverse economic theories and models of growth, but they converge in putting innovation at the core of growth.
- Empirical studies demonstrate that investment in innovation is a core condition for enhanced business productivity at firm level.
- Innovation investments include tangible capital but more importantly intangible assets – such as Research and Development (R & D) but also design, intellectual property, software development, skills, managerial capability, marketing and branding.
- Across the firm population, higher innovation investments are associated with higher levels of new product innovation.
- In turn, higher levels of product innovation are associated with higher productivity in firms.
- Productivity growth is the central driver of economic growth overall.

Innovation is the application of new knowledge to the production of goods and services; it means improved product quality and enhanced process effectiveness. Innovation generates wide improvements in productivity, which are the primary source of enhanced well-being, higher real incomes and resources for Government.

In this chapter we look at four main bodies of evidence to support these claims:

- The literature on growth theory – from the Schumpeterian approach to neoclassical models and the evolutionary approach – is unanimous in putting innovation at the core of economic growth.
- Data analysis across countries shows that innovation has a major impact on productivity at the level of the firm and that innovating businesses are more likely to grow.

- New measurement and analytical efforts, such as NESTA's Innovation Index and surveys, have drawn attention to the large and growing scale of business investments in intangible assets and have identified such investments as key sources of changes in productivity and growth.
- Growth models and econometric studies support the view that higher productivity from innovation-related investment drives economic growth. However, at the aggregate level, the multidimensional nature of innovation is difficult to capture accurately.

The central role of innovation in growth theory

Economics has a range of growth theories, but all give a central role to innovation as a driver of growth. Economists are widely held to disagree on more or less any topic. But they are in accord that all long-term growth processes rest ultimately on innovation and technological change. This is especially important in advanced economies where innovation plays a key role in improving the quality of inputs and in how these are incorporated in the production process.

THE SCHUMPETERIAN APPROACH

In the 1940s the economist Joseph Schumpeter[3] assigned the key role in economic growth firstly to the disruptive activity of entrepreneurs, and secondly to large corporations, each of which fed a process of *creative destruction* by causing continuous disturbances in the economic system. The source of these disturbances was innovation, which created as Schumpeter put it:

> 'competition from the new commodity, the new technology, the new source of supply, the new type of organisation, competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives'.

Schumpeter's analysis was descriptive rather than formal, but later economists developed formal growth models based on his insights, placing innovation at the heart of growth.[4] There is recent empirical evidence, discussed below, to suggest that the extent of creative destruction is linked to the rate of growth.

NEOCLASSICAL EXOGENEOUS GROWTH MODELS

In the 1950s and 1960s Robert Solow developed a formal neoclassical model of growth, based on the concepts of *production function* where output is a function of inputs (capital, labour, management services and materials), and reaches a

3 Schumpeter, J. (1942) *Capitalism, Socialism and Democracy*, London: Routledge.

4 See especially Aghion, P. and Howitt, P. (1992), *A Model of Growth through Creative Destruction'. Econometrica* 60: 323 – 351; Aghion, P. and Howitt, P. (1998), *Endogenous Growth Theory*. Cambridge, MA. MIT Press.

long run equilibrium.[5] If the population grows, then increasing all inputs in the appropriate proportions increases output until equilibrium in goods markets is achieved, at which point the capital stock is in steady state, and investment is only to cover depreciation.[6] In the long run, growth in per capita output depends *only* on the rate of technological progress (resulting from improvements in outputs or the efficiency with which inputs are transformed into outputs).[7] However the theory offered no account of how this occurred: technological improvements emerged from outside the economic system, and were not shaped by decisions within it.

In empirical applications of the theory, Abramowitz and later Solow showed that US long-run economic growth derived overwhelmingly from technological progress rather than increases in capital and labour inputs, a result which emphasised the importance of innovation, though without explaining it.[8]

NEOCLASSICAL ENDOGENEOUS GROWTH MODELS

The Solow growth model treated the sources of technological process as external to the operations of firms. Later, ‘endogenous’ growth models attempted to provide a deeper analysis of the sources of long-run growth, by building knowledge-creating investment into the models.[9] This allowed two-way causation between innovation and growth. Endogenous innovation models saw technological progress as the key to long-run growth, but made it internal to the economic process, dependent on investment in innovation, primarily through investment in R&D and human capital. In these models, the basic process used to explain economic growth is the phenomenon of increasing returns to scale, which follow from the externality aspects of technological change. Several of the most important approaches within this field involve modelling a specific “research sector” of the economy, which produces both specific new inputs, plus general scientific and technical knowledge. In these models, growth results partly from increases in the productivity of tools and equipment (intermediate inputs) resulting from technological change, and partly from “spillovers” of knowledge from one area to another. It is the spillovers which generate increasing returns, basically because production functions are not independent, and the knowledge input can enter into many or all firm-level production functions. A key difference then emerges between this type of growth model and neo-classical growth theory: the growth rate can be permanently raised by activities which increase the flow and use of collective knowledge in the system.

5 Solow (1956), *Model of Cross-Country Growth Dynamics*, Oxford Review of Economic Policy 1 23 (2007): pp. 45-62.

6 Increases in single inputs have by assumption a positive but declining marginal impact.

7 Early models abstracted from firm investment in non-production activities such as innovation to improve the quality of outputs and efficiency of input use, and the impact of the business environment (e.g. market incentives, the taxation and regulation system, infrastructure provision) on firm incentives to invest, be enterprising and innovate. Schumpeter’s focus on the innovating entrepreneur was not taken forward in formal growth models based on the production function. There is a separate literature linking entrepreneurship and growth.

8 Abramovitz, M. (1956) *Resources and Output Trends in the United States since 1870*, American Economic Review*,* vol. 46, no. 2, pp. 5-23.

9 Aghion, P. and Howitt, P. (1998) op.cit.; P. Romer, *Endogenous Technological Change*, Journal of Political Economy*,* Vol. 98, No. 5, (Oct. 1990), Aghion P (2005), *Handbook of Economic Growth* Theory, MIT; Aghion P. and Howitt P. (2009) The Economics of Growth Theory, MIT.

THE EVOLUTIONARY APPROACH

The evolutionary approach to growth focuses on innovation as a mechanism of economic change. In evolutionary theories firms are forced to innovate by technological competition: they constantly introduce new varieties of products, and new production technologies. Both market and non-market processes (such as public procurement) select successful technologies, and out of this growth emerges, as successful technologies and firms replace those that are diminishing in importance. Innovation therefore drives growth, but is accompanied by significant change in either the structure of the economic system, or in the composition of its activities.[10]

A central contribution of recent evolutionary approaches to previous theories is the **'innovation system'**: the set of institutions and organisations which contributes to the development and diffusion of new technologies, processes, and organisations. Within this system, firms seek to survive by developing a variety of diverse strategies and products with selection by the market, with Government intervention through support, procurement and regulation shaping the evolution of the population of firms.[11] The concept of the innovation system will be further developed in Chapter 2.

Innovative activities as a source of business productivity growth

The strength of the relation between innovation and growth is supported by a long-standing range of empirical studies that show positive correlations between various innovation investment and outcome proxies (such as R&D and patent performance), and growth outcomes.[12] More recent studies have drawn on direct measures of innovation investment and innovation output, to show that **firms that innovate do better than those that do not** and that **innovation drives productivity growth**.

DATA SOURCES AND MODEL

A major data source known as the *Community Innovation Survey* provides a wealth of evidence on a variety of firm innovation activities, from investment in innovation (expenditures on design, training, new capital goods, licences, market exploration and R&D), innovation outputs (in terms of sales of new and modified products and processes), and a range of related activities. The survey is implemented in many countries including every country of the European Union; in the EU it covers about 100,000 firms; the UK version has a realised sample

10 Nelson, R. and Winter, S. (1982) *An Evolutionary Theory of Economic Change* (Cambridge, Mass.: Harvard; Metcalfe, J. S. (1998) *Evolutionary Economics and Creative Destruction* (London: Routledge); Metcalfe J. S., Foster J. and Ramlogan R., (2006), *Adaptive Economic Growth*, Cambridge Journal of Economics, Vol. 30, No. 1, pp.7-32.

11 Metcalfe J. S., (2007), *Innovation Systems, Innovation Policy and Restless Capitalism*, pp. 441-454, in Malerba F.and Brussoni S. (eds), *Perspectives on Innovation*, Cambridge, Cambridge University Press.

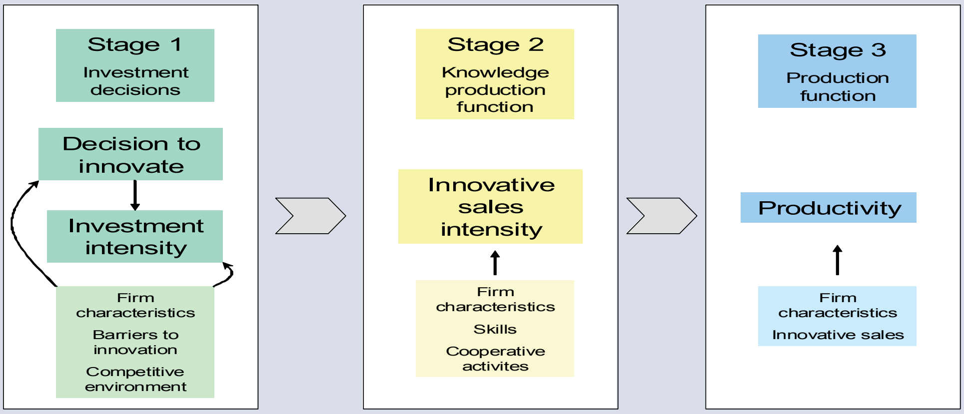
12 Fagerberg, J. (1994), *Technology and International Differences in Growth Rates*, Journal of Economic Literature, vol. 32, pp. 1147-75.

of about 15,000 firms.[13] At the present time it is the only comprehensive data source that seeks directly to measure innovation inputs (across all of their range) and innovation outputs (in the form of sales from wholly new or technologically changed products).

The most rigorous attempt to use this data to look at the link between innovation activity and firm growth is an econometric approach known as the Crepon-Duguet-Mairesse (hereafter CDM) model. It has been applied both nationally and across countries, and we report here on the results both for OECD countries and specifically for the UK. It explores the impacts of innovation activity of firms from manufacturing and most non-public service industries in terms of the links between innovation investment and firm productivity (see Box 1).[14]

Box 1: The CDM Model

The CDM model explores the innovation-growth relationship through a three stage analysis. The stages are (1) an investment decision phase in which firms' decisions to engage with innovative activities and the intensity of their investment is modelled, (2) a knowledge production function which models how that investment relates to sales of innovative goods; and (3) an output productivity stage in which the link between those innovative product sales and labour productivity is considered. The figure below shows inputs to the model and the flow from innovation investment through to productivity with some of the variables that feed at each stage of the process.



Source: Hodges D, (2010) Investigating the links between innovation and productivity: an analysis of UK firms, BIS 2010

13 For an overview of results, see BIS (2010), *UK Innovation Survey 2009*, December.
14 Crépon Bruno, Duguet E. and Jacques Mairesse (1998), *Research, Innovation and Productivity: an Econometric Analysis at the Firm Level*, NBER Working Paper 6696.

KEY FINDINGS

This model has been applied across many countries by the OECD, and has also been applied by BIS to UK data, with consistent results:[15]

- An almost universal correlation between investment in innovation and sales from innovative products was found: that is, innovation outcomes rest on investment commitments, not simply to R&D but to a wide range of non-R&D investments
- A strong correlation between product innovation and labour productivity was found. On average, a one per cent increase in firms' innovation sales per employee was associated with a productivity increase of 0.5 per cent across countries. For the UK this figure was 0.55%.
- Large firms were more likely to engage in innovation activity. For the UK, the impact of firm size was relatively small, with a one per cent increase in employment showing a five per cent increase in the probability of being innovative. However, larger firms invested proportionately less than smaller innovative firms, which can be attributed to higher economies of scale and scope. They also yielded relatively lower impacts in terms of sales of innovative goods.
- Firms operating in international markets are more likely to invest in innovation. Exporting was associated with higher innovation intensity, as were firms belonging to a wider enterprise group and constraints on innovation.
- Generally, co-operation with other firms and public financial support were correlated with higher innovation expenditures at firm level (and these expenditures were in turn associated with better innovation nd productivity outcomes).
- Firms further away from the technology frontier were just as likely to engage in innovative activities as those on the frontier, but firms closer to the frontier spend more on innovation and earn more sales from innovation.

The multi-dimensional nature of innovative activities

Firms' innovation investments are multi-faceted – innovating firms increasingly invest in a wide range of intangible assets which go far beyond R&D. But investments for innovation also include tangible capital, on a large scale. Intangible assets do not have a physical embodiment and can also be referred to as knowledge or intellectual capital. They can be categorised as: R&D; design assets; formal intellectual property; software development (software and databases); and economic competencies (investments in training, organisational development, managerial capability, product development, marketing and branding). Evidence suggests that broad (intangible) and traditional (R&D and

15 Hodges D, (2010) *Investigating the links between innovation and productivity: an analysis of UK firms*, BIS 2010; Criscuolo C. (2009); *Innovation and Productivity: Estimating the core model across 18 Countries*" in OECD Innovation in Firms – A Microeconomic Perspective, Paris: OECD (2009).

patents) innovation activities are complements rather than substitutes, and that UK firms that do both perform better. [16]

NESTA'S INNOVATION INDEX AND SURVEYS

The primary recent work on intangible investment for innovation in the UK has taken place through the NESTA Innovation Index. NESTA's work on innovation investment has two parallel strands:

- High level estimates, using a wide range of metrics and consistent with national accounts, of spending by firms on R&D, software, design, business organisation, skills and reputation.
- pilot surveys of what firms say they spend on these knowledge investments with estimates of how long the new investment lasts.

In this document the Innovation Index estimates of intangible investment are used as a reference point because they allow macroeconomic international comparisons. Key findings from surveys allow a microeconomic understanding of firm behaviours.

Table 1 shows that nominal investment in intangibles was estimated at £137 billion in 2008 with the majority of investment on business process improvements (£31billion) and training (£27 billion). The largest asset investments were design (£23 billion) and software development (£22 billion). R&D investment was £16 billion, of which £4 billion were protected by patents.

Table 1: Tangible and intangible investment (£ bn)

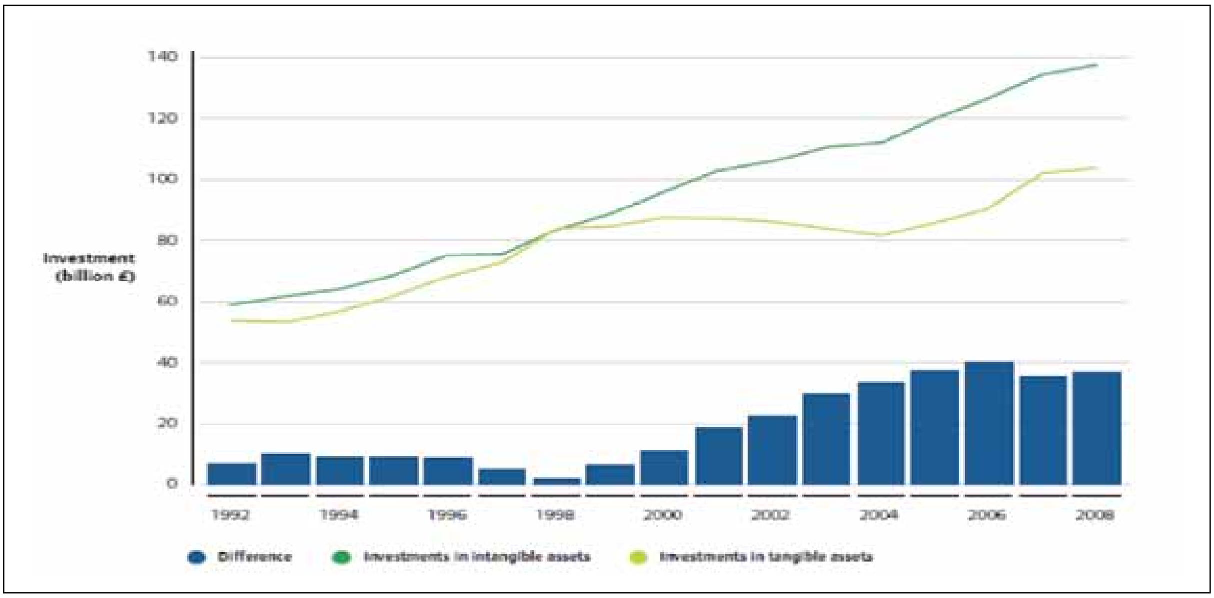
Year	1990	1995	2000	2008
All tangibles	**67**	**62**	**87**	**104**
Intangible category				
Software Development	6	10	16	22
R&D	8	9	12	16
Design	13	13	15	23
Mineral Exploration & Copyrights	3	3	2	4
Branding	5	7	12	15
Training	12	15	21	27
Organisational Capital	9	12	17	31
All tangibles	**56**	**69**	**95**	**137**

Source: NESTA Innovation Index (2010)

16 Battisti, G. and Stoneman, P. (2007), *The Prices of Material and Intermediate Inputs in UK Manufacturing: Identifying the Contributions of World Prices and Domestic Factor Costs*, Applied Economics, vol. 39(7): pp. 859-882.

This research show that nominal investments in intangibles have increased at an average rate of 4.6 per cent since 2000, well above the growth seen in tangible assets at 2.1 per cent per year over the same period. Figure 1 shows the gap between these different types of investments has widened since 1998 such that by 2008 investments in intangibles were higher than those of tangibles.

Figure 1: Investment by UK firms in tangible and intangible assets, 1992-2008

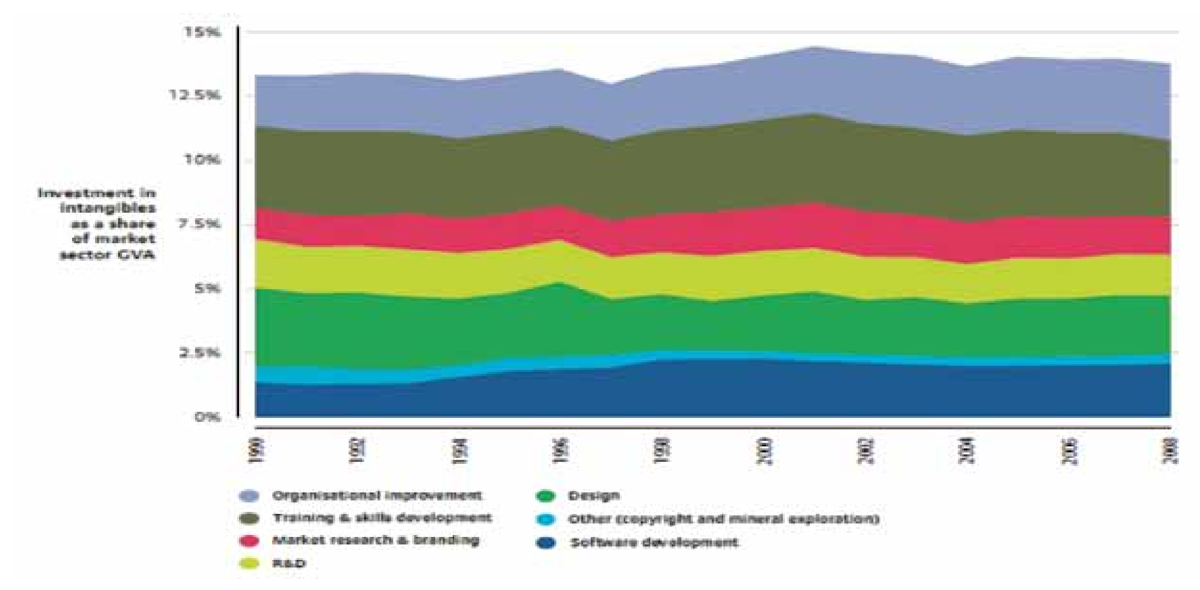


Source: NESTA Innovation Index (2010)

Similar trends are observed in other advanced economies, notably the USA, Japan and leading EU countries.

Figure 2 shows that, as a share of market output, the total investment in intangible assets (excluding government) remained at around 13 per cent during the 1990s, peaking at 14.5 per cent in 2001 before stabilising between 13.5 per cent and 14 per cent during the 2000s. The contribution of each of the asset categories to total intangible investment has also remained broadly stable between 2000 and 2008.

Figure 2: Investment by UK firms in intangible assets by category – share of market sector Gross Value Added, 1990-2008



Source: NESTA Innovation Index (2010)

NESTA's most recent intangibles survey[17] shows that business spending on non-R&D intangibles is much more widespread than just R&D spending:

- Analysing the categories of investment confirmed the importance of training and software investment, reflecting the importance of skills and ICT applications across industries.
- The incidence of both non-R&D and R&D intangible spend was found to be more common in larger and older firms.
- Non-R&D spend was much more common in services relative to manufacturing, especially in financial services. Thus much of the incidence of innovation spending in the service sector, a major part of the economy, is not fully captured in the R&D statistics.
- The breakdown between in-house and purchased investment differed across broad sectors. The overall share of in-house investment was significantly higher among firms in services than those in the production sector. This suggests a strong role for digitalisation in current services activity.

17 To reduce the reliance on assumptions a new micro survey of intangible assets was developed to support the work on intangible assets and productivity within NESTA's Innovation Index project. The survey of 2,004 UK private sector firms explored the level of (a) spending and (b) life lengths of private sector investments in intangible assets. There are three main innovative features of the survey. First, as well as asking about R&D expenditure, the survey asked firms to detail expenditure on a wider range of spending on intangibles: training, software, branding, design and business process. Second, since much spending on intangibles is in-house, the survey specifically asks firms about both purchased and in-house spending. Third, to estimate depreciation rates for intangibles, the survey also asked about the length of time firms expected to benefit from such spending. The work is therefore distinctive from other surveys, the bulk of which do not ask for all intangibles, but just one, such as R&D or design. The main survey that does touch on intangibles is the Community Innovation Survey (CIS). However, the CIS focuses not on intangible investment as a whole, but only on R&D and non-R&D investment related specifically to innovation projects. It does not ask about all intangible categories (business processes for example), nor does it ask specifically about expenditures for in-house and purchased, an important distinction. Finally the CIS does not consider the life lengths of the assets.

- Average benefit lives for all intangibles were found to be over 2 years. R&D had the longest average benefit life of 4.6 years; the average of the others was 3.2 years. In a pilot exercise, respondents were also asked to report time for development and implementation. Adding these times to the benefit time gave average life spans of 8.6 years for R&D and 5 years for other intangibles, with longer life spans in production than services.

CASE STUDIES

Case studies have the advantage of being able to explore the complexity of the innovation process and its impact on firm performance in a depth that is not otherwise possible, but with the disadvantage that results lack generality.

We do not propose to summarise this literature, which is enormous, but simply note that case study evidence supports the conclusions from innovation surveys. Case studies indicate that innovation comes from a wide range of sources, and that leads to improved productivity, profitability and other positive outcomes.[18]

The Alessi case study shown in Box 2 illustrates how a firm's competitiveness can rely on a combination of intangible investments: design, organisational and managerial competencies. It shows how the firm Alessi successfully innovated in the low tech traditional sector of kitchenware.

18 McKinsey Global Institute (2002), *Whatever Happened to the New Economy?*, November; Baldwin, J. R. and Hanel P.(2003), *Innovation and Knowledge Creation in an Open Economy: Canadian Industry and Industrial Implications*, Cambridge: CUP.

Box 2: Alessi's innovation model

Alessi operates in a kitchen and tableware market, a very long-standing 'traditional' sector, where novelty is very important to sales, where production volumes are usually low and where customers are extremely demanding in terms of the manufacturing quality of products. Alessi retains no internal designers. Despite this, design is the very heart of the Alessi market offering. Finding, commissioning and developing new designs from talented designers is the core of the company's business. It has developed sophisticated and successful processes to do this. Key elements of this capability include:

- A formula for the assessment of the potential of new designs in four key dimensions, supported by sophisticated market size and manufacturing cost analyses;
- Skilled technicians who act as intermediaries between designers and manufacturing engineers;
- A network of suppliers with high quality, low volume mass production capabilities;
- A willingness to maintain a large product portfolio and to market test designs for extended periods;

The company has also pioneered the use of new materials in kitchen and tableware, in particular making extensive use of plastics in high-quality contexts. Alessi has also extended its activities, using its design management expertise, to deliver a range of joint venture and licensing activities with outside manufacturers. These activities have included wristwatches, textiles and automotive designs.

Source: Design Council (2011)

Innovation as a source of economic growth

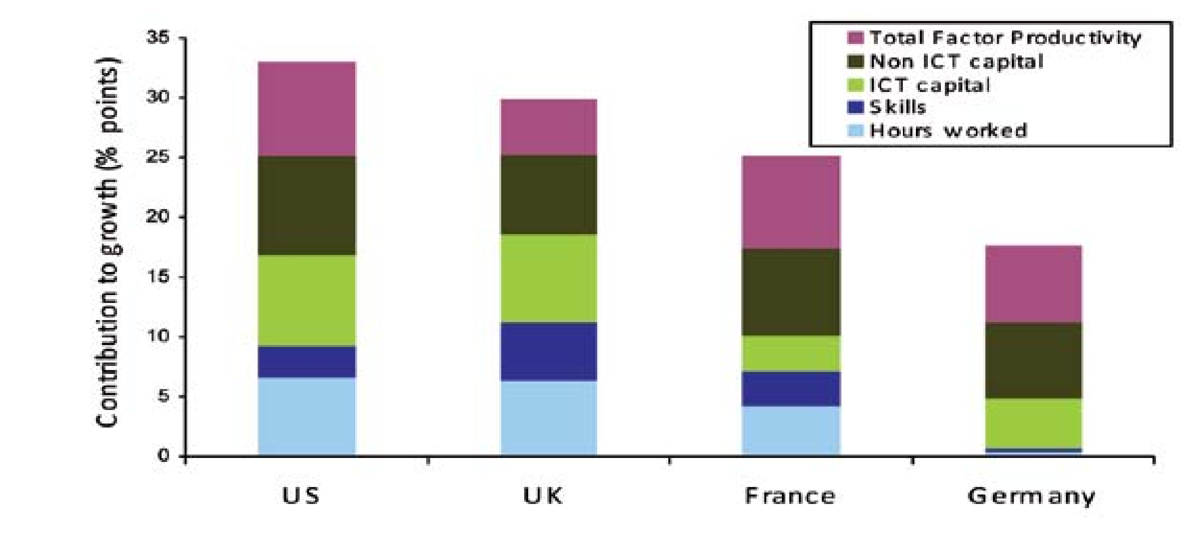
Macroeconomic analyses confirm both the growth theories and the firm level analyses outlined above: business innovation translates into productivity growth at the aggregate level. However, **most of these methods are constrained by current measures of business investment in intangible assets and provide imperfect information about the innovation-growth link**.

GROWTH ACCOUNTING

Growth accounting techniques attempt to analyse growth into the contributions from the main drivers: labour and capital inputs, and Total Factor Productivity (TFP). TFP is a residual: it is the part of the value added that cannot be explained by quality-adjusted labour and capital inputs. It attempts to harness the impact of technological progress and can be used to make international comparisons.[19]

Figure 3 shows that while the UK has seen strong increases in skills and ICT-capital in recent years, the contribution of non-ICT capital and Total Factor Productivity appears less strong than for our international competitors. This tends to imply that government and business investments over this period were either lower or less effective than comparable economies.[20]

Figure 3: Contribution to GVA growth (1997-2007)



Source: EU KLEMS (2010), Gröningen Growth and Development Centre.

However, as noted above, this was also a period when investment in intangible assets by UK firms overtook investment in physical assets, with UK firms investing proportionately more in these areas. Recasting national accounts to treat these expenditures as asset formation rather than intermediate consumption shows a more positive picture.[21]

NESTA research using the investments in intangibles methodology developed for the Innovation Index provides a way of measuring the impact of innovation on productivity growth. The index estimates that UK private sector labour productivity grew 2.24% between 2000 and 2008, with innovation contributing 63% of that productivity growth,[22] as represented in Figure 4.

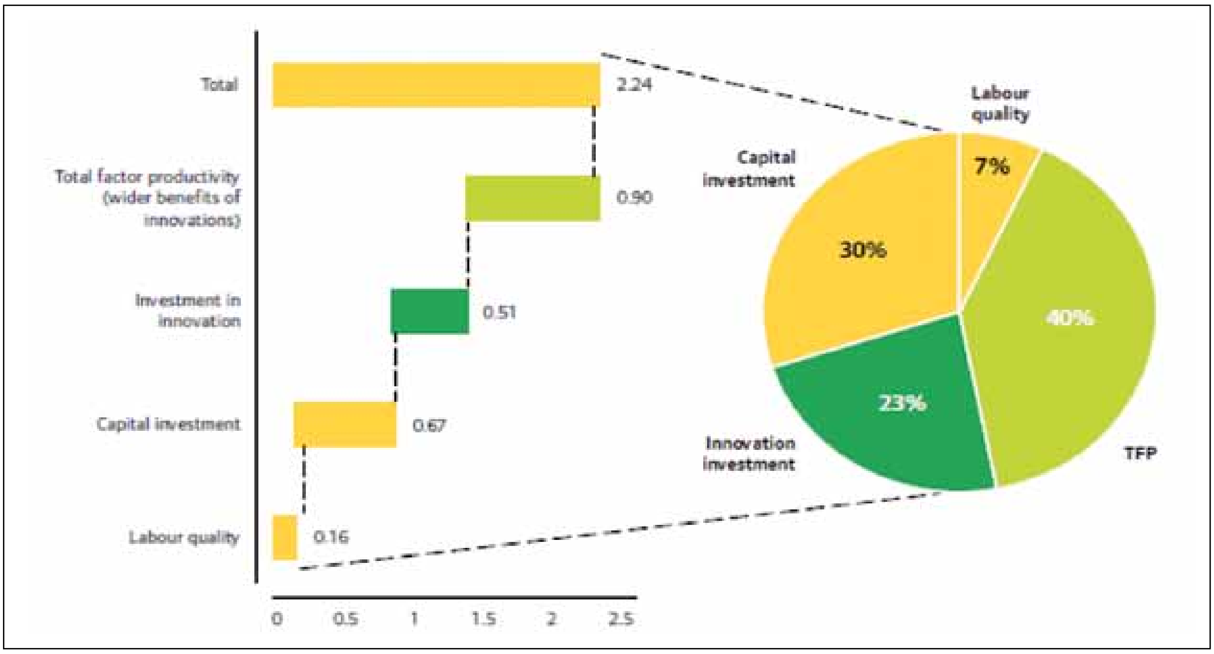
19 This technique can only give approximate answers, because it is non-econometric and so cannot e. g. take account of the interrelations between complementary factors, dynamic effects etc.

20 Growth accounting comparisons for 1995-2004 found that the UK's productivity gap with France and Germany was due primarily to lower investment in capital per worker, while the gap with the US was due to lower TFP. Growth accounting for 1997-2007 using a similar methodology (but separating ICT from non-ICT investment) showed significant changes in this growth composition. BERR, 2008a.

21 OECD (2010), *Measuring Innovation: A New Perspective*, Paris: OECD.

22 Awano G. (ONS), Franklin M. (ONS), Haskel J. (Imperial College) and Kastrinaki Z. (Imperial College) *Investing in Innovation*, London: NESTA, 2010.

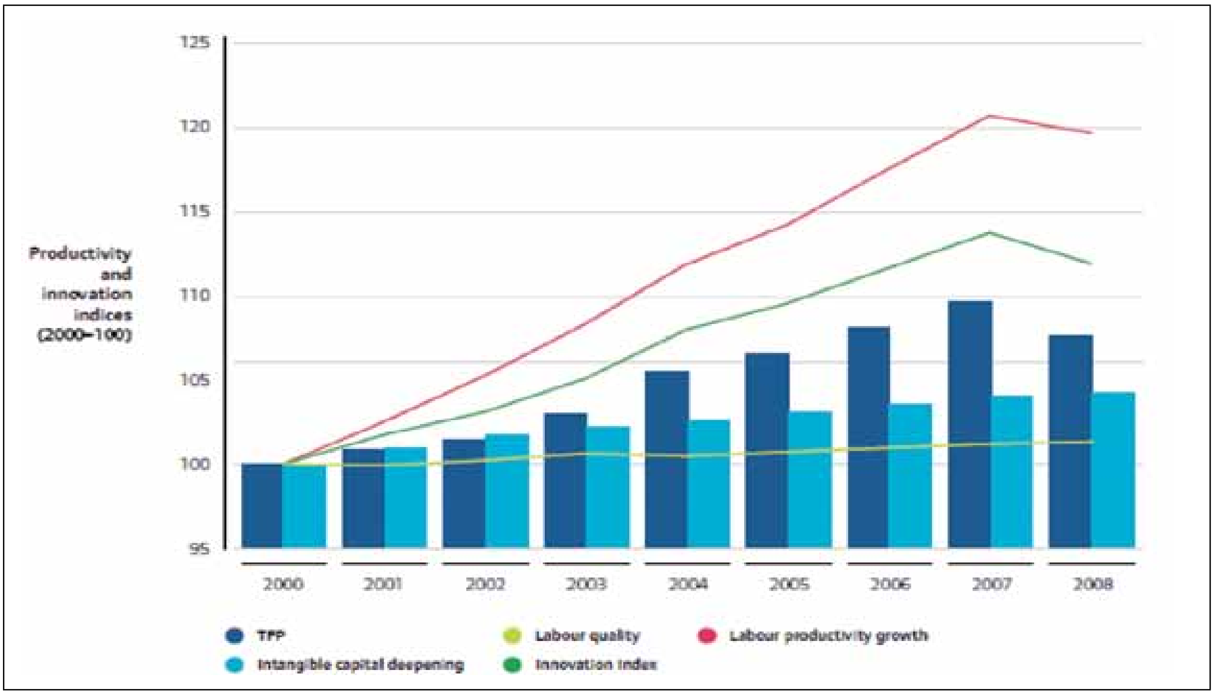
Figure 4: Breakdown of components for UK Average Labour Productivity growth, 2000-2008



Source: NESTA Innovation Index (2010)

The Innovation Index also reflects the first impacts of the economic downturn, which began in the second half of 2008. It suggests that labour productivity growth turned negative and that through 2008 businesses continued to invest in intangible assets, although more slowly than in previous years, as shown in Figure 5.

Figure 5: Components of annual labour productivity growth, 2000-2008



Source: NESTA Innovation Index (2010)

RESEARCH AND DEVELOPMENT IN ECONOMETRIC STUDIES

We have stressed the importance of non-R&D inputs, because hitherto much policymaking and policy analysis has focused on R&D. This focus on R&D has extended into economic analysis. Most econometric studies of the impacts of R&D spending are based on neoclassical models (other approaches are more difficult to cast within a testing framework), and largely in the Solow exogenous tradition, where growth is driven by enhancements to capital and labour quantities or qualities, and TFP.[23] Most have also use traditional measures of innovation such as Research and Development (R & D) and patents, because of the paucity of broader measures.

R&D has obvious limitations as a measure of innovation, since it is an innovation input (budgeted resources), rather than a measured innovation output, and most companies don't engage in what is only one among many innovation activities. In the UK, the UK Innovation Survey suggests that less than half of UK innovators perform any R&D at all, a result reflected across the EU. This suggests that R&D is not necessarily even a good proxy for innovation activity.

A strong simple correlation between R & D and growth is unlikely since growth in per capita GDP is affected by many factors, and the links between R&D and broader innovation and between innovation and growth are complex. This doesn't mean that technological progress doesn't positively affect economic growth, but more sophisticated techniques are required to control for this complexity.

Turning to the firm level, a large number of studies seek to quantify the link between R&D (taken as a proxy for firm-specific technological progress) and labour productivity, either at the firm, sector or national level. This research confirms that it is an important determinant of growth, although estimates of the elasticity of output with respect to business R&D vary.

Recent studies have also attempted separately to capture the impact of R&D carried out by government, public research institutions, or overseas.[24] Although sensitive to the model used, they generally indicate that the spillover effects on productivity from both R&D carried out overseas and in public research institutions are positive and significant, in quite a few cases exceeding the returns to business R&D.[25]

23 Survey in Nadiri, M.I. (1993), *Innovations and Technological Spillovers*, Working Papers *93-31*, C.V. Starr Center for Applied Economics, New York University.

24 Coe, D. T. and Helpman, E. (1995*), International R&D Spillovers*, European Economic Review, Elsevier, vol. 39(5), pages 859-887, May; Mohnen P. (2001) *International R&D spillovers between U.S. and Japanese R&D-intensive sectors*, Journal of International Economics, 44 (2), 315-338; Guellec, D. and Van Pottelsberghe de la Potterie, B.(2004), *From R&D to Productivity Growth: Do the Institutional Settings and the Source of Funds of R&D Matter?* Oxford Bulletin of Economics and Statistics, Volume 66, Issue 3, pages 353-378.

25 Khan, M. and Luintel, K. (2006), *Sources of Knowledge and Productivity: How Robust is the Relationship?*, OECD Science, Technology and Industry Working Papers *2006/6*, Paris: OECD; London Economics (2011), *The Impact of Investment in Intangible Assets on Productivity Spillovers*, Report to BIS, November.

There is also a substantial literature attempting to quantify the rate of return to investment in R&D, and the difference between private and social returns. Some research finds that the private returns to R & D are in the range of 10 to 30%.[26] The broad consensus indicates a rate of return from R&D of between 20% and 50%. A recent study concluded that each pound invested in R&D generates a return of £0.38 in every year thereafter.[27] Thus the spillovers from R&D are assessed to be both positive and substantial.

MEASUREMENT ISSUES

The available data suggests strong links between innovation and growth, but data limitations continue to exist. The complexity of innovation patterns does not lend itself easily to measurement. The measurement of intangible assets in particular presents many conceptual problems, and the issues in measuring innovation inputs and outputs are far from resolved.

At a macroeconomic level, although there is a growing body of research that has sought to quantify total business investment in intangible assets[28], the process of reflecting business spending on intangibles in the national accounts is still at an early stage. This means that currently difficulties remain in making a direct link from micro studies that suggest strong links between innovation and firm growth, to the macro level of the overall economy.

However, even at the microeconomic level, current measures of companies' non financial assets, as reflected in accounting standards, fall short. The result of this lack of information is a distorted picture of a company's asset base, its management decisions and growth prospects for investors and managers. This is all the more problematic as companies are becoming increasingly knowledge intensive. Some major innovators possess relatively very little tangible capital. Google or Microsoft are cases in point. Although the gap is visible for such major firms, this issue can be found across the full range of the firm population in various degrees.

Conclusion

Innovation is a complex phenomenon, which makes it difficult to capture it fully with available measurement technique, and there is no complete body of evidence which links micro-level innovation with macro-level outcomes. The material presented in this chapter, however, suggests the shape of the connection between innovation and growth, and outlines reliable empirical results.

26 Hall, B.H., Mairesse, J., and Mohnen, P. (2009) *Measuring the Returns to R&D*, NBER Working Paper 15622.
27 Wellcome Trust and MRC (2008), *Medical Research: What's it Worth?*.
28 Marrano, M. and Haskel, J. (2006) *How Much Does the UK Invest in Intangible Assets?* Queen Mary, University of London, November; Marrano, M., Haskel, J. and Wallis, G.(2009), *What Happened to the Knowledge Economy? ICT, Intangible Investment, and Britain's Productivity Record Revisited*, Review of Income and Wealth, Vol. 55, issue 3, pages 686-716, September; Fukao, K., Hamagata, S. Miyagawa, T. and Tonogi, K. (2007) *Intangible Investment in Japan: Measurement and Contribution to economic growth,* RIETI, *Discussion Paper Series 07-E-034*.

The main conclusion suggested by such evidence is that innovation is central to growth. This leads to the question: how does innovation happen? The next chapter turns to the answers to this question. The principal argument will be that **it is necessary to think about innovation within an integrated system of growth components**. For example, following from the data presented in this chapter, investment in new technology embodied in physical capital may not augment productivity unless it is supplemented by complementary knowledge assets, by appropriate organisational change and by adaptations in the skill level of the workforce. Both modes of investment need to be financed, often in conditions of considerable uncertainty. Similarly, while competition may provide the incentive to innovate, certain types of innovation – such as those resting on large investments in software – might be infeasible without adequate access to appropriate infrastructure such as high speed data networks.

How Innovation Happens

To be effective, innovation policy must rest on recognition of the real characteristics of innovation in our economy. This chapter draws on recent research to focus on important dimensions of innovation. Our chief arguments are:

- Innovation takes many forms, which involve different patterns of investment. Some modes of innovation are science-based and rest on R&D, while others rest primarily on design or engineering skills, or the ability to absorb information from external sources. Some forms of innovation create entirely new goods and services, while others upgrade what already exists.
- Innovation is pervasive across the economy. It is not found only in high tech sectors, but in low tech manufacturing, business and consumer services, and in public sector and third-sector activities. Services industries have been central to recent innovation dynamics in advanced economies.
- Innovation in firms rests on a wider innovation environment. It is often a joint process involving both private and public institutions. The context of innovation is 'the innovation system': the ecology of knowledge creators, science providers, investors, regulators, problem solvers, and finance institutions that together shape innovation and manage its risks and uncertainties.
- Central to the innovation system are two forms of infrastructure. First, there is the 'knowledge infrastructure' of universities and research institutes. Second, there is what we term the 'innovation information infrastructure' consisting of such organisations as the Design Council, the National Physical Laboratory, the Intellectual Property Office, the British Standards Agency, and organisations providing geophysical information.

The UK innovation system has a very strong science base, relatively low R & D intensity across sectors but relatively high intangible investments, developed financial and venture capital markets, and high international integration. Compared with other economies, the UK is well placed but not amongst the global innovation leaders. A major trend also discussed in this Chapter is that innovation systems are increasingly connected internationally, through networks and value chains, which tends to accentuate the importance of innovation assets as sources of competitive advantages. Globalisation does not imply that national governments are powerless. Decisions on science facilities and performance, education, the regulatory framework, and above all knowledge and information infrastructures remain open to discretionary commitments by national governments. This is why, in the new global environment, advanced economies are reassessing policies to boost their innovation assets, and emerging economies are building the elements of advanced innovation systems at a fast pace.

Recent decades have seen a major expansion in studies of the characteristics of innovation and its effects. In this chapter we look at five aspects:

- Some core results from modern innovation economics are overviewed, the innovation systems approach is presented and the basic components of the system are introduced.
- Concepts of radical, incremental and user-led innovations are also explained. Their policy implications will be discussed in the following chapters.
- The UK innovation system, its characteristics and how it performs compared with the innovation systems of other leading economies, is analysed.
- Globalisation, and its impact on domestic innovation systems through increased competition and collaboration, is then discussed. The policy priorities developed by some major players since the downturn to strengthen their innovation potential are outlined.
- The policy rationale and framework corresponding to a system-wide approach of UK innovation is explored and developed.

Changing views of innovation

Innovation economics has been evolving from linear to interactive models. This is a dynamic field of research and some robust results that have emerged are important for policy design.

FROM LINEAR TO COMPLEX MODELS OF INNOVATION

Innovation means doing new things in new ways. Innovation transforms and improves the technical attributes and performance characteristics of products and processes; it changes organisational forms and business strategies, and through this introduces dynamic change and productivity growth into the economic system. In order to do something new, firms have to learn – if learning does not happen, then nothing new occurs. In studying innovation, therefore, most research has focused on the sources, nature and characteristics of knowledge and learning.

For a long time, the innovation models used in policymaking were built on the idea that innovative learning flowed from some earlier process of scientific or technological discovery.[29] The key element of these linear approaches was that technological change was seen as a sequence of stages (or 'cycles'), with new knowledge (usually founded in scientific research) leading to processes of invention, followed by engineering development resulting in innovation (or the commercial introduction of new products and processes). In this framework,

29 Such models describe approaches to policy, though not necessarily its practice: many post-war policy programmes were mission-oriented and focused on specific technology developments, which meant adapting science to the needs of innovation rather than allowing innovation to emerge from science. For a detailed account of technology-science links in one major arena of UK policy, see D. Edgerton, *Warfare State. Britain 1920-1970*, Cambridge 2005.

technology development and engineering were usually seen as forms of applied science.

This type of model has been rejected by more recent research on the grounds that it neglects a much wider set of links between research and innovation, and neglects elements of innovation beyond research. Innovation economics is by no means a settled field, but **research has evolved towards complex models of innovation where innovation is seen not as an individual process but as a joint one**, with firms drawing on multiple resources from across the economic system as they innovate.[30] Modern innovation studies recognise that innovation can come from new configurations of existing technologies and from service, social, organisational and strategic innovation. There is also a growing understanding of the importance of the demand side and user innovation. Recent research sees innovation as an interactive process in which:

- Firms make conjectures about market opportunities and integrate these with their design, development, financial and engineering capabilities (such as organisational, managerial and learning capabilities). In this framework, research is not necessarily the initiator of innovation, but is rather a problem-solving activity within a complex pattern of innovation-serving activities;
- Innovation is characterised by continuous feedbacks between the above activities, rather than by simple uni-directional transitions; so innovation is a process, not an act;
- Innovation is cumulative, a process over time, in the sense that it depends in part on past achievements and the experience derived from them, but also on the ability to modify and develop qualitatively on the basis of the past. Successful firms do not innovate once – rather they produce a flow of innovations over time.
- Innovation is characterised by complex interactions between enterprises and their external environments. Firms constantly need to solve problems, and they do this by reaching frequently outside the boundaries of the firm for skills, information and capabilities.

A major challenge is to think through the policy implications of this change of perspective.

INNOVATION RESEARCH OUTCOMES

The core results of research on innovation are robust in the sense that they are strongly confirmed by widely applicable data and empirical research across countries and industries. The latest evidence across these areas is discussed in detail in the Chapters that follow. In this section, we introduce important broad characteristics of innovation that need to be considered in policy design:

30 See Van der Ven, A. (1999) *The Innovation Journey*, Oxford, for a comprehensive example of this perspective.

- **Innovation relies on competition, but also on collaboration and interactive learning**, as Chapter 3 will show. Competition between firms is essential to create the incentives for firms to innovate. At the same time, formal or informal patterns of collaboration are frequently found across innovating firms. The reason for this is that innovation entails problem-solving, and this frequently involves problems that are outside the existing capabilities of the firm. So learning happens through an interactive process with other enterprises, organisations, and the scientific and technology infrastructure. Empirical research in a number of countries demonstrates that innovating enterprises are collaborating enterprises, that collaboration frequently persists over long periods, and that the publicly-supported infrastructure, such as universities and research institutes, are important collaboration partners.
- Chapter 3 will also suggest that **clusters are important, and reflect national and regional patterns of industrial and technological specialisation**. Firms located in the same geographic space both compete and collaborate. Geographic clustering is a prevalent feature of competitive advantage, a result that has emerged from a wide variety of studies. 'Horizontal' clusters – meaning groups of enterprises in the same line of business – are widely found, and seem to be associated with better economic performance of enterprises in the clusters. 'Vertical' clusters – in the form of value chains reflecting sustained relationships between enterprises in different activities – can be identified using input-output techniques, and reflect country specialisations that often differ widely. There is evidence that cross-border clusters may be becoming more important. These patterns of specialisation are cumulative, built up over long periods, and appear to be hard to change.
- **There is strong science-technology interaction in innovation**, a point that will be developed in Chapter 4. The research and science system is important for innovation, and there is a strong interaction between innovators and the science system. Many inventions draw on science. For example, analysis of patents show that there have been big increases in citations from patents to scientific research, and that a very high proportion of the papers cited are produced within public sector scientific research organisations. Other studies have shown strong but indirect interactions, through which industries both affect the process of scientific research and use its results. Many traditional industries, from this perspective, draw intensively on scientific results in industry-level knowledge bases. Although science does not provide the raw material for innovation in any simple way, it is a major element of industry and public sector knowledge bases across the economy and central to problem-solving across many forms of innovation.

- Chapter 5 will examine how **innovation outcomes rest on complex investment patterns that transform the capabilities of enterprises.** It is sometimes argued that competition forces firms into similar patterns of operation. Innovation, however, rests on difference: competitive firms need quite specific and separated areas of competence and capability that must be constructed. This, in turn, requires investment in assets, including a wide range of skills and knowledge that make up the intellectual capital of an enterprise. Some of the intangible investment patterns that result from this have been shown in Chapter 1. But the processes through which this investment happens are complex and difficult for corporate managers. They face a constant tension between the demands of current production and the need to create assets for the future. Innovation outcomes are rarely predictable (even where innovation is incremental) and while processes can be managed, final results and impacts are often very uncertain. Because innovation inputs can be combined in very different ways, there is no general path towards innovative success, and the result is considerable diversity and variety in approaches to innovation.
- **Innovation is pervasive across industries.** This is an important fact that will be presented in Chapter 5. Innovation is not something that happens only in a relatively small group of high-technology industries, nor is it something that is driven by a small set of technologies. Innovation data, deriving from innovation surveys, show clearly that innovation in the sense of development and sales of new products is distributed right across the system in all advanced countries. Industries that are regarded as mature or 'low-tech' often generate substantial amounts of sales from technologically new products and processes. Likewise, the service sector is also strongly innovative, across almost all of its component activities. This is particularly important since the service sector is the largest sector in all advanced economies. This suggests that we cannot resolve innovation policy problems by focusing only on high tech industries.
- **Innovation processes are themselves changing.** Innovation processes are dynamic, and change their characteristics over time as well as across activities. For example, digitalisation permits new forms of visualisation, simulation and experiment, just as modularity permits new forms of innovation collaboration, and as new materials change the ways in which products can be designed and so constructed.[31]

31 Dodgson M, Gann DM, Salter A (2007), 'The impact of modelling and simulation technology on engineering problem solving', *Technology Analysis and Strategy*, Vol:19:471-48; Dodgson M, Gann D, Salter A (2006), 'The role of technology in the shift towards open innovation: the case of Procter & Gamble', *R&D Management*, Vol: 36: 333-346.

- Chapter 5 will also discuss the implications of the fact that **innovation is highly uncertain**. Innovation involves serious risks and uncertainty, both in technological and in economic terms. It has very rarely been possible to predict the path of innovation, even in general terms. It is rarely possible to predict the economic outcomes for new products and processes. Enterprises very often make major forecasting mistakes, even when they are very well informed, and managed by highly competent and knowledgeable people. One reason for this is that it is very difficult to predict the ways in which society will in fact use new technologies. This leads to major problems for enterprises in making investment decisions involving innovation activity, and so a major problem for innovation performance is to understand how the economy creates mechanisms for allocating, reducing and sharing risks.
- **The public sector is part of the innovation system itself.** This central aspect of innovation will be discussed in Chapter 6. The public sector influences innovation rates and directions by shaping the innovation environment, by being a major source of demand and by producing innovations related to its own activities. Government agencies, across many countries, have been closely involved in the innovation of many modern technologies. Importantly, the public sector seeks to address societal long term demand that are systemic in character – such as climate change, food and energy security and the ageing society. The initial drive to boost innovation potential in these areas will almost certainly involve the continued role of governments.

Basic components of the innovation system

One of the most persistent themes in modern innovation studies is the idea that **innovation of all kinds is systemic**. That is, enterprise-level innovation is more than a matter of independent decision-making at the level of the business firm. There are multiple external institutional, organisational and infrastructure factors shaping the behaviour of enterprises. Taken together these factors make up a system, and system conditions can have a serious impact on the extent to which enterprises can make innovation decisions, and on the modes of innovation which are undertaken.[32] Innovation occurs within the corporate sector and in public sector organisations. Both are affected by a wider system where institutional structures, administrative and regulatory frameworks, educational and scientific capabilities, and physical and knowledge infrastructures all interact to shape the innovation environment. These elements of the innovation system are specific to local and national contexts. Here we turn to the basic elements that constitute this innovation environment.

32 Systems approaches are elaborated in: Nelson, R. R. (1992), *National Systems of Innovation*, Oxford: OUP; Nelson, R. R. (1992), 'National innovation Systems: A Retrospective on a Study', *Industrial and Corporate Change*, Vol.1, issue 2, pages 347-374; Lundvall, B.-Å. (ed.) (1992), *National Innovation Systems: Towards a Theory of Innovation and Interactive Learning*, London, Pinter Publishers; Edquist, C. (1997), *Systems of Innovation: Technologies, institutions and organizations*, London,Pinter; Shapira, P., Smits, R., and Kuhlmann, S. (eds) (2010), *The Theory and Practice of Innovation Policy: An International Research Handbook* (Cheltenham: Edward Elgar); F. Gault (2010), *Innovation Strategies for a Global Economy* (Cheltenham: Edward Elgar).

INSTITUTIONAL STRUCTURES

Economic behaviour rests on institutional foundations, in the sense of legally or customarily established 'rules of the game' which evolve because of the advantages they offer in reducing uncertainty. Different modes of institutional set-up lead to differences in economic behaviour and outcomes.

One example of an innovation-relevant institution might be corporate governance. Corporate governance is largely to do with management accountability when ownership and control are separated. But this can have important effects on the ways business corporations allocate resources, and this is, of course, central to innovation. We have seen in Chapter 1 that innovation requires investment, and such investment must be made by managers. Governance systems can promote or limit the strategic types of investments managements make (and how returns are to be distributed as wages, profits or retained earnings). Around the world, many different national systems of corporate governance prevail, although both regional economic integration and globalisation are creating pressures toward convergence.

The relation between corporate governance and economic performance is therefore one of the ways in which institutional structures affect system performance. But other relevant institutional areas include the operation of labour-management relations, cultures of entrepreneurship, and frameworks of corporate law (including the market for corporate control), all of which can have innovation implications.

ADMINISTRATIVE AND REGULATORY FRAMEWORKS

Public policy systems affect innovation outcomes, but there are important cross-country differences in organisational structures and policy cultures. The differences include the specific arrangements and powers of ministries and agencies responsible for innovation. However, there are strong national differences in such areas as accounting standards, and regulatory frameworks affecting labour markets, health and safety, or environmental change.

EDUCATION AND R & D CAPABILITIES

Human resources are an important element of innovation systems, a point which will be discussed in more detail below. There has been a substantial rise in the highly qualified labour force in OECD countries, formal skills are increasingly important, and there is significant mobility of highly skilled labour.[33] This has directed attention to schooling and university systems as components of the innovation system. Universities can differ sharply both within and between countries in terms of financing, scientific research organisation, governance, teaching priorities and capabilities, and so on. Recognizing the importance of

33 OECD (2008), *The Global Competition for Talent: Mobility of the Highly Skilled*, Paris: OECD.

education in innovation therefore involves complex decisions about the nature and organisation of education systems.

PHYSICAL AND KNOWLEDGE INFRASTRUCTURES

There are two broad roles for infrastructures in shaping technological change in innovation systems. Innovation may require significant physical infrastructures. Information and communications technologies, for example, rely on extremely substantial infrastructure investments – for example in electricity distribution networks and broadband networks.

On the other hand, many important technological innovations have close links with the knowledge infrastructure of universities and research organisations. Product and process improvements or breakthroughs, and their subsequent dissemination, are enabled by infrastructure such as standards and standardisation bodies, and by measurement science and its embodiment in scientific and production facilities. These infrastructures are central to public policies for innovation.

Modes of innovation

There are some important distinctions to make between modes of innovation and especially between radical and incremental innovations. Although the concept of user-led innovation is not new, both technical and cultural changes have intensified this form of participation to the innovation process.

RADICAL AND INCREMENTAL INNOVATION

At a general level, a technology can be understood as a combination of technical artefacts, theoretical and practical knowledge, and organisation. Together they use energy and materials to transform the material world. Most technologies are complex. They are often thought of as 'paradigms' or 'regimes' which integrate knowledge bases (often of very differentiated kinds), with disparate engineering practices, production organisations and management methods (often of very different forms), combined with marketing or distribution methods, and with social patterns of consumption and use.

Innovation is change in one or more of the elements that make up a technology, involving some form of learning that modifies (for better or worse) the performance characteristics of a technology.[34] It involves learning because it is new (if there was no novelty then we wouldn't need to learn). It is possible then to think about innovation as having many different degrees of change. It is common, for example, to think of innovation as either radical or incremental. The transition from horse-drawn transport to the internal combustion engine

34 From this point of view, it makes little sense to distinguish between technological and non-technological innovation: organisation, for example, is part of every technology, not separate from it.

was a radical shift, involving completely new forms of knowledge, production systems, urban planning and social use. Such transitions are often very slow (as late as the Second World War, armies continued to use large quantities of horse and mule transport). But they change the technological paradigm or regime more or less completely. In contrast, an improvement in the fuel efficiency of a car engine is an incremental shift, inside a well-established regime.

The distinction between radical and incremental innovation is an important one for policy. Incremental change occurs within technologies that are usually well-known, and in which the development path may be reasonably clear. Radical change is disruptive, unpredictable, and uncertain. The two forms of innovation can be closely linked: radical innovations often don't work very well, and need long periods of incremental improvement before they can have a significant impact. But this distinction, though a very broad one, points to the need for policymakers to be clear about the types of innovation that are being targeted.

USER-LED INNOVATION

Many important and lucrative new ideas today do not come from formal research and development. Today's innovations owe much to the ingenuity of consumers – this process can be called 'user-led innovation'.

The evidence base on user led innovation is relatively new.[35] However, it points to the fact that **the current degree of user involvement in production is probably unprecedented and redefines the boundaries between producers and consumers.** The sources of these changes are partly technical. While user-led innovation is not a new phenomenon, technology makes it easier than ever for users to modify and develop ideas, both as individuals and collectively. But institutional and cultural factors also come into play such as increased appetite for revealing and sharing information and on-line communities.

User innovation has important implications for how firms do business. For firms engaging in innovation, the role of consumers in the process used to be primarily 'consultative' and associated with the involvement of 'lead users' at the time of new product development. More recently firms are experimenting a 'tool-kit' approach where producers directly outsource innovation tasks to user themselves, with significant reduction of the costs of gathering information on consumer preferences. However, the reliance upon user feedback can also lead to missing new opportunities as existing consumers are not always able to see how a new underlying technology will be useful to them.

The applicability of user-led innovation varies across industries and products. This kind of innovation tends to emerge out of not only technology-specific environment but also culturally-specific context of industries. Industries and products that have a following, a group of hobbyists previously organised or

35 Aoyama, Y. and Izuhi, H. (2008), *User-led Innovation and the Video Game industry*, paper submitted to the IRP Conference, London, May 22-23.

disorganised, are the most likely sources of active user-led innovation. For example, the video game industry is particularly suitable for user-involvement in production processes, as demonstrated by the development of Nintendo Wii. This in turns leads to a strong possibility that user-innovation in its application is constrained in those industries that do not have such a cultural base among users.

Identifying the scale and importance of user innovation was a part of the NESTA's Innovation Index:[36]

- An estimated 6.2% of the UK adult population have undertaken some type of user innovation.
- The innovation categories reported show higher levels of innovation that appear to map well upon major categories of leisure time activities reported by UK consumers such as sports, DIY, use of the Internet, and arts and crafts which are all among the top 10 leisure activities in the UK.
- Additional interesting patterns found are, first, that 34% of the innovations reported by consumers can be regarded as process innovations – tools for crafts, home workshop, and gardening. Second, the great majority of the innovations made involved physical products. Only 14% (7% creations and 7% modifications) involved software.
- Analysis of the results identified five personal characteristics that significantly improve the odds of consumer innovation: having a university degree, being technically educated, being male, and being a student or aged over 55 and not working all made innovation significantly more likely.
- With respect to innovation protection, only 2% of the consumer innovators surveyed formally protected their intellectual property rights. The low level of compensation for innovation sharing – only 4% reporting any type of compensation – seems consistent with the low level of formal IP protection.

The public sector is a major, and sometimes lead, consumer in a number of areas: health and pharmaceuticals, energy and environment, construction, transport and logistics, and security. In principle therefore the potential for using public demand as a participant in the development of innovative products and services is considerable. However, the public sector is a complex customer and there are big challenges in using public demand as an engine for innovation. These issues will be discussed in Chapter 6.

The UK innovation system

Since innovation is systemic, differences in industrial activities and technological capabilities persist between national economies, even between economies that

36 The Index project had two elements: firstly, a business survey that followed the same approach as other international studies and secondly a consumer survey and this is the first time consumers have been surveyed on such a scale. A second wave of fieldwork in 2010 has increased the sample to 1,173.

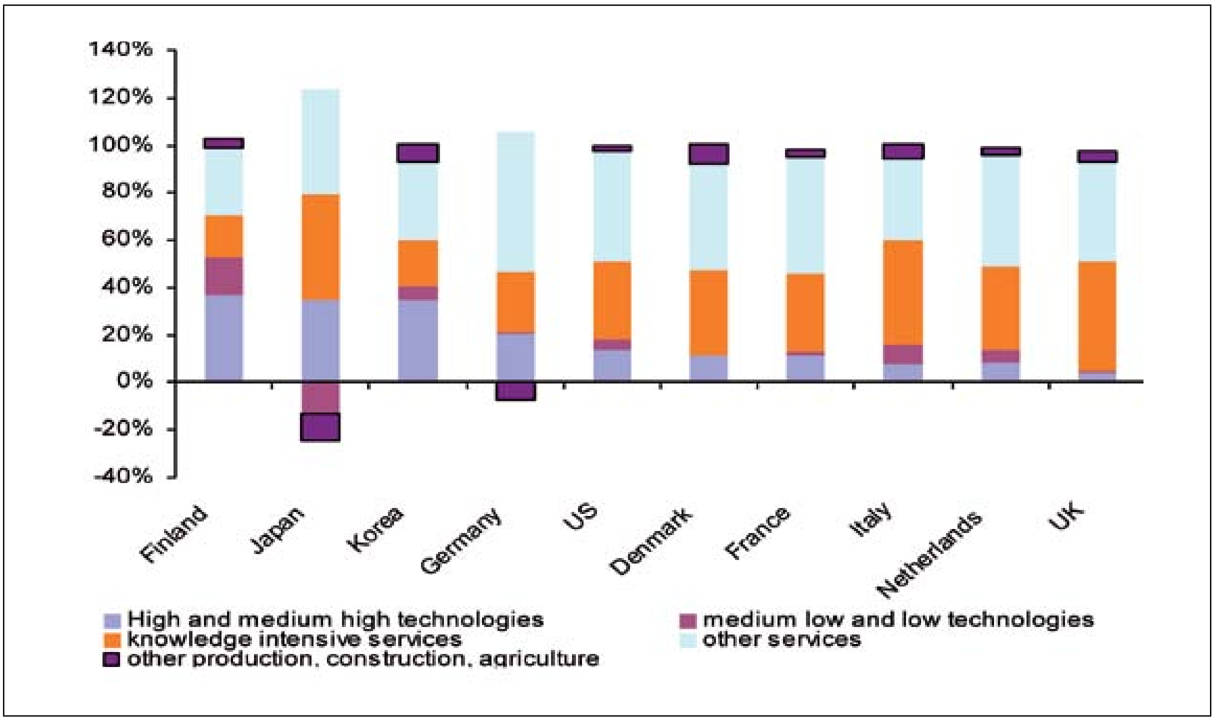
have similar income and development levels. **Despite international economic integration, national differences remain important.**

SALIENT UK FEATURES

The UK industrial structure is underpinned by an innovation system with some well defined characteristics.

Between 1992 and 2007, the UK experienced a period of almost continuous growth, with the volume of output increasing by around 55% over this period. This growth was characterised by changes in the industrial structure. Compared with other advanced economies, the UK has become increasingly dominated by the services sector, with the smallest contribution to overall volume from high and medium high technology manufacturing in the OECD, as seen in Figure 6.

Figure 6: Percentage contribution to growth in total economic output (GVA volumes) 1992-2007

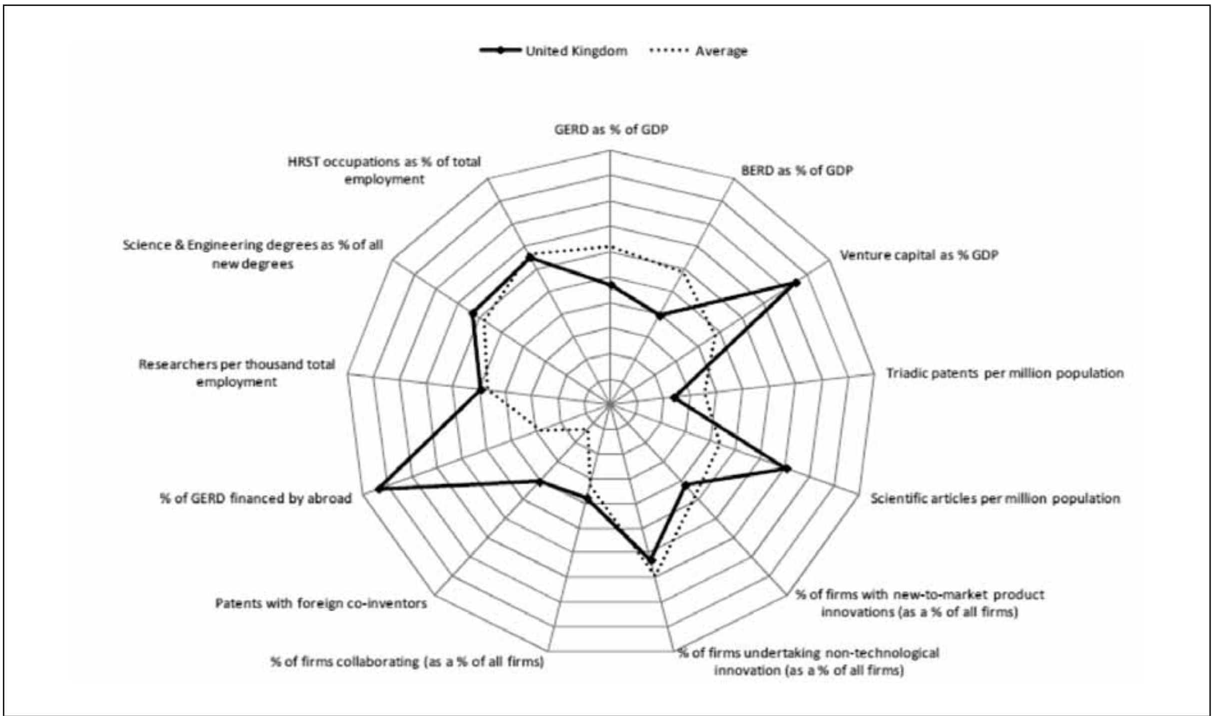


Source: BIS calculations based on OECD STAN database data (2011)

The largest increase in output volumes came in the knowledge intensive services sectors (communication, finance and business services – excluding real estate). This part of the service economy contributed more to growth in the UK than in comparable economies, except Italy. The high technology manufacturing sectors achieved the next highest growth in output. However, medium low and low technology manufacturing activities barely increased output volumes at all over this period.

This growth of the services sector partly explains the salient features of the UK innovation system, which are summarised in Figure 7.

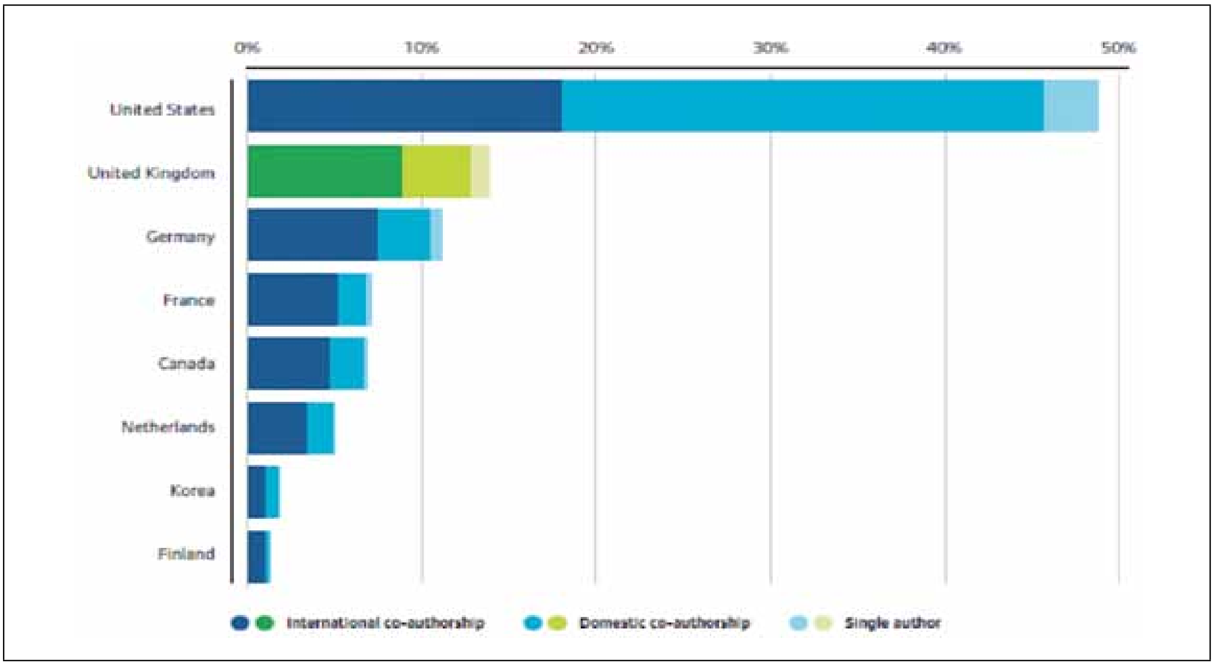
Figure 7: Key features of UK innovation system (UK-OECD average)



Source: OECD (2010) Business Innovation Policies: Selected Country Comparisons, Paris: OECD.

- **A strong science base** – The UK has a strong reputation for world-class research, second only to the US in terms of output of widely cited research. The UK produces 8% of the world's scientific papers, but of the most widely cited scientific papers, UK authors account for 14%, as shown in Figure 8. The majority of these papers, 9%, are co-authored with international researchers – the highest percentage outside the US.

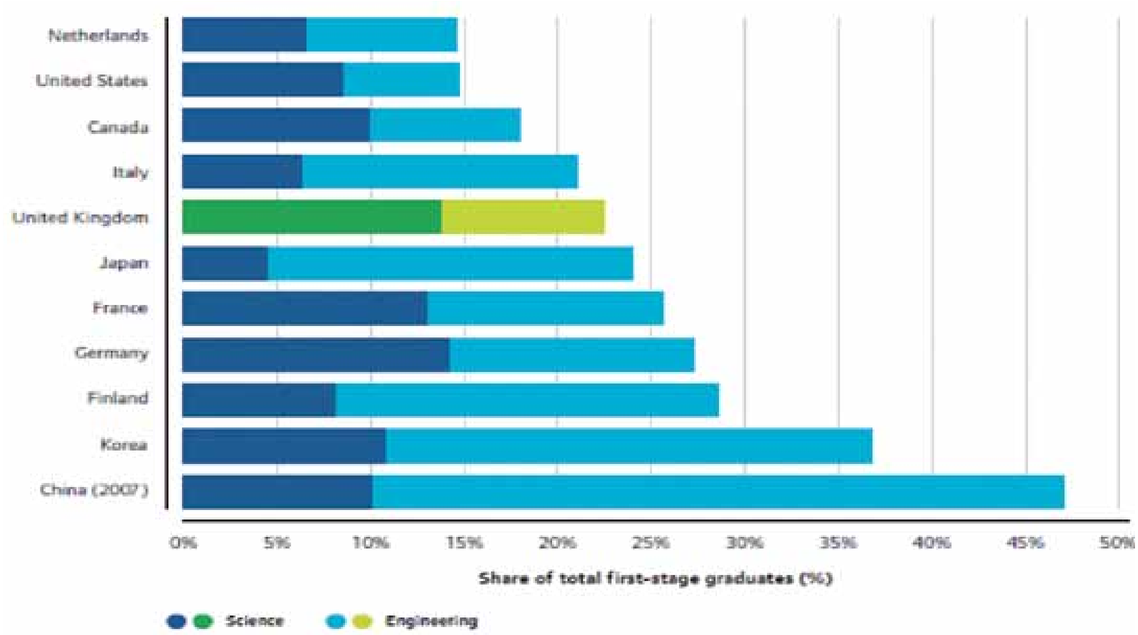
Figure 8: Authorship of most cited 1% of published scientific articles, 2006-2008



Source: OECD STI Scoreboard (2010)

The UK also produces a significant number of science and engineering graduates, both at first degree and doctoral levels and is second only to the US in numbers of international doctoral students. The share of researchers in the workforce is above the OECD average, at over 8%. However, the UK graduate rate for science and engineering at 22.5% of total graduates in 2007 is low in comparison to some countries (see Figure 9) and the share of the workforce in science and technology-related occupations is below the OECD average, with a rather slow annual growth rate for this group over the last decade. This probably reflects the evolving structure of the UK economy as services became more dominant.

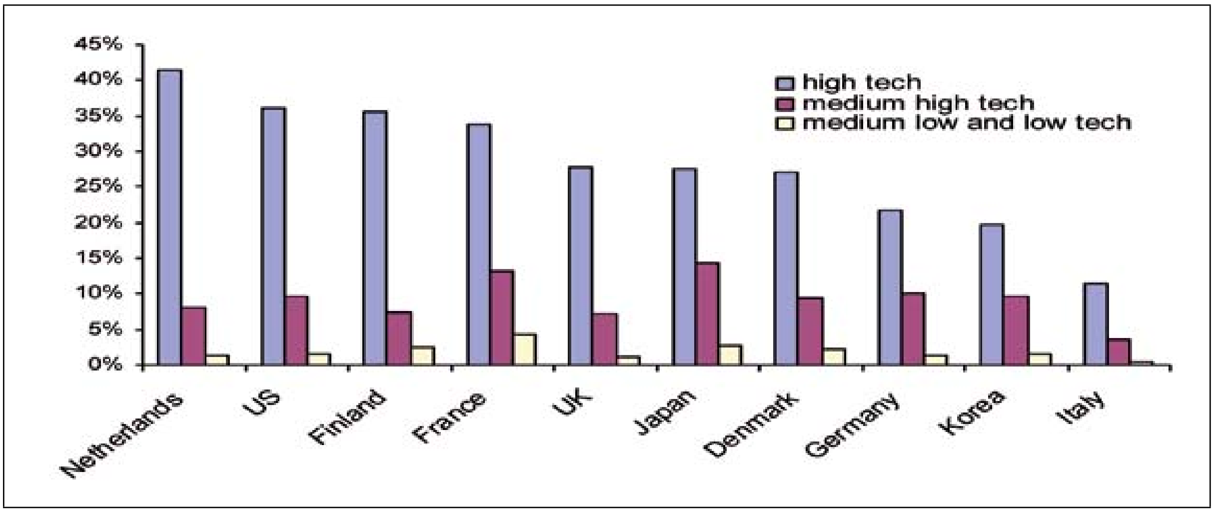
Figure 9: % of total first-stage graduates with science and engineering degrees



Source: OECD (2006)

- Lower R & D intensity – Business expenditure in R & D is lower than the OECD average at about 1.6% of GDP overall. But this must be interpreted carefully, because the real difference between the UK and other major countries lies not in the level of R&D but in its industrial structure. Figure 10 shows that the UK performs well in high tech industries (such as pharma, aerospace and ICT). The UK's R&D intensity in these industries is below France and the US, but higher than Japan, Germany and Korea. It is in the large medium and low tech industries, such as vehicles, metal products or food processing, that the UK is weak – significantly below Germany, Japan and Korea, as seen in Figure 10. In other words, a distinctive feature of the UK innovation system appears to be strong performance in a small group of high tech industries, but relatively weak innovation performance across the large medium and low tech sectors.

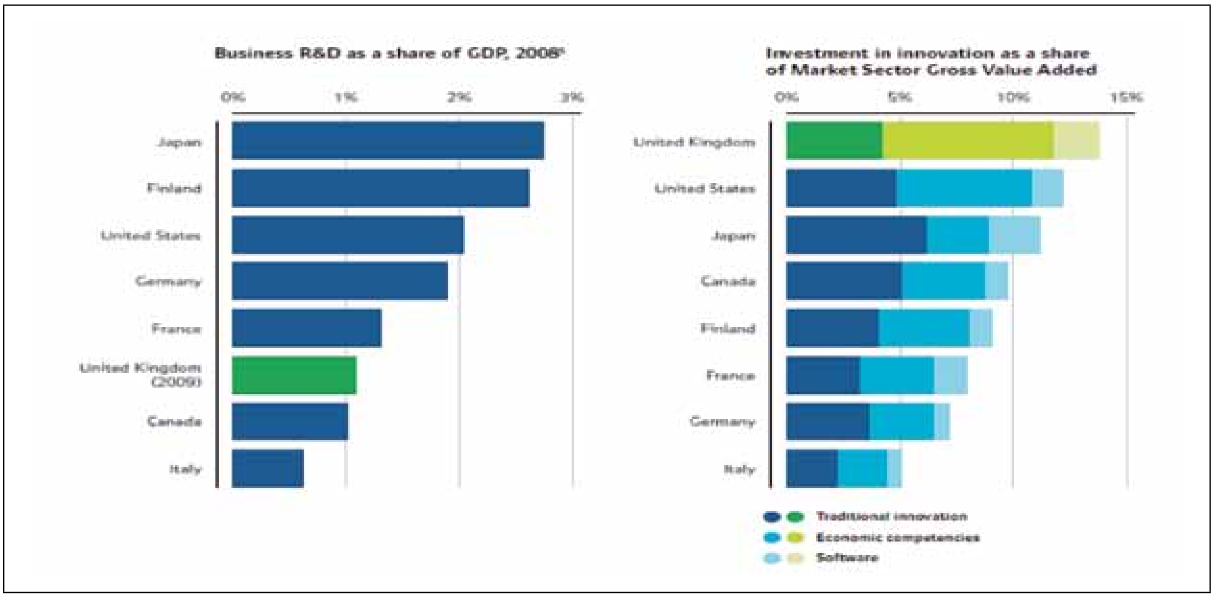
Figure 10: R & D expenditure in businesses as % of GVA, annual average (2003-2006)



Source: BIS calculations based on OECD data (2011)

- **High intangible investments** – Although UK investment in traditional innovation inputs such as R & D are lower than average, investment in the development of software and databases, and economic competencies such as training and skills, organisational improvement, market research or branding is strong, and higher than average. Figure 11 illustrates this point, although it should be noted that this type of investments is less consistently measured across countries and therefore international comparisons should be interpreted with caution. The importance of intangible investments can be partly explained by the predominance of the services sectors in the UK economy.

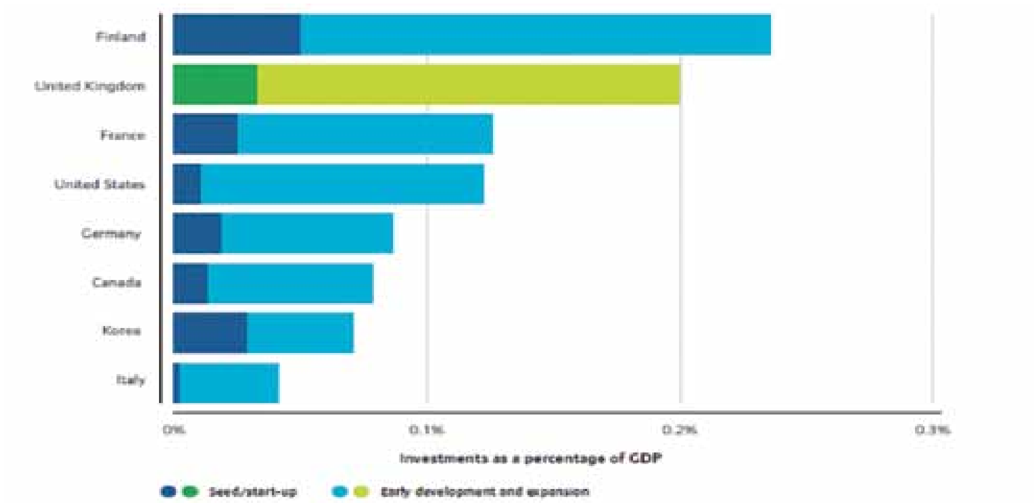
Figure 11: International comparisons by type of investment



Source: OECD, MSTI May 2010 *Source: NESTA's Innovaton Index 2010*

- **Developed venture capital markets** – It should also be noted that the UK saw large venture capital investments in 2008 (0.2% of GDP as shown in Figure 12, although this market is directed towards European as well as UK businesses. However, it is important to emphasise that this was before the full impact of the financial crisis and its impact on credit and seed capital availability.

Figure 12: Venture capital investment by stage of financing as % of GDP



Source: OECD STI Scoreboard (2010)

- **High international integration** – The UK innovation system ranks first among OECD countries in terms of the share of business enterprise expenditure on R&D funded from abroad (23% in 2008) and registers a high share of patent applications having co-inventors located abroad (about one in four).

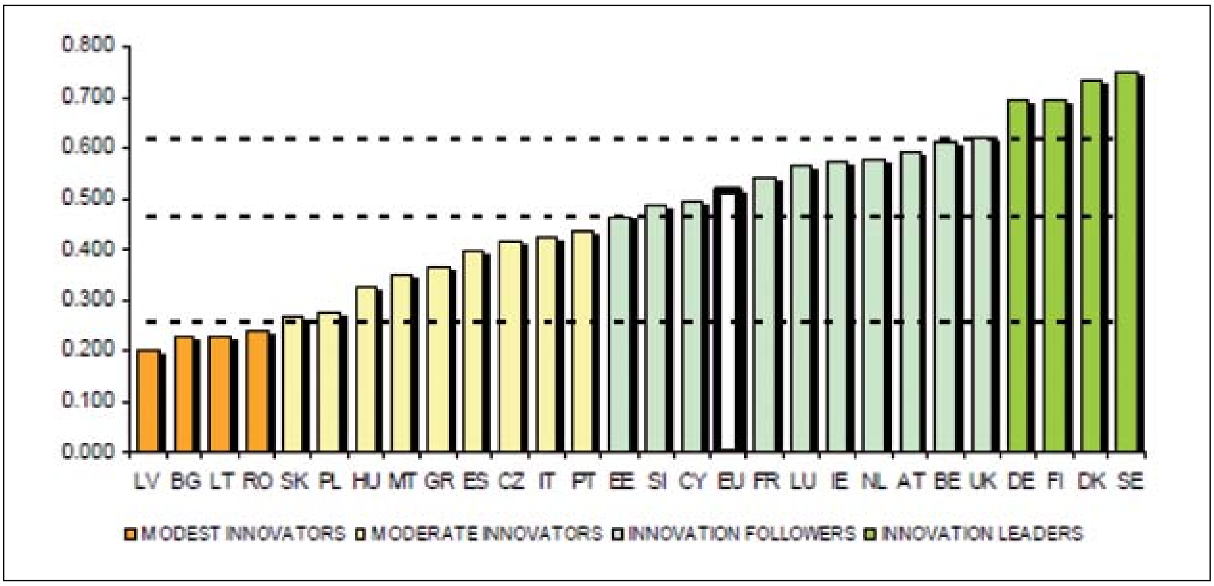
THE GLOBAL INNOVATION LANDSCAPE

Although the UK is well placed compared with other economies, it is not amongst the global innovation leaders. The European Innovation Scoreboard 2010 for instance ranks the UK as an 'innovation follower', with overall innovation performance appreciably below that of the top four innovation leaders Sweden, Denmark, Finland and Germany. [37] Overall rankings can be seen in Figure 13[38].

37 The Scoreboard covers the 27 EU Member States and draws on 25 research and innovation-related indicators, grouped into three main categories: "enablers", i.e. the basic building blocks which allow innovation to take place (human resources, finance and support, open, excellent and attractive research systems); "firm activities" which show how innovative Europe's firms are (firm investments, linkages & entrepreneurship, intellectual assets); and "outputs" which show how this translates into benefits for the economy as a whole (innovators, economic effects).

38 This finding is supported by an OECD composite innovation indicator which confirms the finding that Sweden, Finland and Denmark outperform the UK, as do the USA and Canada (Japan and Germany notably under-perform the UK in this indicator). See *Globalisation and the European Union* (2007) Paris: OECD.

Figure 13: Comparison of innovation performance (EU 27 countries)



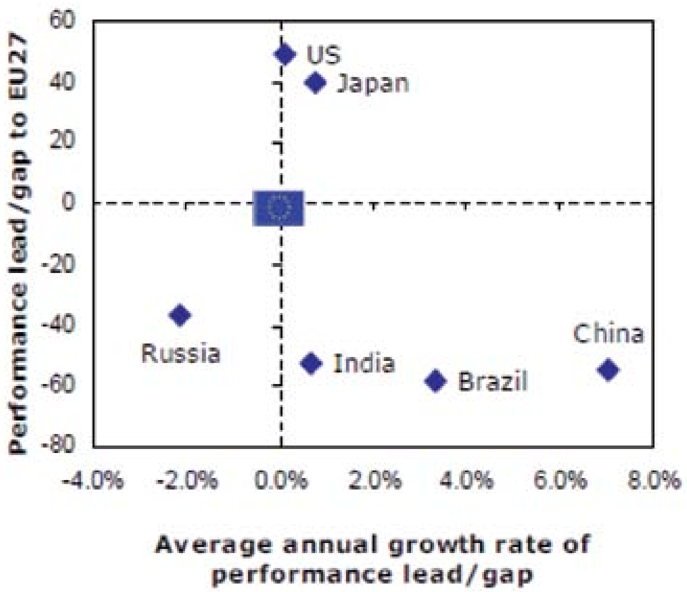
Source: EU Innovation Scoreboard (2010)

We need to be careful in using such data, because in scoreboards of this kind much depends on the weighting of the factors that contribute to the overall score. Nevertheless, the EU Innovation Scoreboard suggests that the UK is among the top of the second tier of European innovators.

Germany, the Scandinavian countries and also Switzerland are widely recognised to be the European innovation leaders. It is interesting to note that, although scale effects play a role in innovation performance, small countries can be highly innovative. In the global economy, the US and Japan are usually regarded as the world's most innovative economies. More information of the innovation system of these global innovation leaders is presented in the Appendix.

Figure 14 indicates that the US and Japan are extending their lead over EU countries, while Brazil and in particular China are closing the gap.

Figure 14: Comparison of innovation performance beyond the EU



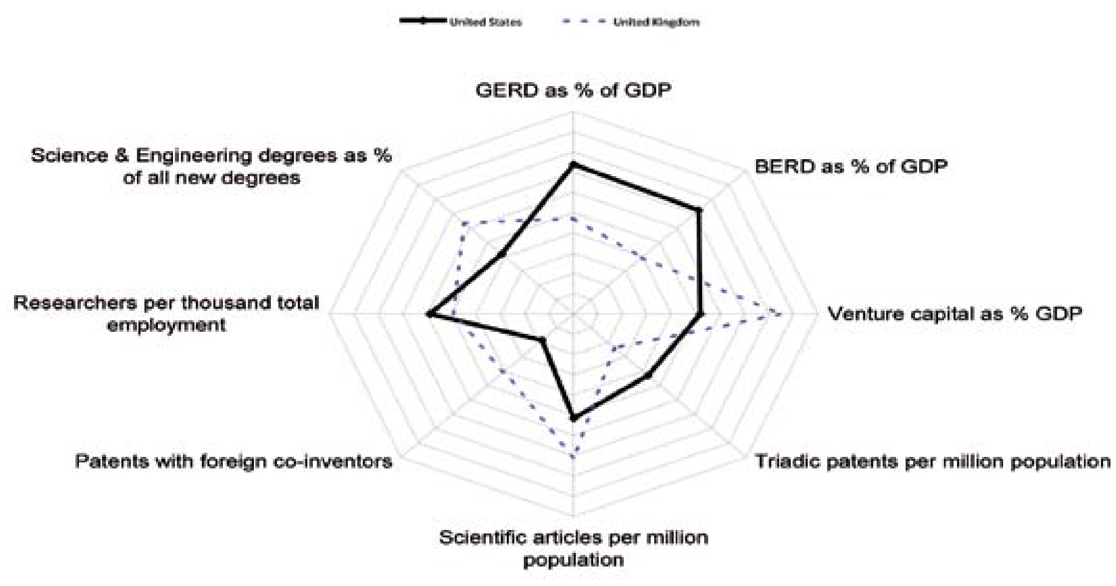
Source: EU Innovation Scoreboard (2010)

COMPARISONS WITH LEADING INNOVATION SYSTEMS

Closer comparisons between the UK innovation system and the systems of some innovation leaders allow a better understanding of the UK performance.

Figure 15 shows that relative strengths of the US include Gross and Business Expenditure on R&D as a proportion of GDP, exceeding that of the UK quite substantially.

Figure 15: US and UK innovation systems

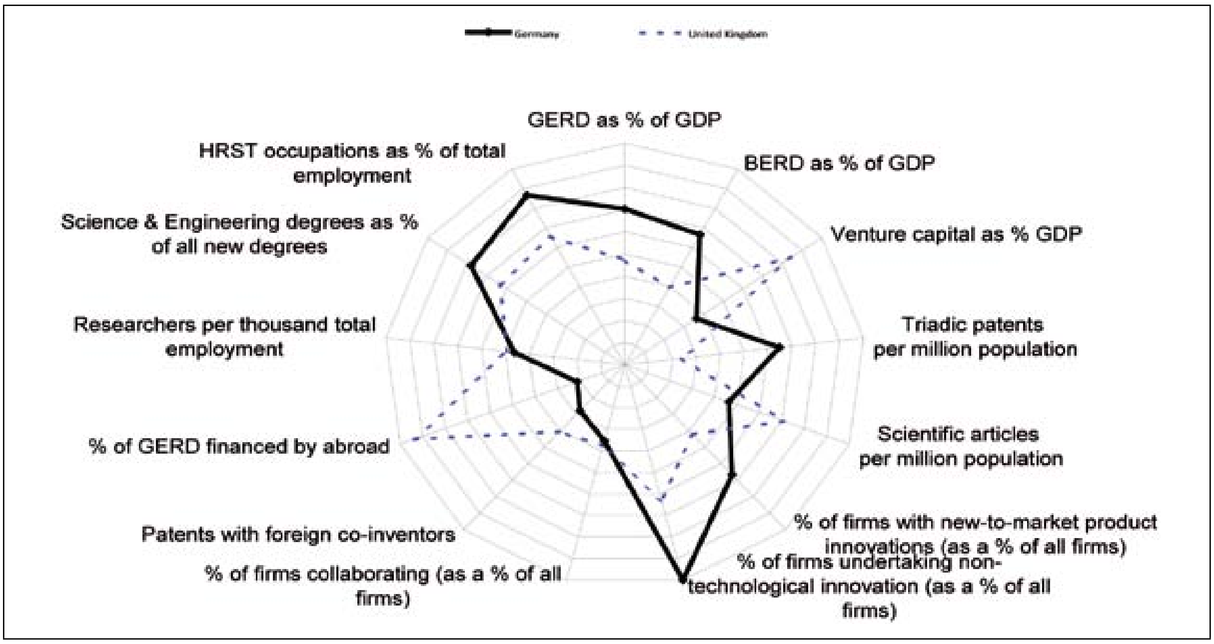


Source: OECD (2010), Business Innovation Policies: Selected Country Comparisons, Paris: OECD.

Another key strength of the US compared with the UK is triadic patents per million of population.[39] The US triadic patent families per million is roughly twice of that of the UK (itself less than half of that of Switzerland).[40] However, the US has a scale advantage, with total R&D expenditure approximately ten times that of the UK, BERD almost twelve times, a number of researchers at least five times, triadic patents almost nine times, and patent applications over seven times.[41]

The German innovation system tends to reflect the industrial composition of the German economy, as illustrated in Figure 16. Germany outperforms the UK on a number of indicators, including in Gross and Business expenditure on R&D as a proportion of GDP, triadic patents per million population, new-to-market product innovations as a percentage of all firms (19%), and proportions of Human Resources Science and Technology occupations and science and engineering degrees.

Figure 16: German and UK innovation systems



Source: OECD (2010), Business Innovation Policies: Selected Country Comparisons, Paris: OECD.

The UK outperforms Germany on the proportion of GERD financed by abroad, patents with foreign co-inventors, scientific articles and venture capital. The UK marginally outperforms Germany on firm collaboration, and researchers.[42] German strengths such as R&D expenditures can be traced to the more industrial orientation of the German economy compared to the more services-oriented UK economy, while UK strengths relate to the internationalisation of the

39 A Triadic patent is a patent for an invention filed at the European Patent Office and the Japan Patent Office and granted at the US Patent and Trademark Office

40 OECD (2010), *Science, Technology and Industry Outlook*, Paris: OECD

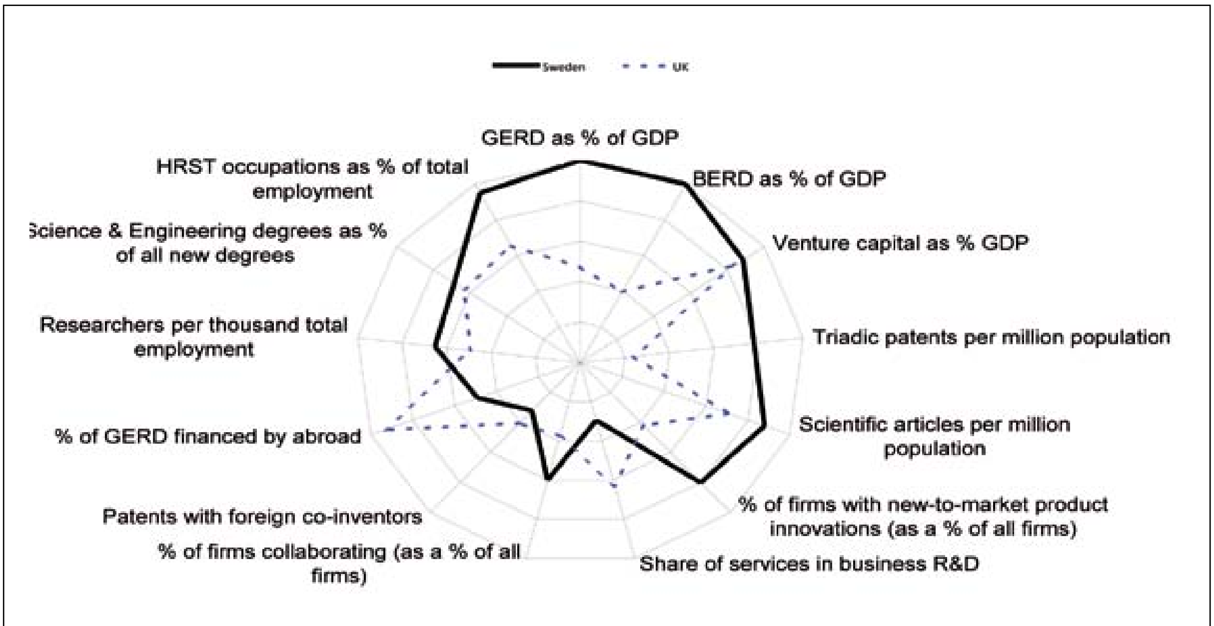
41 OECD statistics: http://stats.oecd.org/BrandedView.aspx?oecd_bv_id=strd-data-en&doi=data-00182-en

42 While the proportion of German researchers in employment is comparable to that of the UK, it should be noted that the new German Excellence Initiative (disbursing €1.9b over five years), which seeks to promote cutting-edge research at German universities, has been extended until 2017, with a 30% increase in funding volume, potentially enabling Germany to eventually overtake the UK in this dimension.

innovation system. However, it is important to point out that firms undertaking non-technical innovation as a percentage of all firms is exceptionally high in Germany (69%). Germany built much of its economic growth over past decades through maintaining high-value added engineering and heavy industries. Almost 80% of R&D is channelled into automotive, electrical engineering, chemicals and machine tool industries. It is the integration of high-tech and intangible assets into low and medium-tech products that forms the basis of German innovation. The influential Mittelstand – family-owned innovative SMEs – lies behind Germany's leading position in the export markets, from machine tools to laser systems.

Sweden outperforms the UK on most innovation dimensions, as shown in Figure 17. The Swedish economy has a strong international orientation and this is reflected in its innovation system. The high performance of Sweden is also linked to the interplay between large multinational companies, industrial policy, university research, dynamic public sector organisations and the bank system.

Figure 17: Swedish and UK innovation systems



Source: OECD (2010), Business Innovation Policies: Selected Country Comparisons, Paris: OECD.

Sweden's science and innovation profile is one of the strongest in the OECD area, particularly strong in relation to Gross and Business Expenditures on R&D, venture capital, triadic patents, scientific articles, new-to-market product innovations, firm collaboration and Human Resource Science and Technology occupations. Sweden outperforms the UK on most dimensions – even including UK strengths in the venture capital and scientific articles dimensions. The case of Sweden illustrates that the UK is a step behind world-leading innovators.

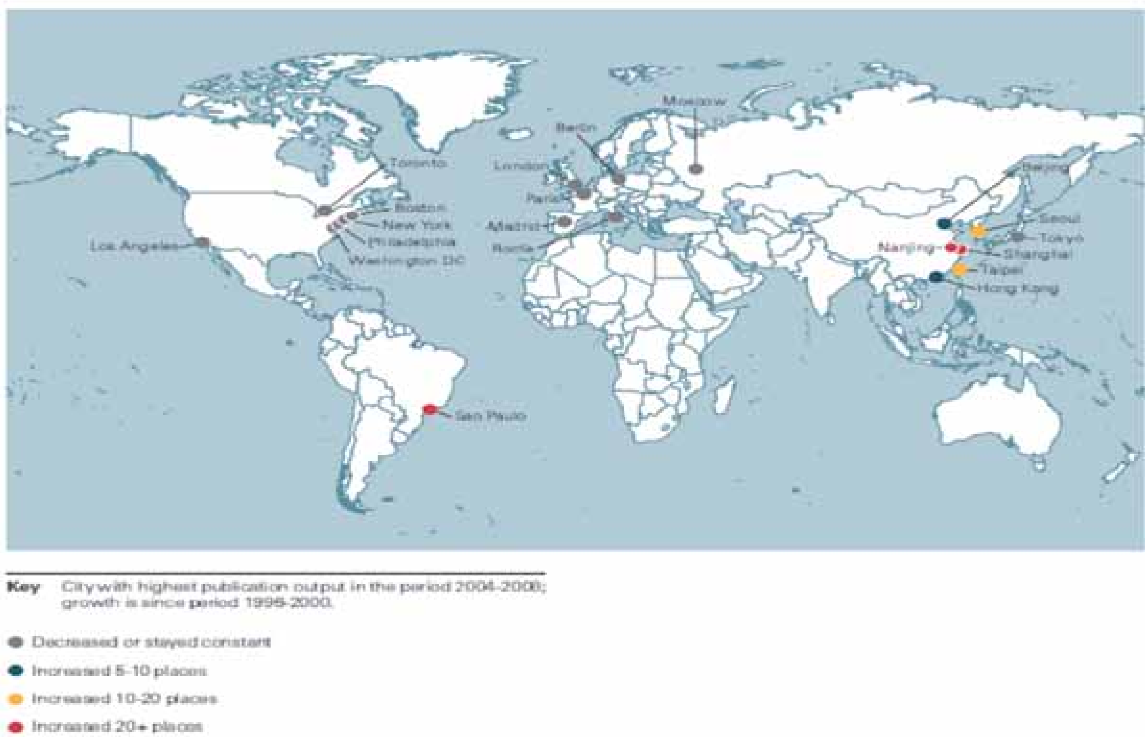
Global competition and collaboration

In the new post-crisis environment **it is important to better understand the impact of global trends towards increased competition and collaboration.** Globalisation has been leading to increased competition between universities and research centres, and fragmentation of production processes across the world.

THE EMERGENCE OF NEW SCIENTIFIC HUBS

The global landscape for science and innovation is being recast as an increasingly multi-polar scientific world. This process is driven by the creation of new hubs, through the rapid development in scientific research in developing countries, particularly China, and new emergent scientific nations in the Middle East, South-East Asia and North Africa, as well as a strengthening of the smaller European nations[43]. Figure 18 illustrates that new hubs have been created over the period 1996-2008 in China, Brazil and South Korea, increasing scientific competition between universities and research centres across the world.

Figure 18: Top 20 publishing cities 2004-2008, and their growth (1996-2000)



Source: Royal Society (2011), Knowledge Networks and Nations, London: Royal Society.

CAPTURING VALUE IN GLOBAL CHAINS

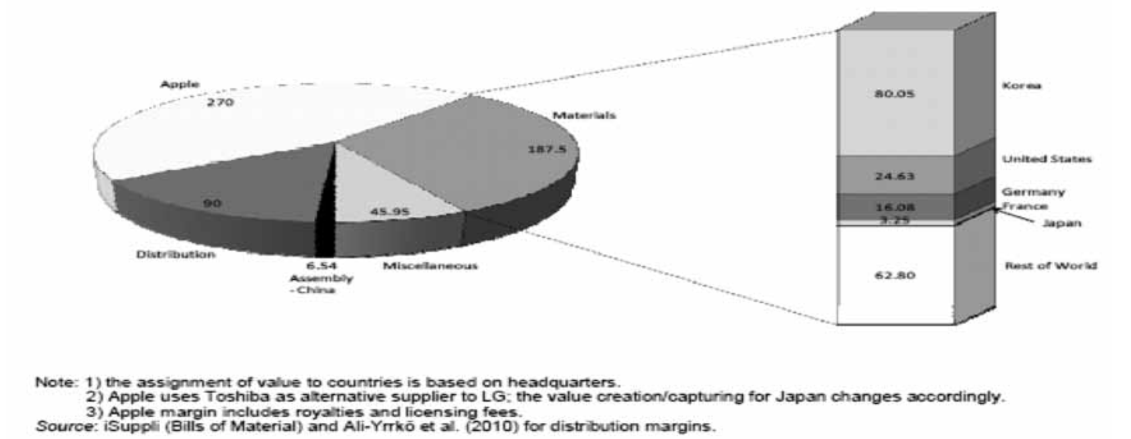
Globalisation is also associated with the emergence of increasingly globalised value chains and greater geographical fragmentation of production processes.

43 Royal Society (2011), *Knowledge Networks and Nations*, London: Royal Society.

The globalisation process has tended to accentuate the strategic importance of intangible assets, not only as a source of value creation, but also for effectively capturing the value from innovation.[44]

A concrete and well-known illustration of this trend is the case study of the Apple iPhone4 undertaken under the auspices of OECD. It shows that only a tiny portion of the value is created and captured by assembly of parts and components, and that even production of parts and components captures only a little more than a quarter of the value (see Figure 19). Apple captures the lion's share of the value, covering labour costs, depreciation of tangible and intangible assets, investments (including R&D) and profit. Other case studies such as Nokia products and high-quality shoes provide further evidence that a large share of value is captured post- and pre-manufacturing. Most of this appears to be captured in the home bases of the firms concerned, where key intangible assets are accumulated.

Figure 19: Value creation and capturing for Apple iPhone4 (retail price: $600)



Source: OECD (2011), Global Value Chains, Paris: OECD.,

Recent research therefore is increasingly suggesting that the extent to which companies create and capture value is directly dependent on their capabilities in branding, product development, design, knowledge integration and management, and business model innovation. Complementing this, a growing evidence base suggests that investment in intangibles shapes the firm-specific capabilities that allow firms to influence the competitive conditions within the whole value chain and thereby capture a larger share of value. Firms that invest in intangible assets can capture value by:

- Enhancing the appropriability of innovations (the extent to which a firm can protect its innovations through patents or skills or through getting innovations to market quickly). A high degree of appropriability gives firms time to develop ideas and experiment.

44 OECD (2011), *Global Value Chains*, Paris: OECD.

- Controlling complementary assets: the value from products may relate to other services, such as marketing and after-sales support. Capturing this value requires control of assets, for instance unique knowledge of specialised complementary assets that can be translated into a service that enables or enhances the functionality of the product.
- Aiding integration of fragmented and decentralised innovation activities through development of systems integration skills.

More research is needed in this area but the evidence available points to intangible assets as a source of competitive advantage.

GLOBAL PARTNERSHIPS

Although some innovative assets are used to create a competitive advantage and develop differences among product and companies, **other assets such as scientific publications and R & D are created through instigating and maintaining collaboration at an international level**. But it is important to emphasise that firms can and do locate where knowledge assets are to be found, and that, even though firms and highly-skilled individuals are globally mobile, **most firms retain strong connections to their home bases**.

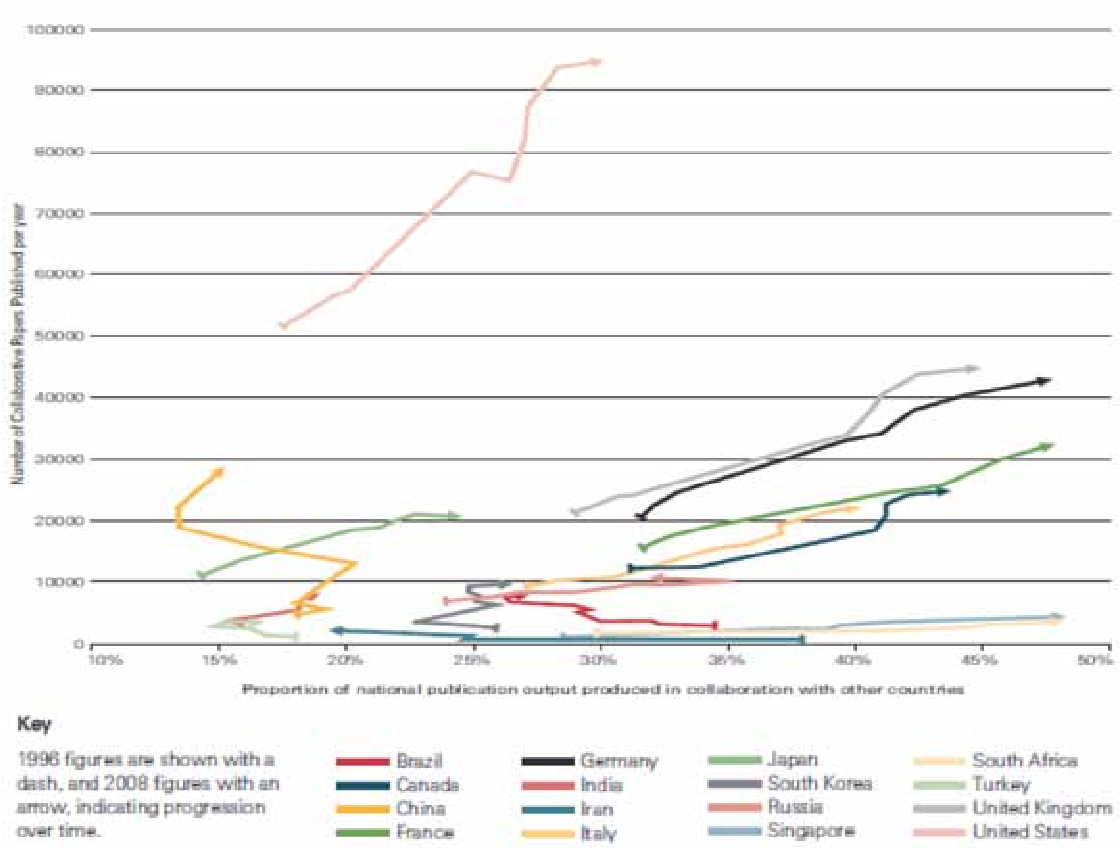
Scientific collaboration

A key feature of this multi-polarisation is the **growth of international scientific collaboration, facilitated by networks that increasingly span the globe**. Motivated by the bottom-up exchange of scientific insight, knowledge and skills, and led by scientists themselves, this development of global networks is accelerating the focus of science from the national to the global level, and facilitating benefits from enhanced collaboration (such as improved quality, efficiency and effectiveness).[45]

The UK has been an active participant in this global process of enhanced international collaboration. Figure 20 shows that the annual publication by the UK of internationally collaborative papers increased substantially over 1996-2008. The UK maintained its position as second in the world during this period by increasing its total output of collaborative papers as well as the share of its total publications that are produced in collaboration with other countries.

45 Royal Society (2011), *Knowledge Networks and Nations*. .

Figure 20: Growth in internationally collaborative papers for selected countries and the proportion of national papers output that this represents (1996-2008)



Source: Royal Society (2011), Knowledge Networks and Nations, London: Royal Society.

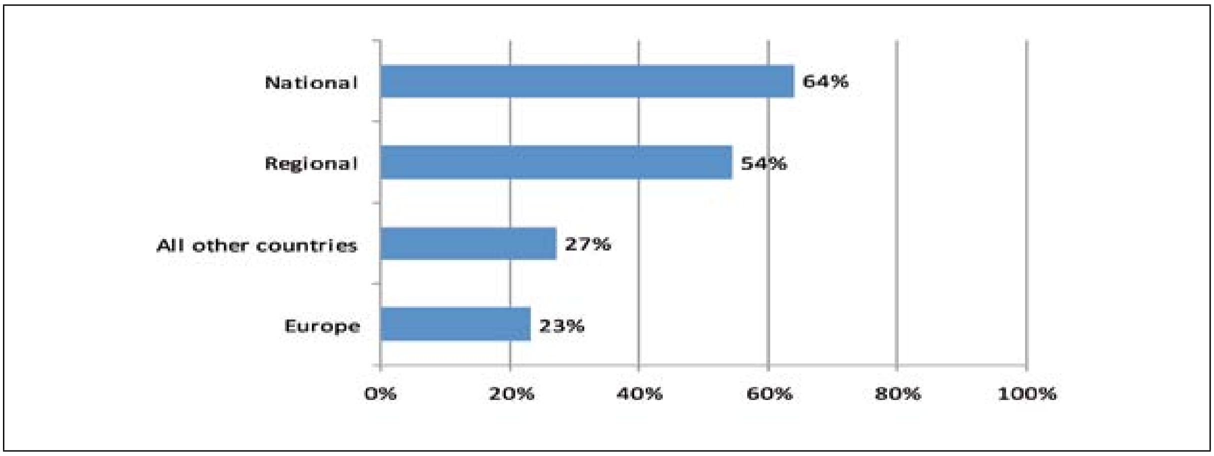
Figure 20 underlines the US's position as the world leader in publication of collaborative papers, the emergence of new hubs in China, India, Brazil, South Korea and elsewhere, as well as an increased interconnectedness (through international collaboration). Particularly striking is the fact that China succeeded in increasing its output of collaborative papers by more than a factor of five over this period.

Business collaboration

Innovating also increasingly forces companies to partner internationally to share costs, find complementary expertise, gain rapid access to different technologies and knowledge, and thus collaborate as part of networks spread across several national economies.[46] Figure 21 shows that over a quarter of innovative enterprises have cooperation agreements with foreign partners, mostly located in Europe.

46 OECD (2009), Innovation in Firms: A Microeconomic Perspective, Paris: OECD.

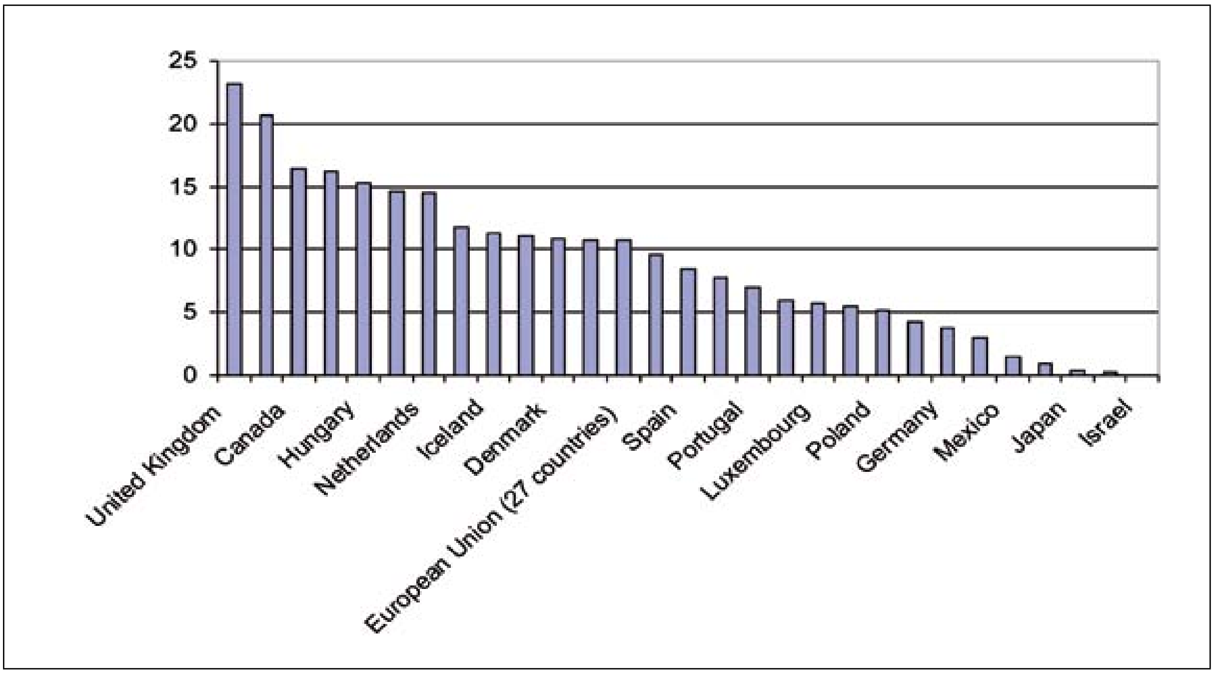
Figure 21: Location of co-operation partners % of UK innovative enterprises with co-operation agreements, 2006-2008



Source: BIS (2009) UK Innovation Survey, London: BIS.

As we have seen, the UK innovation system benefits considerably from foreign investment in innovation. The UK ranks first among OECD countries in terms of the share of business enterprise expenditure on R & D funded from abroad (23% in 2008), as shown in Figure 22.

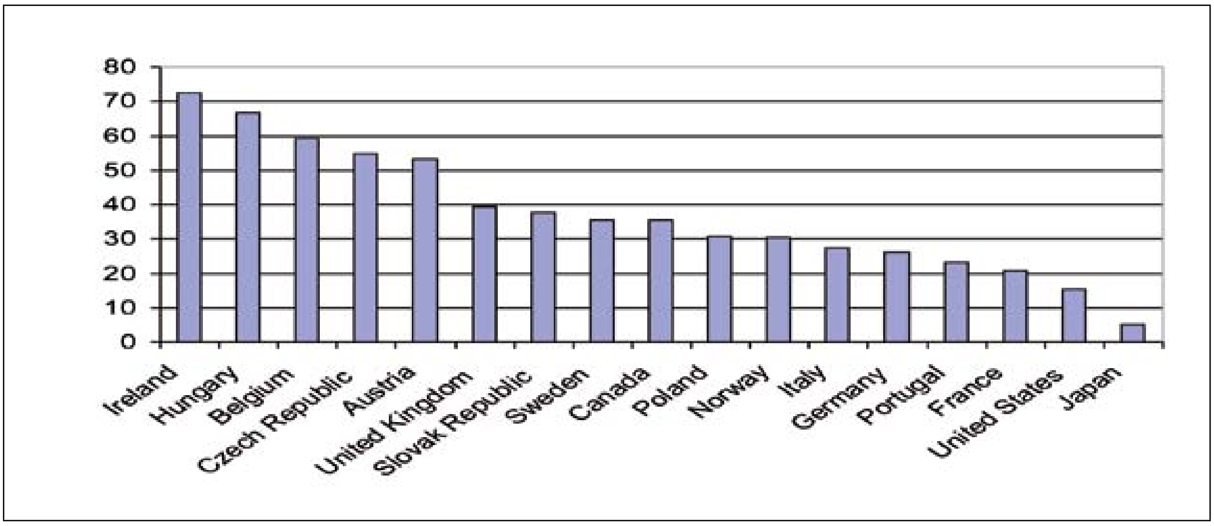
Figure 22: Percentage of business R & D expenditure financed from abroad



Source: OECD (2008) The Internationalisation of Business R&D: Evidence, Impacts and Implications *(OECD: Paris)*

Foreign affiliate's expenditure in R & D represents about half of the total R & D expenditure in the UK (Figure 23 below).

Figure 23: R & D expenditure of foreign affiliates as a percentage of R & D expenditures by enterprises



Source: OECD (2008) The Internationalisation of Business R&D: Evidence, Impacts and Implications *(OECD: Paris)*

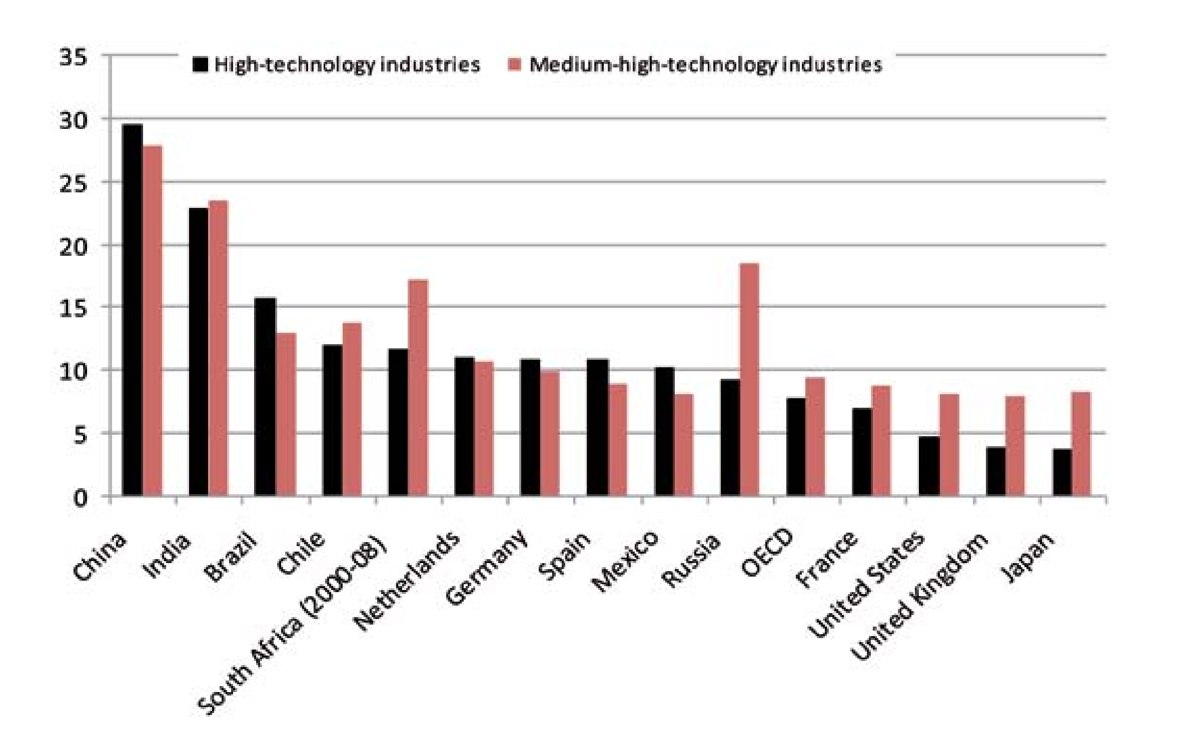
These patterns mean that foreign investment is a key element in the performance of the UK innovation system.

SOURCING KNOWLEDGE

A lack of data makes it difficult to draw strong conclusions on how companies draw on the global research community to source knowledge – not least as only the US records data on the foreign R&D activities of their Multinational enterprises (MNEs). However, it can be observed that **competition for foreign investment in R & D is intensifying as emerging countries are becoming increasingly attractive locations.** While the internationalisation of corporate R&D continues to be primarily directed to the US, Japan and Europe, the growth in the share of new host countries such as China, Korea and Brazil over the past decade has been impressive[47]. As emerging countries rapidly develop their innovation capabilities, some of them – most notably China – are rising up the value chain. This is reflected in Figure 24, which shows the rapid growth of China in high and medium-high technology exports.

47 For instance, US R&D performed in non-traditional markets, namely Singapore, Israel, Ireland, China, Hong Kong, Mexico, Brazil, Malaysia, Taiwan, and South Korea, accounted for just $1.3 billion or 11 percent of the R&D expenditures of US foreign affiliates in 1994. This had grown to $3.5 billion, or 18 percent of affiliate R&D expenditures, by the year 2000 (measured in current dollars).

Figure 24: High and medium-high technology exports average annual growth rate (1998-2008)



Source: OECD (2008) The Internationalisation of Business R&D: Evidence, Impacts and Implications *(OECD: Paris)*

This rise has been facilitated by intense innovation policy efforts by Governments in emerging countries, as well as by greater outsourcing and off shoring by firms from developed countries. Building on lessons from the experience of Korea, BRIC countries have developed policies to increase their innovative capacity, and they have enjoyed fast increases in R&D expenditure and skills. Similarly, dramatic increases in R&D expenditure and skills, particularly in China,[48] are enabling emerging economies increasingly to compete in the R&D stage of the value chain. The share in total R&D expenditure of non-OECD countries (for which data are available) rose by 5% over the period 2003-2007, from 15% in 2003 to around 20% in 2007.[49] China accounted for around half of the non-OECD share and by 2007 ranked third worldwide in total R&D expenditure. This is the result of a strategy by the Chinese government to go beyond acquiring global knowledge through copying, reverse engineering, FDI and technology licensing to invest in innovation on its own account. This looks set to continue: in 2006 the Chinese government announced a 15-year plan to increase expenditures on R&D to 2% of GDP by 2010 and to 2.5% (the average level of more advanced developed countries) by 2025.

Innovation capabilities in emerging countries are also being driven by off-shoring and outsourcing practices by firms from developed countries, particularly as they relate to high tech manufacturing, services and R&D. Off-shoring of manufacturing is increasingly extending to high-tech industries and to new

48 OECD (2010) *Measuring Innovation: A New Perspective*, Paris: OECD.
49 Using purchasing power parity.

segments of production process, while some services (for instance higher skilled services) that were formerly difficult to outsource reliably can now be managed at distance.[50] Firms are increasingly offshoring R&D to other countries, both to link R&D to markets but also to source technological capabilities, tap into centres of increasingly multidisciplinary knowledge, lower R&D costs and access highly skilled human capital. MNEs in particular are increasing their R&D work in developing countries, particularly China and India.[51]

However, an overview of the existing evidence suggests that while much of the process of globalisation of knowledge sourcing is attributable to the growing role of MNE foreign affiliates in generation of knowledge,[52] **there remains a continuing reliance of firms on the home country as a base for sourcing knowledge and innovating**,[53] including in supporting the activities of MNE affiliates abroad.[54] A recent review of location determinants undertaken by the OECD[55] confirms that whereas market size and growth are typically of greater importance for production and distribution activities, the existence of suitable private and public partners to source knowledge is an important sustainable competitive advantage to attract international investment from innovative companies.

Traditional determinants of R & D location are primarily related to market size and attributes, whereas more recent determinants are supply driven in some industries. For instance, high-technology industries are attracted by the supply of skilled labour, the availability of high quality scientific infrastructure, the proximate location of other high-tech industries, and established links with public knowledge centres such as universities. Cost considerations, including labour costs, appear secondary, although of growing importance. This can be explained by the strategic importance in some industries of creating and maintaining their intangible assets. The continuing importance of the home-base in the sourcing of knowledge emphasises the importance of the UK as a location supporting the innovation needs of MNEs, including through its interconnectedness within the global science system.

50 OECD (2007), Globalisation *and Regional Economies: Can OECD Regions Compete in Global Industries?* Paris: OECD.

51 OECD (2007) *Globalisation and the Spatial Reorganisation of Production*, Paris:OECD. Indeed, by 2006 there were more than 750 MNE R&D labs in China and over 250 in India.

52 For instance, in 2000, the proportion of R&D performed abroad by the foreign affiliates of U.S. MNEs was 13 percent, considerably higher than the 7 percent of R&D undertaken outside the United States in 1982, but nevertheless a relatively small amount./(National Science Board, 2004).

53 Dunning, J. H. and Lundan, S. M. (2009), *The Internationalization of Corporate R&D: A Review of the Evidence and Some Policy Implications for Home Countries*, Review of Policy Research, Volume 26, Issue 1-2, pages 13-33, January-March.

54 Criscuolo, P. Narula, R. and Verspagen, B. (2005), *Role of Home and Host Country Innovation Systems in R&D Internationalisation: A Patent Citation Analysis*, Maastricht University.

55 OECD (2010), *Attractiveness for innovation: Location Factors for International Investment*, Paris: OECD.

Towards a framework for policy

The fact that innovation is so central to growth makes it a high priority on the agenda of government. **Many of the innovation phenomena outlined in this chapter have implications for policy**. The following section discusses, first, rationales for policy actions, and second, specific issues arising from the evidence. We begin with market failure approaches, but then move to consider factors relevant to the innovation system. Since innovation performance is affected by the overall system, the efficiency of the system as a whole is important.

MARKET FAILURES

Market failures are the generic economic circumstances under which Governments consider policy action. Here we distinguish four forms of failure that are summarised below.

Externalities in innovation are well documented in the economic literature and arise most obviously where the technical characteristics of some innovation input or output prevent property rights being established and/or enforced. The most common form of this problem for innovation lies in the production of information and knowledge. In some cases, businesses cannot appropriate the full returns from their own investments and this leads to sub-optimal investment for the economy as a whole, which can be resolved by direct or indirect public support. In this respect, the knowledge produced by universities and public research institutes is a public good that contributes strongly to national innovative capabilities. Public support for R & D, often under the form of tax credits, aims to address under-supply by the private sector and is used by most OECD countries. Externalities can also be resolved by the creation of adequate property rights that can then be traded, and by the creation of new markets. Carbon pricing is an example of this method of creating incentives for eco-innovation.

Informational asymmetries occur as a problem, for instance, in financial markets. Here finance providers, like innovating firms themselves, can lack full information about innovation characteristics and success probabilities. Some businesses, especially SMEs, can be constrained by the provision of small volumes of risk capital for high-tech ventures or by gaps in the market for early-stage equity finance. There is a wider range of information issues which may prevent individual businesses from investing in innovation, particularly where there are long timescales before returns can be achieved. Businesses may not be aware or in a position to understand new opportunities from emerging markets or technologies. There can be particular problems if Government action is needed to create such markets, or if the Government is a key consumer in the market, and there are uncertainties about future policies. This is particularly the case in markets with major public good characteristics such as markets for environmental goods and services, certain health services and other public and semi-public services such as education.

Institutional deficiencies occur where existing rules inhibit or prevent innovation investment. Inadequate property right enforcement, standards or regulation, competition regimes with high entry costs or high switching costs to new technologies can create specific barriers for innovation. Innovation can be inhibited by inappropriate corporate governance frameworks, or by inadequate corporate finance systems.

Coordination failures occur where the innovation system lacks appropriate organisation for collecting, sharing, analysing information related to innovation opportunities. For instance, in high tech markets there is frequently a need to create new partnerships involving the research base and all those along the supply chain. Similarly, investments in infrastructure are particularly complex. They require a combination of private and public sector institutions and bodies, and from the business viewpoint this type of investment can appear fragmented and difficult to navigate. Such programmes of investment and innovation at multiple points call for coordination in order to deliver successful products and services in the market place.

Actions carefully designed to encourage collaboration and knowledge transfer between firms or between firms and scientific institutions or public organisations can have a major impact on innovation performances. Coordination failures are particularly prominent in a system approach to innovation, where they can take the form of system failures.

SYSTEM FAILURES

However, the system approach to innovation emphasises the nature of the links between components of the innovation system, and how well those linkages work. **Strengthening complex interdependencies is a major policy challenge.[56] Government has a fundamental role in addressing system failures**.

These links may take various forms. They may be economic, or they may involve the transmission of knowledge, or they may involve the joint use of infrastructures, and so on: the precise connections cannot be specified in advance, and often need detailed empirical investigation to uncover. But components of the system must work in a coherent way (that is, all moving in more or less the same direction, with more or less compatible objectives) towards the development and use of the new technology that is the object of the innovation process.

Where institutions, infrastructures or inter-firm connections are well established within a particular technological framework, the coordination needed for innovation may be unproblematic (although even stable technologies can run into novel problems). But **where a new technology involves a major disruption, coordination can be very difficult**. Some innovations are radical with respect

56 J.S. Metcalfe (2005), *Systems Failure and the Case for Innovation Policy*, in P. Llerena and M. Matt, *Innovation Policy in a Knowledge Based Economy*, Springer, Berlin.

to existing procedures, engineering capabilities or technical knowledge bases – they involve major discontinuities, and 'shocks' to the existing technological systems. Innovation for green growth is a good illustration, and we will discuss this in more detail in Chapter 6. The system coordination problems that arise are relevant at all levels of innovation. Even if innovation is seen in terms of incremental improvements to existing technology, current organisations and regulation systems can readily run into technological or economic problems that require new forms of coordination to solve. But if we see the task of innovation in a more radical way, as shifting the fundamental technological systems on which the current industrial economy is based, then the coordination problems become really critical.

A systems approach strongly suggests that **the identification of co-ordination failures, the design of policy instruments to overcome them, and the development of relevant actors, are likely to be an important rationale for public policy intervention,** and important also in deciding its scope and objectives.

Conclusion

The argument that innovation performance is shaped by the innovation system, and its characteristics, is important for public policy. The basic reason for this is that many of the core elements of innovation systems are under the control of national governments or are heavily shaped by decisions of national entities. These elements include education provision, institutional frameworks, research capabilities, industrial and technological specialisations, and infrastructure provision. All of these elements of the system can be the focus of important policy levers. Although the dynamics of globalisation influence how innovation assets are developed and utilised in a new environment, there remain many differences between national economies in terms of specialisations, capabilities and performances.

Although we need to be careful about exaggerated claims of change, this analytical review argues that the nature of innovation has broadened and that the challenge for policy is to strengthen the UK innovation system to significantly improve its overall coherence and competitiveness in the global economy. **The proposed approach, developed in the following chapters, is built around 4 priorities:**

- **Strengthening the sharing and dissemination of knowledge;**
- **Supporting a coherent and integrated knowledge infrastructure;**
- **Encouraging business investment in all forms of innovation;**
- **Improving the innovative capacity of the public sector.**

Strengthening the Sharing and Dissemination of Knowledge

This Chapter explores the use of knowledge, showing that intensified collaboration – sometimes called 'open innovation' – is a feature of highly performing innovation systems:

- Business innovation rests on learning and the application of knowledge. But innovative knowledge derives from many sources and takes many forms. Firms must integrate these multiple forms of knowledge to generate new products, services, processes and systems.
- Innovation outcomes are uncertain, and innovation processes frequently involve unexpected problems. Firms must often step outside their own boundaries is seeking to solve innovation-related problems.
- To do this, businesses need to connect with a wide array of partners, some of which are in the private sector and some in the public sector. This is the 'knowledge infrastructure', which consists in part of universities and research institutes, in part of the innovation information infrastructure that provides technical and scientific information, and in part of knowledge-trading firms (such as R&D firms, consulting engineers, management consultants, etc).

Intensified collaboration is creating particular challenges for the competition and property rights frameworks, involving trade offs between:

- Encouraging intensified forms of collaboration between players whilst discouraging anti-competitive arrangements.
- Sharing knowledge as a basis for further invention whilst giving creators incentives to invest and to innovate.

Depending on how such regulations are structured and applied, they can promote or dampen innovation, and this area is therefore central to public policy.

This Chapter explores the ways through which knowledge flows inside the innovation system and the policy challenges that arise.

- First, the knowledge system is presented: forms of collaboration, including clustering effects, are examined and emerging forms of collaboration that are enabled by information technologies are introduced.

- Secondly, knowledge is created and used within regulatory and legal frameworks. We explore, in particular, the challenges for competition and property rights regulation.

Fostering open innovation

Collaboration between innovating firms and other firms, researchers, and experts is by no means new. The recent concept of 'open innovation' refers not to a new phenomenon but to an apparently increasing need for inter-organisational cooperation, rich communication flows and supportive institutions at every geographical level, to generate new knowledge in modern economies. The reason why such needs are increasing lies in the steadily greater complexity of technologies (in terms of their components and underlying knowledge bases). **A source of sustained competitive advantage for advanced economies like the UK is the presence of active networks that facilitate and sustain knowledge flows.** Some of these are market-based, whilst others operate through non market mechanisms. **These flows affect the performance and diffusion of innovation and are responsive to policy interventions.**

THE KNOWLEDGE SYSTEM

The knowledge production system as a whole matters because even relatively simple forms of innovation may involve multiple forms of learning. These forms of learning often involve many actors – firms, research institutes, universities, etc. So the ability of actors to collaborate will affect how the innovation system performs. Many manufactured products are increasing in complexity, in terms of the number and types of components involved, and their inter-operability, over time. It is now often the case that component suppliers, in for example the car industry, supply entire sub-systems of a technology rather than simply specified components. The technologies involved in many service activities are likewise becoming more complex. So when a firm seeks to innovate, by developing some form of new product concept, it may have to step well outside its existing areas of competence to develop the product. But innovation processes are also highly uncertain. Even if a firm tries to innovate by developing what it already knows, it may run into problems that it cannot solve. At this point it must find a solution from outside, either by recruiting, buying expert advice, or by otherwise accessing new knowledge.

An important recent idea describing this process is the concept of 'open innovation', developed by the US economist Henry Chesborough.[57] Open innovation points to the fact that innovating firms must be porous to their environment: they must adapt to the wide scope and reach of the knowledge that is necessary to innovate. This means that, in many cases, **firms cannot control internally all of the knowledge and skill necessary to bring a product to the market. Instead they must collaborate, network, monitor their environment**

57 Chesbrough, H. (2003), *Open Innovation: The New Imperative for Creating and Profiting from Technology*, Cambridge: HBS Press.

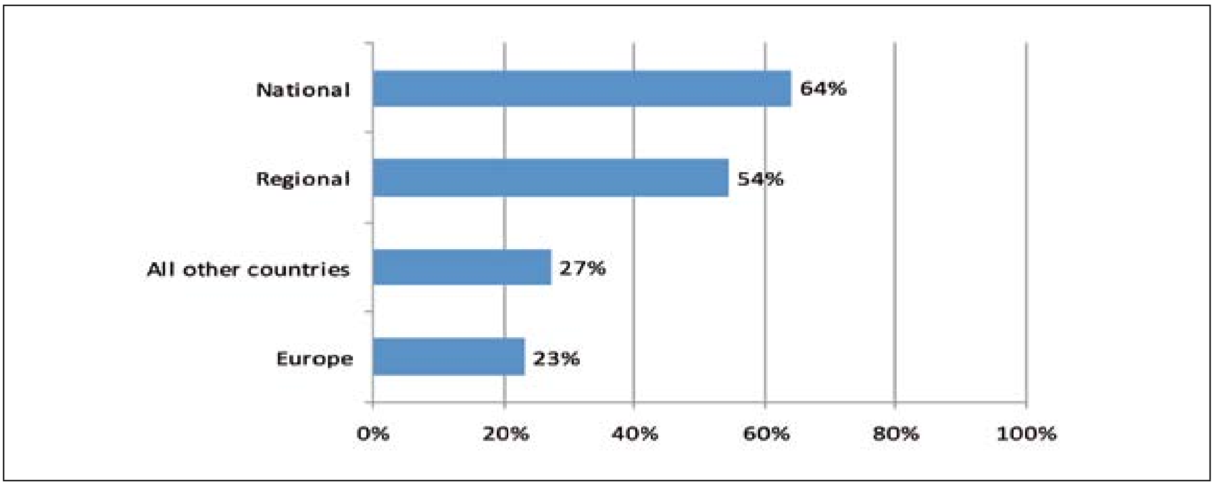
and interact with individuals, firms and other organisations as they seek to assemble the knowledge that underpins innovation. This type of behaviour is rational for an individual firm, because it gives access to knowledge it cannot create itself, or to markets that it cannot otherwise reach. Open innovation coexists with the use of intellectual property rights (IPRs), which help firms and individuals appropriate value from innovation. It is not necessarily a new phenomenon: the history of technology contains many examples of innovators looking outward. But the increasing complexity and availability of innovation-relevant knowledge means that firms can now innovate successfully with reduced internal knowledge development and a much enhanced openness. This suggests a need to focus on the full complexity of the knowledge creation system and its impact on incentives.

NATIONAL KNOWLEDGE EXCHANGES

The variety of cooperation arrangements is considerable and defies simple classification. Although there is not yet a well-developed taxonomy of collaboration available, some broad conclusions can be drawn. **Firms and industries are part of larger inter-linked systems involving market and non market knowledge exchanges.**

Overall, a large proportion of innovative enterprises report formal cooperation arrangements. In Chapter 2, we have seen that collaboration is spread among a range of locations and that about a quarter of firms work with partners at the international level. Development of technology standards is an obvious example of international cooperation in which knowledge is shared openly, but many collaboration arrangements are exclusive. However, cooperation at the national level remains the most common form. Figure 25 shows that just under two thirds of UK enterprises with cooperation agreements collaborated with partners that are based nationally.

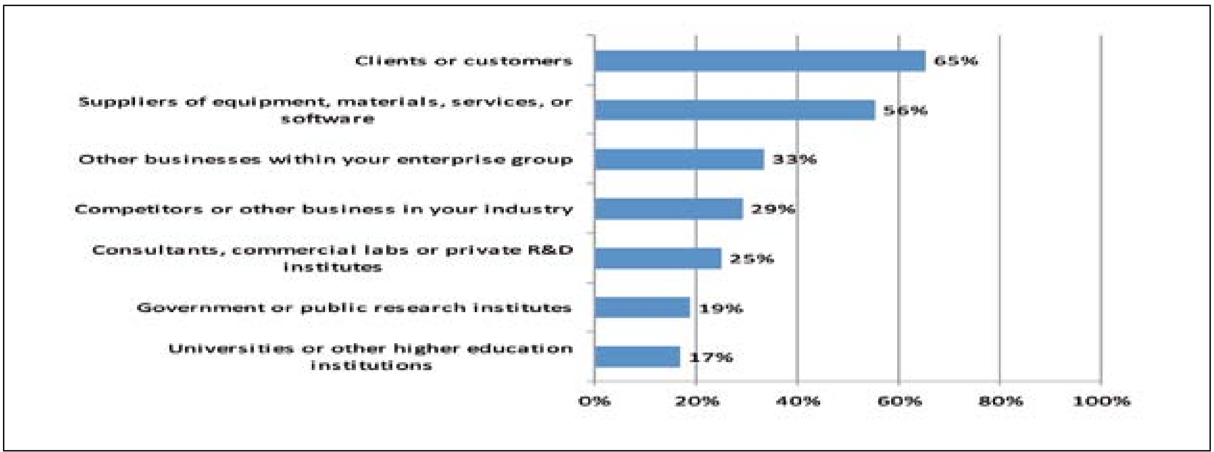
Figure 25: Location of co-operation partners % of UK innovative enterprises with co-operation agreements, 2006-2008



Source: *UK Innovation Survey* (2009)

At the national level, collaboration is spread among a range of partners, but vertical cooperation is more frequent than any other form. Figure 26 shows that the most frequent cooperation partners were clients or customers (65 per cent). 29 per cent of innovators included competitors or other businesses in their industry among their partners and 17 per cent cited Higher Education Institutions as cooperation partners.

Figure 26: Types of national co-operation partners % of innovative enterprises with national co-operation agreements, 2006-2008



Source: UK Innovation Survey (2009)

Analysis from the UK Innovation Survey data also suggests that firms which undertake design activities for innovation processes are more likely to also pursue open strategies for innovation. Similarly, knowledge-intensive services stand out as leading sectors for open innovation activities. More research is needed to better understand and identify different types of collaboration for firms and sectors.

CLUSTERS OF KNOWLEDGE AND INNOVATION HOTSPOTS

Clustering effects

Although firms are increasingly mobile, modern technologies have not made spatial barriers insignificant. Figure 21 displayed above shows that just under half of UK enterprises had agreements with partners located regionally. The freedom of location choice by a firm remains limited by the nature of innovation processes which favour the geographical concentration of interdependent value-adding activities and lead to 'clustering' effects.

A cluster is typically understood as a geographic concentration of interconnected businesses and suppliers, and associated institutions in related fields. They invariably compete and collaborate depending on time and place, but in doing so reinforce the strength of the 'cluster'. They are by no means new entities, with many being around for centuries. Many of the latter are based on old trade guilds. Clusters tend to encourage innovation through the process of collaboration and competition but not all innovation occurs within clusters.

In some industries, the geographical proximity of interdependent firms and related organisations is an important factor in competitiveness. This has been recognised since Alfred Marshall's[58] work on 'industrial districts' in the late 19th century, and rests on the following factors:

- A cluster of firms can support large immobile inputs, such as specialised infrastructures or facilities, which are not available for isolated firms.
- A large pool of skilled labour, within concentrations of specialised labour markets, allows firms to fill job vacancies with appropriately skilled workers more easily.
- Geographically concentrated industries benefit from information and knowledge spillovers and rich inter-firm communication flows that are a prerequisite for high levels of coordination efficiency and innovation potential in advanced industries. These interdependencies are critical in the knowledge economy. However, there are also some incentives for firms to guard against the release of knowledge to competitors, so that some firms that depend on proprietary knowledge may actively avoid industry clusters, e.g. in the automotive industry.

UK production tends to be concentrated in particular places. A similar level of concentration activity is seen in other countries, with the extent of concentration increasing as the country develops. However, the contribution of clusters varies greatly. Table 2 below shows a distribution of clusters in the UK, with London and the South East, and to a lesser extent the East, having significantly more clusters. Northern regions see fewer clusters and the North East sees no clusters of international significance.

58 Marshall, A. (1890) Principles of economics, Vol 1, London: Macmillan; Marshall, A. (1920) Principles of economics, Vol 2, London: Macmillan.

Table 2: English clusters of international or national importance

	International Clusters	National Clusters
North East	• N/A	• Chemicals (organic)
North West	• Leisure software • Aerospace (military, airframe) • Automotive (assembly) • Nuclear fuel processing	• Chemicals (inorganic, speciality) • Household textiles and clothing • Plastics (primary, products) • Tourism
Yorkshire and Humber	• Leisure software	• Agriculture/ food (processing) • Chemicals (speciality) • Construction and construction products • Medical/ surgical equipment
East Midlands	• Aerospace (engines)	• Agriculture/ food (processing) • Automotive (assembly) • Clothing
West Midlands	• Antique dealing • Ceramics	• Automotive
East	• ICT/ electronics • Pharmaceuticals/ biotechnology • R&D activity • Software development	• Agriculture/ food (cereals, processing) • Instrumentation
London	• Business services • Clothing • Financial services • Travel, entertainment, tourism • Advertising • Music industry • Publishing • TV, film, radio	• Computer related services • Property and real estate
South East	• Antique dealing (AND exporting) • ICT/ electronic equipment • Leisure software • Pharmaceuticals/ biotechnology • R&D activity • Software/ computer services	• Consultancy/ business services
South West	• Antique dealing (AND exporting) • Aerospace (helicopters/ design/ systems)	• Environmental industries • Marine industries • Tourism

Source: BIS (2000) Business Clusters in the UK, London: BIS.

A more recent study found that the service sector tends to cluster more than firms in the manufacturing sectors.[59] Many service sector clusters, including the media, culture and financial sectors, are located in London. There are some highly clustered manufacturing sectors located in historical centres such as Sheffield, Nottingham and Birmingham. R & D activities are also predominantly clustered in the East of England, London and the South East with some notable exceptions, such as vehicles and aerospace in the West Midlands, and chemicals and pharmaceuticals in the North West.

59 Simpson H. (2007) *An Analysis of Industrial Clustering in Great Britain*, Report for the Department of Trade and Industry.

NESTA's recent study,[60] focusing on creative clusters, found that London is the heart of the creative industries in Britain in the most intrinsically creative layers of the value chain. Nine other creative hotspots are identified: Bath, Brighton, Bristol, Cambridge, Guildford, Edinburgh, Manchester, Oxford and Wycombe-Slough. The research analyses co-location between creative sectors and other innovative industries such as High-Tech Manufacturing and Knowledge Intensive Business Services (KIBS). It shows statistically robust patterns of co-location in several cases:

- Advertising and Software firms are very often found near both High-Tech Manufacturing businesses and KIBS.
- Other creative sectors that provide content and cultural experiences show weaker, although still significant, patterns of co-location with KIBS.

These findings suggest the existence of complementarities between some creative sectors and innovative businesses in other parts of the economy. These complementarities may be brought about by value chain linkages and shared infrastructures. They could also be a consequence of knowledge spillovers that happen when creative businesses share new ideas with their commercial partners, or when creative professionals move into other sectors, bringing useful ideas, technologies, and ways of working with them. In other cases, the presence of creative firms generates an 'urban buzz' that attracts skilled workers and encourages collaboration.

Nurturing clusters

Notwithstanding the historic nature of many 'clusters' there is a view widely held by many public and private actors across the world, including in the US, that the main determinants of prosperity are created and not inherited and that there are actions which can be taken by governments to support and even create clusters.

Assessing such views is complicated by the fact that clusters can be highly heterogeneous. There is no single model and account has to be taken of local circumstances[61]. These include the quality of the skills and knowledge available, market-size and opportunity. Variation in these factors explains why many attempts at 'cluster building' from the ground floor up have not succeeded. This is a central conclusion of a study of 779 clusters across 49 countries.[62] It seems to be particularly difficult to create 'high tech clusters' such as biotech, software, semiconductors and information technology in regions which lacked the 'fundamentals' for success.

Innovation clusters have arisen in different circumstances across the world. For Silicon Valley the key interplay appears to have been the relationship developed in the 1950s between Stanford University's engineering and electronics

60 NESTA (2010) *Creative Clusters and Innovation: Putting Creativity on the Map*, November, London: NESTA.
61 NESTA (2011) *Innovation clusters, think piece*, unpublished.
62 Van der Linde, C (2003), *The Demography of clusters: Findings from the Cluster Meta-Study*, in Brocker J., Dohse, D and Soltwedel R (eds) , *Innovation Clusters and Interregional Competition*, Heidelberg, pp.130-149.

departments led by Frederick Terman and some alumni, notably but not exclusively, Hewlett and Packard. In this case, entrepreneurial alumni allied to strong supporting infrastructure, including Stanford Industrial Park, great research departments and the generation of capital for investment by successful start-ups with supporting services, such as lawyers and venture capitalists all created over time 'Silicon Valley.

Closer to home, the Cambridge phenomenon, which presently employs about 50,000 people across a broad range of software, IT and biotech industries was the creation of 'Cambridge Consultants', who gave rise to a series of further consultancies from academics which, in turn, created an environment where working with industry became the norm. Whatever the reason, it is hard to see the direct hand of significant public intervention in what happened subsequently, although there is no doubt that the creation of the Science Park did much to encourage private sector investment.

Some UK clusters such as automotives and aerospace have a long and distinguished history and in that sense occurred in an organic way, but they have also been strongly reinforced by significant flows of inward investment, especially in automotives. In that sense, one can point to state sponsored 'cluster' development as an outcome of targeted interventions and there is no doubt that in some cases these have led to strong and highly innovative clusters.

Some very traditional industries such as finance have also been further strengthened by inward investment in cities such as Edinburgh, Glasgow and Leeds. By contrast, the semiconductor design cluster in the South West of England, which is now one of the largest of its kind in Europe, is in part an outcome of a failed attempt by a British government investment agency to create a British owned semiconductor industry in the form of Inmos, with an R & D centre in the South West of England. It was not profitable and was subsequently sold, but some of the engineers it employed stayed on in the area and went on to create a number of successful start-ups .The skill base also offered significant opportunity to attract inward investment and there are now at least 100 semiconductor companies operating in the South West.

There are a few successful examples across the world of sponsored innovation clusters led by governments, with Asian countries to the fore such as the semiconductor cluster in Taiwan, and through inward investment, as in Ireland. Others have been outcomes of public-private partnerships, with the presence of excellent research universities, as in Austin, Texas, or the Research Triangle in North Carolina. This approach seems to have been much more successful than the Asian model, perhaps because it combines market knowledge and skills allied to state investment and support in procurement and supportive regulatory regimes. Inward investment has been shown to be important in helping grow and reinforce clusters and in the case of some countries such as Ireland has been used as a catalyst to grow from very modest starting points what have now become deeply embedded clusters such as the software industry and pharmaceuticals. Ireland's approach suggests that a deep understanding of the needs of investors for good infrastructure, a well trained supply of staff, good links to universities and fiscal stimulants in the form of highly competitive corporate tax rates can lead to successful innovative clusters.

There seem to be, therefore, a number of pathways leading to the establishment of innovation clusters and it is hard to draw clear and empirically verifiable conclusions about how innovation clusters emerge. However, there are some common denominators, not least strong links to universities for both a supply of graduates and collaborative research, sympathetic tax and regulatory regimes held constant over time and good infrastructure in both building and digital connectivity.

COLLABORATION ENABLED BY ICT

Technologies that assist innovation are changing, and we are seeing the emergence of ICT-enabled collaboration practices. ICT allows reduced informational costs and reinforces the competitive pressure on firms to introduce products to the market place more rapidly, whilst making it easier to access the best knowledge source anywhere in the world. These new practices have the potential to profoundly affect the innovation process.

ICT has also made a fundamental change to the way service businesses innovate. The development of data capture, sharing and analysis across and between firms has made it possible to experiment with business systems in services in ways which were previously only possible in manufactured products. The ability to experiment with customer experience, and understand the impacts on efficiency and value has made a real difference to firm behaviour.[63] It has also raised the value of collaboration between firms in developing and using data on customers.

Although the emergence of these new forms of collaboration is now widely recognised, quantifying their diffusion and impact is challenging. There are no widely accepted measures. Metrics are in the process of being developed to capture these innovative efforts, capabilities and outcomes. Case studies are currently used to gather key information on these practices; some are presented in Box 3.

63 Erik Brynjolfsson, Andrew McAfee, Michael Sorell, Feng Zhu (2008), *Scale without Mass: Business Process Replication and Industry Dynamics*, Working Paper 07-016 Harvard Business School.

Box 3: Examples of new forms of innovation practices	
Innovation Technologies (IvT)	Procter & Gamble have developed or engaged with varieties of internet-enabled mechanisms to implement its strategy of open innovation. For example, on InnoCentive companies can post their R & D challenges on the website, providing details of the problem, requirements, deadline and reward that can range from $5,000 to $1m. The company's identity is kept secret. Scientists from around the world can attempt to solve the problem. InnoCentive website boasts a network of more than 200,000. YourEncore is the company's network designed to keep a productive relationship with early retirees by building a portfolio of high quality talent and making them available to member companies on an as needed basis.
Internet platforms	The NHS National Innovation Centre (NIC) supports innovators commissioners and clinicians to speed up the development and use of innovations that will benefit the NHS. For example, the Statements of Clinical Need (SoCN) is an online tool provides a forum for clinicians to express what they need. The information helps the industry to understand what innovations they can mobilise or develop to meet those needs. The online Scorecard tool helps identify the strengths and weaknesses of ideas and provides suggestions for improvement. It essentially acts as the 'first interview' with an innovator and explores what assistance the innovator needs. Project Zone on the NIC website lists needs identified and likely to change to enable innovators to take-up and run swiftly with their ideas.
Web 2.0 and Web 3.0	These are terms generally associated with a set of internet-based applications characterised by user created content: video sharing, blogs, wikis, podcasts, RSS, social networking etc. It is hard to overstate how far-reaching these applications have become with the likes of Wikipedia, Facebook and YouTube now established as major businesses or web entities. An increasing number of businesses and organisations are using Web 2.0 in their strategies, in particular in the field of marketing. Web 3.0 will involve personalisation, intelligent search and behavioural advertising. The NIC has started developing tools which utilise the technology of Web 3.0 as a way to significantly improve the speed and quality of decision making in the area of health technology innovation.

Source: BIS (2010)

These new forms of collaboration share some characteristics[64]:

- They are interactive and encourage the participation of a growing and diverse set of stakeholders, bringing more individuals and organisations into daily contact at a lower cost and expanding companies' pools of knowledge.
- They involve a wide range of co-operative arrangements for innovation, ranging from open forms of interacting innovation like open innovation or user-driven innovation, to more formal and closed cooperation. Some models accelerate the trading and sharing of existing knowledge: for example expert knowledge networks (between members of a community of practice) and expertise markets (between knowledge holders and seekers). Other models facilitate the production of new knowledge: for example outsourcing R & D models (involving a large firm contracting various parts of its knowledge-generation programme to a large number of start-ups) or other mechanisms involving the advertisement of a research question that can be answered by any registered researcher.

64 OECD (2009), *New forms of innovation: challenges for policy making*, Paris: OECD. OECD (2010), Knowledge Networks and Markets: A Typology of Markets in Explicit Knowledge, Paris: OECD.

- Table 3 presents four modes of collaboration that can be identified on the basis of two dimensions: the barrier to participate (open or closed collaboration) and the governance of the collaboration (hierarchical or flat).

Table 3: New modes of collaboration

Mode	Example
Open hierarchical	Through InnoCentive.com, sponsor companies post scientific problems that are smaller pieces of their larger R&D program. Anyone can offer solution ideas. The "kingpins" understand the relevant technologies and user needs and can coordinate collaborators' work.
Open, flat	In open-source software community Linux, anyone can participate, define valid innovations, and use any code they deem useful.
Closed, hierarchical	Home-products design company Alessi drwas on the talents of 200 independent designers. It decides who participates in its network, which concepts get developed, and which products are launched.
Closed, flat	IBM invited a few select partners to join its Microelectronics Joint Development Alliance for developing semiconductor technologies such as memory and chip-manufacturing processes. Each member has a voice in how technologies are developed.

Source: Pisano, G. and Vergantini, R. (2008), Which Kind of collaboration is Right for You, Harvard Business Review, December, 78-87.

- They lead to a growing interaction between knowledge areas. Increasingly firms are adopting innovation strategies that go beyond the development of a new technology and develop complementarities between forms of innovation. Many products and process innovations do not involve a technological component but are associated with marketing innovation, for example in the services sector. Likewise, some marketing and organisational innovation can have a technical component. This leads to a growing interaction between disciplines and knowledge areas.
- They use a diversity of strategies to appropriate economic rents from innovation. In some knowledge markets suppliers are compensated for their contributions by monetary reward either from those acquiring the knowledge or from the network managers. In other markets contributors obtain access to other parties' knowledge or can showcase their skills to a broad audience, thus enhancing their reputation to potential partners.

PROMOTING COLLABORATION

Although collaboration and cooperation have come to dominate successful innovation, businesses, and especially small firms, and some industries often run into information and coordination problems at the different stages of the collaboration process.

- The nature and benefits that networks afford are not always well-known and internalised. In some industries, the network principle may be hard to establish, with fears of possible unfair appropriation of the benefits from any collaborative undertaking.
- Co-ordination problems among geographically dispersed firms may also create inertia in the establishment of business networks. Besides awareness, the costs of setting up a network e.g. the process of finding suitable partners, setting up common rules for cooperation and building the necessary shared resource tends to fall primarily on the organisation that actively promotes it whilst the benefits tend to diffuse to all members.
- These externalities problems are even more pronounced at the international level. The costs of getting access to foreign markets, even when the domestic market is too small for highly specialised products, and the search for suitable local partners in foreign target markets may be too high for small networks of firms.

Competition policy and innovative markets

Cooperation, alliances and partnerships are extremely important in the information economy but they raise new challenges for competition policy and enforcement. Competition also creates the incentives for firms to innovate. The granting of limited monopoly rights in the form of intellectual property is also critical in some business strategies seeking to capture value from their assets. **The question for policy hinges on the trade off between encouraging intensified collaboration between players in the innovation system whilst discouraging anti-competitive arrangements.** This is a difficult but essential balancing act in supporting innovative businesses.

PROMOTING COMPETITIVE MARKETS

Competitive markets are important for innovation to thrive and deliver growth. Competitive conditions reveal themselves in cross country comparisons of changing market shares of firms within national markets. Recent research shows that this is strongly linked to national productivity growth rates.[65] This reflects not only allocation of resources from less to more efficient firms, but also the freedom of consumers to choose new suppliers, often on the basis of new products and services. Studies sponsored by Eurostat on ICT adoption demonstrate the relationship between such market churn and technology adoption.[66]

However, the way innovation happens can differ quite significantly from traditional models of competition on which standard price theory is based. Standard models of perfect competition, monopoly or oligopoly are static and

65 A. Bravo-Biosca (2011) *A look at business growth and contraction in Europe'*, NESTA; Paper to 3rd European Conference on Corporate R&D and Innovation.

66 Franklin, M., Stam, P. and Clayton, T. (2009), ICT Impact Assessment by Linking Data, *Economic and Labour Market Review*, Vol. 3, Issue 10, pages 18-27.

take technology as given, and inter-firm collaboration plays little or no role. US initiatives in technology policy over the last couple of decades have tended to reduce antitrust restrictions on collaboration, with arguably some positive results for innovation performances.

The relationships between competition and innovation are all the more complex as they are likely to differ across industries and sectors, and in some industries collaboration must be encouraged. For example in mobile telephony there is a need for collaboration on compatible standards and competition on prices. A growing body of research, including recent research under the auspices of the Office for Fair Trading , attempts to better understand these issues. [67]

Interdependent firms and concentrated markets

Innovation has some characteristics that bring new forms of restrictions to competition and new challenges for anti-trust analysis:

- The existence of complex high-technology products and systems means that firms must communicate, cooperate, or even merge, for complementary products to work together. This cooperation may take many forms, including the joint setting of standards, cross licensing of patents, patent pools and the provision of timely information about new products that may affect the ability of firms producing complementary products to keep their products up to date and compatible. Complements and interfaces allow interoperability. This is challenging for competition authorities that are accustomed to viewing cooperation among firms with suspicion and tend to look for ways in which communication and joint action lead to collusive practices.
- Firms innovating in markets involving large fixed (and sunk) costs face significant risks when entering markets, and require reasonable prices and volumes to survive. These markets will tend to exhibit large amount of price discrimination (to recover sunk costs) and high margins. Competition authorities are traditionally concerned by these issues as they can lead to abuse of market power. However, reducing the share of the market available for the entrant to contest, or reducing the price the entrant can expect for its products, or substantially raising the risk, may have considerable potential to deter entry, and investment in new products.

67 Shapiro, C. (2000), *Competition Policy in the Information Economy*, in *Foundations of Competition Policy Analysis*, London: Routledge; Shapiro, K.(2002) *Competition Policy and Innovation, Report for the OECD*, OECD; Varian, H. Farrell, J. and Shapiro, C. (2004*) The Economics of Information Technology*, Cambridge University Press, Office of Fair Trading (2002*) Innovation and Competition Policy*, Economics Discussion Paper 3, March 2002, Part I – conceptual issues, Part II – case studies.

- Linked to this, in some high-tech industries supply-side and/or demand-side economies of scale can lead to natural monopoly. With network externalities, for instance, the more users join a particular telephone network, the more valuable the network becomes to those users, as they are able to contact more people as the size of the user base increases. This can lead to very large market shares for leading firms and products and high barriers of entry. The Microsoft case provides a widely publicised example of such effects and is presented in Box 4.
- ICT-enabled forms of collaboration seen above contribute to further exhibit scale economies. As virtual networks grow, the control of interface and compatibility standards, amongst other issues, also increase in importance.

In a modern innovation system, the number of avenues for anti-competitive action can also be limitless. Risks of failure are high and the line between who is a competitor and who is not becomes blurred. In this context, real monopoly power can be difficult to observe and detect.

Box 4: Case study 1 – MICROSOFT	
Ruling	In May 1998, the US Department of Justice charged Microsoft with four specific antitrust violations: • unlawful exclusive-dealing arrangements, • unlawfully tying MSIE to Windows 95 and 98, • unlawful maintenance of a monopoly in the PC operating system market, and • attempted monopolisation of the internet browser market. The overarching theme was the accusation that Microsoft had used its market power in the operating systems market in an anti-competitive fashion to preserve its dominant position, especially from the threat of so-called 'middleware' products (software as an intermediary to applications) from Netscape, and also from Sun's Java.
Issues for competition policy	The markets where Microsoft is active are characterised by strong network externalities and, to a large degree, incompatibility between different networks. These characteristics result in markets that are likely to be characterised by near monopolists. Specifically, they are prone to tipping effects and high barriers to entry. When players in a market are taking risks by innovating, it is important to prevent incumbents from gaining a reputation for taking away innovators' rents. When Netscape became so successful that Microsoft felt threatened, Microsoft 'closed the door' on Netscape, preventing Netscape from reaping the rewards for its innovations in the browser market. Reacting vigorously to entry is not anti-competitive in itself. Intent is important. There is a difference between competing vigorously on the merits of a product and taking anti-competitive measures to drive out competitors for the sake of protecting a monopoly position. Microsoft did the latter in this case. This case shows that: • compatibility/standards issues can lead to serious competition issues as they can create significant barriers to entry, • where markets tip, monopolies in themselves should not be a concern unless they lead to serial monopolies, • tying that is benign in a static setting can increase barriers to entry in a dynamic setting and hence damage competition, and • firms can create barriers to entry and chill innovation by creating a reputation for very aggressive and/or anti-competitive responses to entry.

Source: OFT (2002) innovation and competition policy, March.

Another challenge for the competition system in its approach to innovation is its treatment of customer / supplier relationships. In an increasing range of industries, the scale required to integrate technology and approaches to markets – especially global markets – is significant. In this type of situation, **the role of large multinational companies as integrators of innovation can be important.** Often, the first step in the growth of a young innovative company is as part of the supply chain for a much larger partner. In some markets this relationship leads to the acquisition by the larger partner of the source of innovation, either by buying the smaller company or buying the IP Rights. The role of competition policy in governing the balance of power in such relationships is highlighted by new research for the IPO showing that the 'patent premium' achieved by smaller inventive firms in the UK is significantly lower than that enjoyed by large firms and MNEs. Maintaining incentives for smaller innovative firms is important to sustain the overall system. At the same time, enabling larger firms to perform the integrating role is vital for UK competitiveness.

Applying competition frameworks

A very good understanding of the system-like features of the knowledge economy is crucial if enforcement is not to deter innovation. Some competition authorities have been using a 'watch and wait' strategy, The British Interactive Broadcasting case in an example of such a strategy (Box 5). Rather than speculating on possible future anti-competitive outcomes, the EU Commission chose an approach of caution and watchful waiting, and allowed cooperation between competitors with strong market positions to go ahead.

Box 5: Case study 2 – BRITISH INTERACTIVE BROADCASTING	
Assessment	British Interactive Broadcasting Ltd (now named Open) is a joint venture company created and owned by British Sky Broadcasting (BSkyB), British Telecommunications (BT) Holdings Limited, Midland Bank and Matsushita Electric Europe. The EU Commission was notified of this joint venture in 1997. The prime concern raised by the Commission was that the joint venture combined BT and BSkyB, who in the view of the Commission were both potential competitors in the digital interactive television services market, and given their market positions the (potential) restriction of competition was appreciable. However, the joint venture was allowed to proceed because the Commission believed that the potential reduction in competition was balanced by the ability to provide a better service, more quickly. The Commission imposed a number of conditions that aimed at increasing the likelihood that competitive access would be provided by a non-BT, cable-based, access provider; ensuring service providers of digital interactive services would have access to the BiB system on fair and reasonable terms, and ensuring competing content distributors were not disadvantaged through being unable to distribute content that included interactive features.
Issues for competition policy	This case provides a useful demonstration of both the uses, and limitations, of market definition in innovative markets. A key challenge when undertaking competition analysis in markets such as this is ensuring that the traditional competition analysis framework is used as a useful tool to aid understanding, and not allowed to become a part of the analytical problem. In this case, the competition in the future market for digital interactive television services could not be viewed in isolation from the markets for content (pay-TV) and access, which were both essential to the success of any interactive television system. It is also a good example of how a regulator can use its discretion. Preventing the venture from proceeding may have materially damaged the rate at which interactive services operated from television-based technologies were introduced into the UK. This would be to the detriment of consumers, without any certainty of balancing benefits in other areas. Rather than speculate on possible future anti-competitive outcomes, the Commission chose in this case to let the deal proceed while reserving the option of taking future action.

Source: OFT (2002) innovation and competition policy, March.

THE ROLE OF INTELLECTUAL PROPERTY RIGHTS

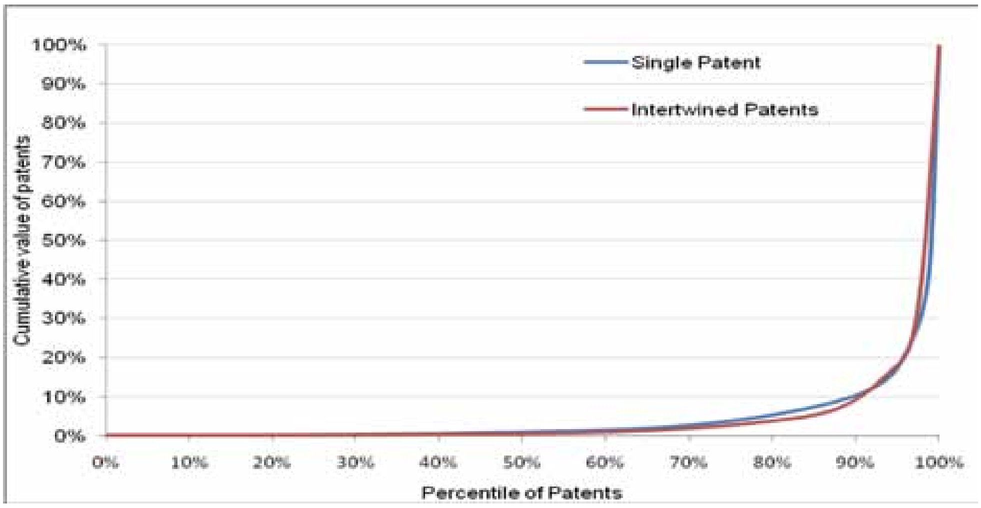
Intellectual Property Rights (IPRs) provide legal protection to exploit intangible investments. IPRs include patents, copyright and design rights which protect new knowledge and creativity, and trademarks which protect brand identity, used to communicate product and service innovation to users. **Patents give creators the power to deny use of knowledge to others while publicly disclosing the knowledge itself as a basis for further invention.** Trade marks protect reputation for commercial communication, again through an open public register. Copyright and design are largely protected through unregistered rights, with varying degrees of effectiveness. As the innovation system evolves, the IP framework has to be significantly reviewed to support innovation.

The Intellectual Property System

Of the £140bn invested in IP by UK business in 2008,[68] £65bn was protected by IPRs. This includes all of copyright (and software) investment, branding investment protected by trade marks, the majority of design investment and around 30% of R&D investment which produced patented inventions.

Reliance on formal rights affects a minority of British firms, with less than 15% of innovative large firms using patents to protect their innovation, and less than half of that when it comes to SMEs.[69] More firms use secrecy, speed to market or complex design to protect their technical innovations.[70] Most commercial value rests in relatively few IPRs, and even fewer IPR owners. Studies of European patents showed that the most valuable 0.8% of all patents account for half the value of all patents, as illustrated in Figure 27. It demonstrates the dangers of 'patent counting' as an approach to assessing innovation outcomes.

Figure 27: % Cumulative value of EU Patents*:*



Source: EU PatVal Survey (2005)

Part of the explanation for this is that IPR based industries, such as creative industries, are often characterised by 'winner-takes-all' competition, which provides strong incentives to become a lead innovator.

Innovation is of course not limited to industries which are IPR intensive, although firm level evidence shows that patents or trade mark use can improve innovation and productivity performance.[71] IP investment, like innovation as a whole, is spread across all sectors of the economy.

68 Expected figure from forthcoming report from Haskell et al for the IPO.
69 Mina, A. (with A. Hughes), (2009), *The Impact of the Patent System on SMEs'*, book chapter prepared for the UK Strategic Advisory Board for Intellectual Property Policy (SABIP), forthcoming.
70 Farooqui S., Goodridge P., Haskel J. (2011), The Role of Intellectual Property Rights in the UK Market Sector, Report for the Intellectual Property office, July.
71 Greenhalgh C. and Rogers M. (2006), *The Value of Innovation: The Interaction of Competition, R & D and IP*, Research Policy, Issue 35, pages 562-580.

Impact of the IP system on innovation performances

The IP system gives creators (or those to whom their rights are assigned) the right to stop other market participants exploiting their ideas in exchange for full disclosure about how their innovation was created. However, many IP rights are exercised through licensing agreements, allowing others to exploit knowledge, so effective licensing arrangements for IPRs can be vital for innovation. What are the key results on IPR use and innovation?

The use of patents is associated with a better use of knowledge within firms,[72] better transfer rates of knowledge between firms and universities, and improved knowledge creation.[73] Trade mark use is similarly associated with higher firm productivity in both France[74]and the UK,[75] while the use of IPRs by small firms is associated with significantly better chances of firm survival[76] and company growth. Similar results exist for Ireland,[77] while in the US, innovation returns with patents are also higher than for non-patenting firms,[78] and particularly so for patent intensive sectors, such as pharmaceuticals, biochemistry, aeronautics, etc.

New work for the Hargreaves Review on the relationship between patent intensity and competition suggests that in several UK industries this relationship works, with higher rates of competitive activity associated with higher prevalence of patents. However, there are industries where increasing patent density is associated with diminishing contestability, with the suggestion that patent 'thickets' may reduce the scope for new entrants to innovate. This appears to be true in areas such as software, and other technologies where innovation is sequential. This leads the review to recommend that the UK should not encourage the spread of patents to areas where their effectiveness is open to doubt (as noted above, contestability appear to be linked to productivity performance).

There is mixed evidence on the role of patent thickets influencing the innovation process, but smaller firms in particular have provided evidence to the Review on the risks they run if they accidentally infringe patents of which they are unaware. More pernicious are the activities of 'patent trolls' – firms which buy up unused patents, and then use the threat of legal action to extort licence payments for whom the costs – and risks – of going to court are too high. The Hargreaves review recommends further study of incentives to 'thin out' thickets around unused patents. One option already being pursued in France is 'France Brevets',

72 C. Criscuolo, J. Haskel and M. Slaughter (2006), *Global Engagement and the Innovation Activities of Firms*, National Bureau of Economic Research Working Paper 11479.

73 Crespi, C. Criscuolo, C. Haskel, H. and Slaughter, M.(2007), *Productivity Growth, Knowledge Flows and Spillovers*, discussion paper, Centre for Economic Performance, LSE.

74 OECD (2009), *Patterns of Trademark Used by French Firms and the Link with Innovative Activity*, Paris: OECD.

75 Greenhalgh, C. and Rogers, M (2007), *TradeMarks and Productivity in UK Firms*, working paper, University of Oxford.

76 Helmers, C. and Rogers, M. (2008), *Innovation and the Survival of New Firms Across British Regions*, working paper, University of Oxford.

77 Roper, S. and Hewitt-Dundas, N. (2010), *Path Dependency and Innovation: Evidence from Matched Patents and Innovation Panel Data*, draft paper, University of Warwick and Queen's University Belfast.

78 Arora, A., Ceccagnoli, M. and cohen, W (2008), R & D and The Patent Premium, *International Journal of Industrial Organization*, Volume 26 (5), pp 1153-1179.

a part publicly funded organisation to acquire unused or otherwise available patents to licence to SMEs in order to give them 'freedom to operate' in markets where they wish to innovate. The EU is examining the possibility of a wider scheme along similar lines.

The UK, along with most of Europe, has a relatively strict interpretation of what can be patented, only awarding rights for inventions which meet the test of an original 'inventive step', which moreover is not obvious. Patents which cover the UK can be granted by IPO, EPO, or through the Patent Cooperation Treaty (PCT) by application to WIPO. Unlike Germany, the UK does not grant 'utility patents', which have limited force, and all UK patents go through an examination procedure.

Software patents and Business Method patents (both valid in the US, only software in Japan and neither in the EU) do not disclose the underlying technology and appear to have little impact on software innovation.[79] There is an ongoing debate about the merits of genetic patents, while medical procedure patents are not allowed in the EU, and seem to contribute to the high cost of medical treatment in the US.

Areas in which the UK is currently working with other IP offices include:

- reducing backlogs in patent processing, which increase costs and uncertainty and can delay innovation, where IPO and USPTO are leading international studies;[80]
- international efforts to promote work sharing between IP offices, reducing cost and speeding up the examination process;
- progress towards a workable European patent system, through effective cooperation between leading EU offices, where the IPO is developing new models for an EU system, and the evidence to show why it should benefit UK and EU innovators;
- other international initiatives include the Green Patent fast-track system, and sharing with other nations the 'Lambert agreements' designed to facilitate university – industry collaboration, increasingly important as UK multinationals tend to organise their research globally.

Design Rights – UK business investment in Design is higher than in R&D. For instance, the UK has the EU's largest fashion industry, focused on London. Despite success in design-intensive activities, UK firms register fewer design rights than firms from other countries, either through IPO or through the Office for Harmonisation of the Internal Market (OHIM), which issues EU wide rights. IPO is examining the use of registered and unregistered UK and EU rights by key sectors, to identify areas where the rights system is effective, and where it might be improved. The Hargreaves review identifies this work as urgent.

79 Motohashi, K. (2009), Software Patent and its impact on software innovation in Japan, RIETI Discussion Paper series 09-E.

80 London Economics (2009), Economic Study on Patents and Computer-Implemented Inventions, *Report for IPO.*

Understanding and enforceability of design rights appears worse in the UK than in other countries, and the role of the national system given the apparent success of the EU design right is not clear.

Copyright value and licensing – The UK earns large returns on copyright licensing, and is one of only three nations to earn a net surplus from exports of music, lyrics, text and other rights.[81] Like patents, returns to copyright are highly concentrated on relatively few 'blockbuster' works, with a long tail of rights which earn very little. This affects the ease with which licensing systems can operate. Where licensing of copyright content is targeted at a well defined group need, with good guidelines and prices that can be arbitrated, licensing systems have evolved to allow the public to use copyright material – as with schools, universities etc. Where such a distinct group need does not exist, licensing has been slow to emerge and copyright content remains locked away, preventing possible innovation and exploitation of copyright assets, as in the case of orphan works, or user "mash-ups". It is argued that complexity and lack of transparency in access to content have hindered innovation in digital markets more broadly.

The Hargreaves review identifies this as an issue which requires resolution, for a number of reasons:

- copyright, especially as applied in the UK, has become a factor inhibiting the use of digital technologies which rely on copying, with the result that a large proportion of the UK population unknowingly infringes copyright in the normal course of consuming music or video;
- the legal uncertainties have inhibited useful technology applications, which damages both consumer welfare and business innovation;
- the costs for new innovators in digital services of navigating the complex forest of copyright licensing – which is still segregated nationally across Europe – are too high to enable them to compete in global markets;
- a copyright system designed for the printed word is also inhibiting research to make use of past knowledge which can now use text and data analytics;
- the copyright system also inhibits the protection of culture and historical assets through digital archiving, which is also subject to prohibitive costs for permissions and licenses to copy, increasing costs for both public and private sector players.

Hargreaves makes proposals to overcome these major barriers to innovation in use of digital content, without prejudicing the economic interests of content creators. The key recommendations are for:

81 PRS for Music (2010), Adding up the Music Industry 2009, from *CISAC 2008 Accounts*.

- Development of a **Digital Copyright Exchange** system, to encourage low cost, simple systems for licensing material and reduce transaction time and costs. This will require new work to develop understanding of 'markets for knowledge' into practical applications, in products which are non-rival and which have different values for each of the many possible buyers.
- **Implement available EU copyright exceptions** to something closer to those enjoyed by EU consumers and researchers, effectively liberalising the copyright system for the digital age, and enabling consumers to gain from new technology.

Copyright terms – There is a serious lack of empirical evidence around copyright and copyright policy, and its role as a stimulus to innovation.[82] Extensions of term in films for 17 OECD countries appear to have had no statistical impact on output.[83] Similar evidence in relation to Music showed a net cost to the UK economy, with 80% of performers gaining less than £38 per annum.[84] Historical work has questioned the effect copyright has on publishing competition, finding that output was higher and more diverse, to the authors benefit, before copyright systems were created[85]. Empirical work has shown that extending term did not increase the commercial use of in-copyright works.[86]

Enforcement – IPO's strategy aims to improve enforcement of IP rights, although in this area there is little evidence of economic impact.[87] The effect of on-line piracy is ambiguous, with no high quality peer-reviewed research.[88] Similar work on counterfeit and brand look-alike goods suggest possible net benefits to consumers if they understand that they are buying/using imitations,[89] counterfeits may not decrease the status or value of status goods,[90] and consumption of fakes increases the profits of legitimate goods.[91] However, there is almost certainly some disincentive effect to creators of new designs and luxury brands from imitation. IPO research aims to address the overall economic effects of enforcement strategies in 2011/12.

82 Corrigan and Rogers (2005) *The Economics of Copyright*, World Economics, 6(3) pp.153-174,

83 Png , I.P.L. and Qiu-hong Wang. (2009) *Copyright Law and the Supply of Creative Work: Evidence from the Movies*, SERCI documents, http://www.serci.org/2009/png.pdf

84 Goodridge P and Haskel J. (2011), *Film, Television & Radio, Books, Music and Art: UK Investment in Artistic Originals*, Report for the Intellectual Property Office, July.

85 E. Höffner (2010),*Das Urheberrecht: Eine Historische und Ökonomische Analyse*, Munich: VEW Verlag.

86 Heald, P.J (2009) *Testing the Over- and Under-Exploitation Hypotheses: Bestselling Musical Compositions (1913-32) and their Use in Cinema (1968-2007)*, 6 REV. ECON. RES. ON COPYRIGHT 31 (2009), reprinted in 60 Case W. Res. L. Rev.; Heald, P.J.,(2008) *Property Rights and the Efficient Exploitation of Copyrighted Works: An Empirical Analysis of Public Domain and Copyrighted Fiction Bestsellers*, 93 MINN. L. REV. 1031 (2008).

87 GAO-10-423, April 2010, *Intellectual Property: Observations on Efforts to Quantify the Economic Effects of Counterfeit and Pirated Goods*, April.

88 An overview of the grey literature is provided by the IPOs *Annual IP Crime Report* available at: http://www.ipo.gov.uk/ipcreport10.pdf

89 Wall, D.S. & Large, J. 2010. *Jailhouse Frock: Locating the public interest in policing counterfeit luxury fashion goods*. British Journal of Criminology 50(6).

90 Arghavan Nia, Judith Lynne Zaichkowsky, (2000) Do *counterfeits devalue the ownership of luxury brands?*, Journal of Product & Brand Management, Vol. 9 Issue 7, pp.485 – 497.

91 Barnett, Jonathan, *Shopping for Gucci on Canal Street: Reflections on Status Consumption*, Intellectual Property and the Incentive Thesis, Virginia Law Review, October 2005.

Business Support and Knowledge Transfer – Awareness of IP systems among SMEs is may be insufficient,[92] partly because IP is not covered by most business education, or design schools, despite the fact that business needs are increasing as the proportion of investment by firms in knowledge assets rises. As one policy response to this, IPO is developing its business outreach program with partners to fill the gap, and seeking ways to support the IP needs of future innovators.

Making the most of knowledge developed in universities is a key policy objective, and IPO has put major resources into standard 'Lambert' agreements to simplify technology transfer issues. Patenting by academics appears positively related to research output in sciences. It encourages funding but has a neutral effect on basic or applied science.[93] Evidence also suggests that there are positive spill-over effects from competing firms' rate of entry on incumbent patenting, [94] and from locating close to firms in related technology areas, at least within UK science parks.[95] IPO has published work on the changing role of universities as sources of knowledge for business innovation, and on the university characteristics associated with success.[96] Further work is planned in 2011 to better understand the 'demand side' of knowledge transfer, from the user firms' point of view.

Conclusion

Increasing complementarities between different kinds of knowledge, together with increasing dissimilarities between these bodies of knowledge[97], raise new challenges for regulation in areas related to market organisations and property rights. **How the diffusion of knowledge can be improved is a priority area for innovation policy**. This applies especially to patent and copyright related knowledge, where even legally defined rights can be hard to realise and value. It is important to recognise that many of the features of knowledge markets – including most of the IP system – are used by multinational firms.

Another priority area relates to how efficiently and appropriately knowledge is produced. The links between businesses, universities, research institutes and other agencies that are in the public sector are pivotal in this respect. Nowadays innovation is as much a matter of organisational and institutional design relating to the flow of knowledge as it is of R & D expenditure. This directs attention to knowledge production itself. The next chapter therefore focuses specifically on 'the knowledge system' and its role in innovation.

92 IPO, *UK Intellectual Property Awareness Survey 2010* Available at: http://www.ipo.gov.uk/ipsurvey2010.pdf

93 Larsen (2010), "*The Updated Classic on UK Intellectual Property Law, A Book Review*: Cornish, Llewelyn and Aplin, Intellectual Property, Patents, Copyright, Trademark & Allied Rights" (Sweet & Maxwell, 7th ed., 2010), 2 *Queen Mary Journal of Intellectual Property Law* 196 (2011).

94 Helmers (2010) "The *Effect of Market Entry on Innovation: Evidence from UK University Incubators*," *CEP Discussion Papers dp1002*, Centre for Economic Performance, LSE.

95 Helmers (2010) "*Choose the Neighbour Before the House: Agglomeration Externalities in UK Science Parks*". Available at: https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=res2011&paper_id=264

96 B. Andersen and P. Rossi (2010) "*The Flow of Knowledge from the Academic Research base into the Economy: the use and effectiveness of Formal IPRs and "Soft IP" in UK Universities*" A Report to SABIP available at: http://www.ipo.gov.uk/ipresearch-flow-201010.pdf

97 Metcalfe S. (2003) '*Knowledge of growth and the growth of knowledge*', in J.S. Metcalfe and Uwe Cantnor (eds), *Change, Transformation and Development*, Berlin: Physica Verlag.

Supporting a Coherent and Integrated Knowledge Infrastructure

This Chapter focuses on the creation of knowledge, showing that innovation performance frequently involves a range of organisations that are closely linked to the public sector. These organisations produce intangible assets that are vital for UK innovation performance because they are used as inputs for value creation across most economic activities. They are a source of competitive advantage for the UK and form the 'knowledge infrastructure'. We regard the knowledge infrastructure as having two main components:

- The science infrastructure, which consists of universities, and research and development institutes (both public and private) and is heavily involved in solving problems, creating knowledge and training skilled people. It is a key strength of the UK innovation system.
- The innovation information infrastructure comprises institutions supporting public goods information such as standards, measurement, accreditation, and design concepts, enables connectivity through a range of common languages and standards, best practices and reference sources, although its economic impact is only partly quantified.

Good coordination of these large systems of inter-connected organisations strengthens the innovation system as a whole, but raises issues of strategic management for public policy. The UK research system performs well in generating high-quality and high-quantity scientific outputs, and in linking the science system to firms, especially in high tech sectors. But while this part of the innovation system is working well, there are continuing questions over coordination between business, government and organisations in the wider knowledge infrastructure. Better coherence and integration of the science and innovation information infrastructures is an important challenge. It requires an exploration of how organisations in the system can interact more effectively to leverage existing investments.

Knowledge that is relevant to production can be defined at three broad levels:

- firm-specific knowledge bases, on the basis of which firms specialise and compete – these are more or less entirely the province of firms themselves;
- industry-level knowledge bases, which are the knowledge bases shared by all firms in an industry – these are often distributed across industry-relevant organisations, including specialised university departments and research organisations;

- generic (largely scientific) knowledge bases that are relevant across many industries; these include scientific disciplines, measurement methods and standards, and are strongly supported by the public sector through knowledge infrastructures. They are at the centre of this Chapter.

Infrastructures are essentially overhead assets that provide inputs to production or consumption across many economic and social activities; they have the economic effects of decreasing uncertainty and increasing the cohesion of economic actors. It is common to think of infrastructures in terms of physical infrastructures but in this Chapter we discuss large systems of knowledge or information institutions that provide inputs to production in a similar way:

- the 'science infrastructure' is first defined, and its performance and functions are analysed.
- the main institutions composing the 'innovation information infrastructure' are then categorised, and their outputs and contributions are examined.

Improving connections with the science infrastructure

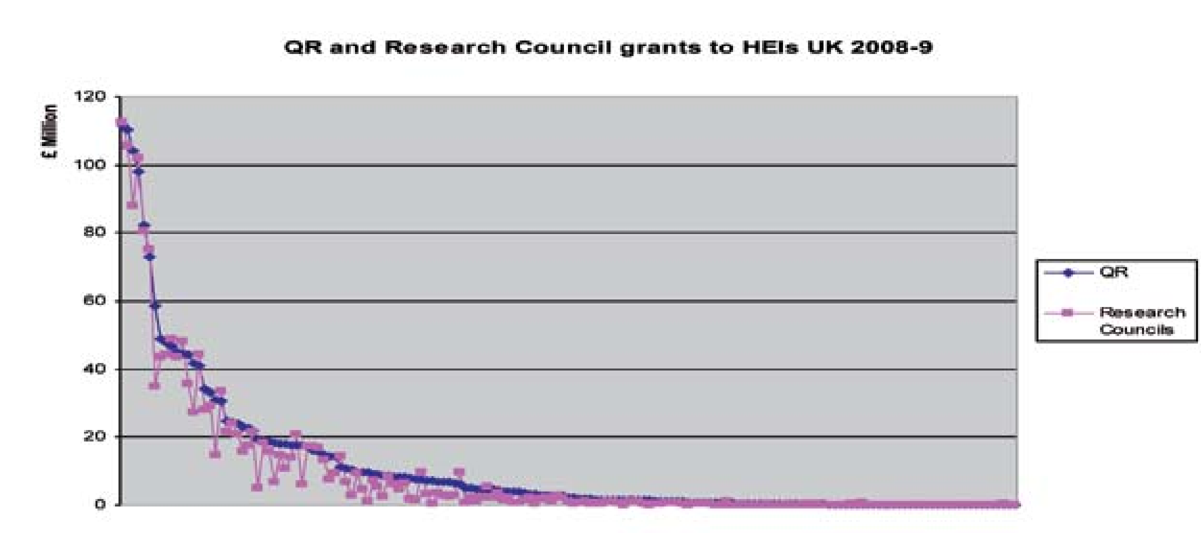
The UK science infrastructure consists in part of universities, and in part of a diverse collection of research and development institutes, both public and private, of which the largest group are the so-called Public Sector Research Establishments.

PERFORMANCE OF THE UNIVERSITY SYSTEM

The UK as a whole has over 150 universities carrying out different combinations of teaching and research, including 30 in the top 200 world universities. Some of these (Oxford, Cambridge and Imperial College) are in the top ten of the THES ranking of world universities, and the same group plus University College, London are in the top ten of the QS ranking. Eleven are in the top twenty of the THES ranking of European universities.

In terms of field, two UK universities are in the top ten in engineering and technology, two in life sciences, four in clinical medicine and health, two in physical sciences and two in social sciences. Publicly funded research investment in UK universities is asymmetrically distributed among them, as Figure 28 shows. Approximately two thirds of research expenditure is concentrated in the top twenty universities.

Figure 28: Distribution of research funding across universities



Source: HESA (2009/10)

A primary outcome of university research is knowledge contained in scholarly publication and scientific publication patterns are monitored regularly by BIS, benchmarking the UK position on a global scale, and shown in Table 4. In terms of volume the UK ranks third, attracting a share of world publications of 6.4% trailing the USA and China.[98] In terms of excellence, however, the UK accounts for the second largest share of citations after the USA. Citation impact is highly concentrated in a limited number of papers, of those that are highly cited, the UK attracts an even larger share, 14%, also trailing only the USA which accounts for 56% of the world's top 1% cited articles.

Table 4: Scientific publication pattern

Percentage World Shares 2010

Growth rates from 2006: Growing (green), static (amber) and falling (red)

	UK	China	USA
Population	0.9	19.6	4.5
Researchers	4.2	18.9	23.8
GERD	3.0	13.3	35.0
Articles	6.4	17.1	24.0
Citations	10.9	7.6	41.4
Highly Cited	14.0	5.0	55.8

Source: BIS (2011), International Comparative Performance of the UK Research Base, Elsevier, report to BIS

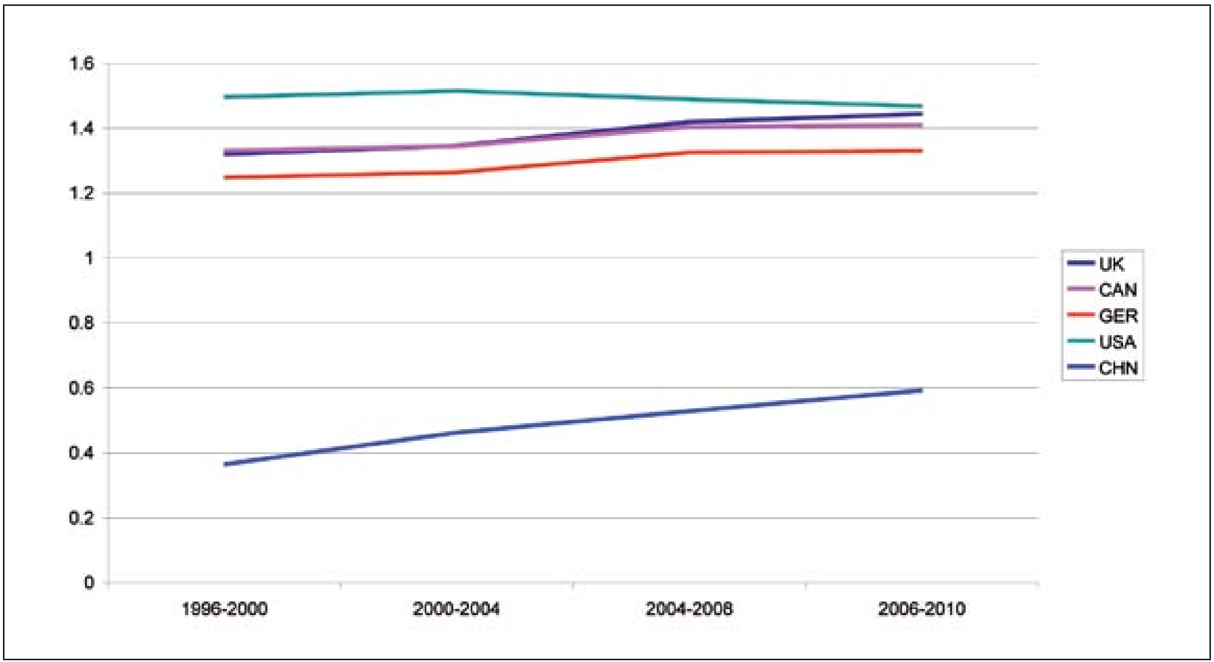
Notably however, while UK research output is declining in terms of world share, because of growth by emerging research nations, the UK research quality is still growing at a time when competing countries' shares like the USA are falling on

98 *International Comparative Advantage of the UK Research Base 2011*, e-report: www.bis.gov.uk/ukresearchbase2011/

both counts. Moreover, when the relative size of investment in R&D is accounted for, the UK research base achieves the best value for money among the large economies, leading on all counts of papers, citations and highly cited papers per pound spent on R&D.

National performance is inevitably shaped by the balance of disciplines on which the research takes place. While some of the longer established research nations have research strengths in a broad range of disciplines, emerging research nations tend to concentrate research efforts (and therefore strengths) around more limited range of disciplines. Weighting the outputs of research gives a more accurate picture of the relative position of countries in international league tables since it takes into account the research field mix. Figure 29 below shows recent evolution in field weighted citation impact for a selection of comparable nations. Only the UK and China have been increasing their field weighted impact since 2004.

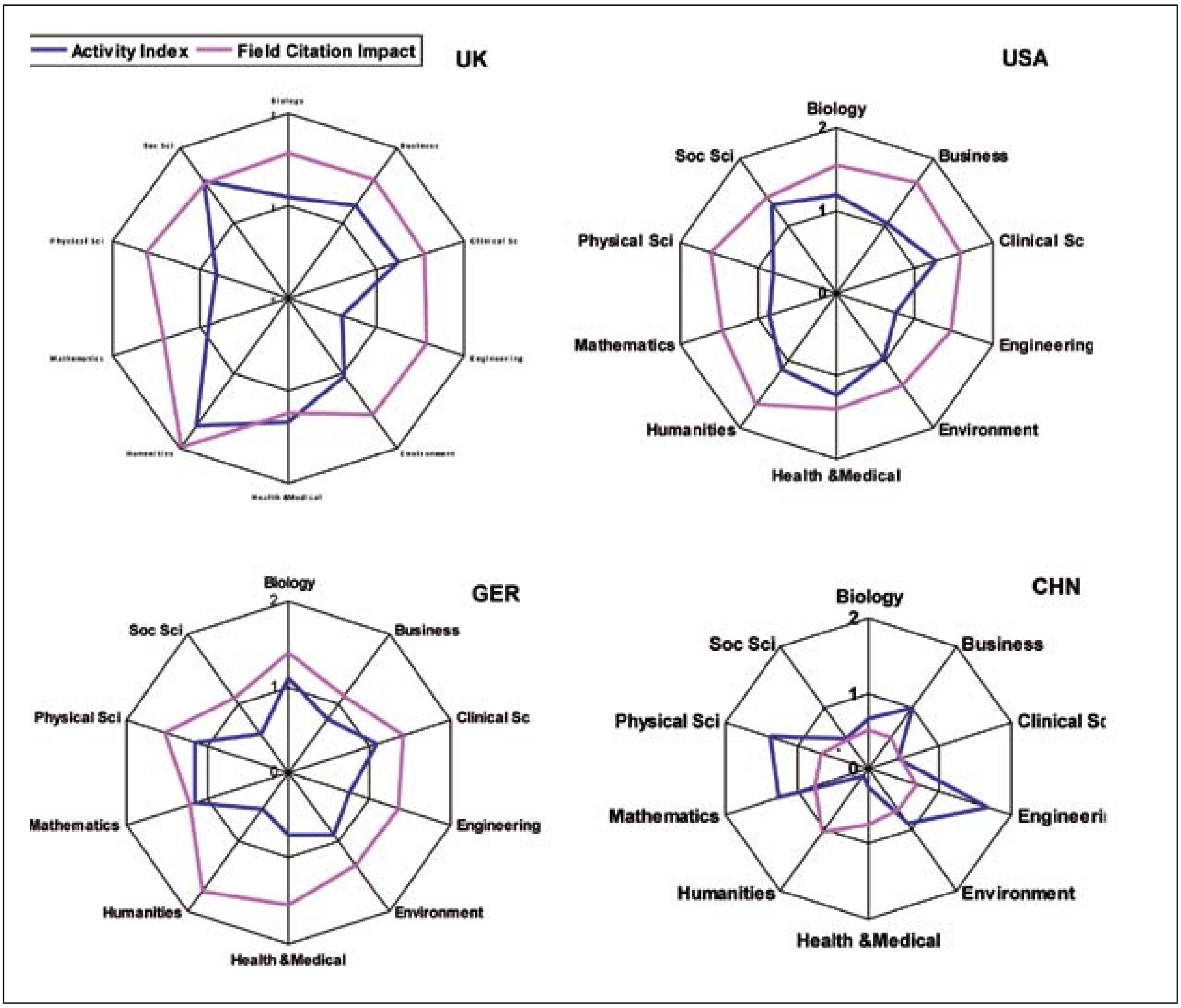
Figure 29: Field weighted citation impact



Source: BIS (2011), International Comparative Performance of the UK Research Base, Elsevier, report to BIS

The UK citation impact is high even in areas where publishing activity is low and losing ground to emerging nations, like Engineering and Mathematics. Figure 30 shows how activity and citations are not correlated. Comparing the “height” in the axis for each discipline it is clear that while the UK is not a world leader in activity in all disciplines, it is a world leader, comparable only to the USA in excellence in all disciplines.

Figure 30: Publication activity in 2010 relative to World compared with Field Citation in 2006-2010.



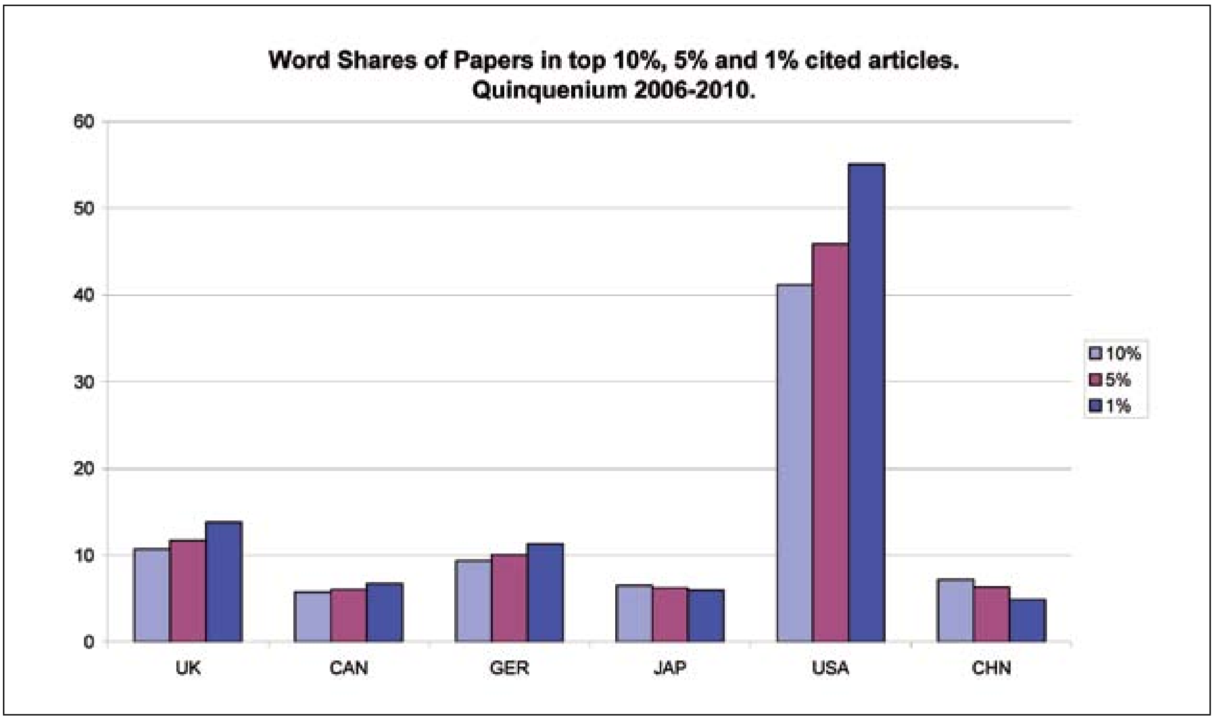
Values above 1 indicate publication rate or impact above world average.

Source: BIS (2011), International Comparative Performance of the UK Research Base, Elsevier, report to BIS

These facts point to a relatively advantageous position of the UK research base in the global markets but falling shares of research inputs as indicated by investments and researchers counts pose a risk over time.

Traditional research nations continue to lead on excellence and research quality, Figure 31 shows increasing concentration of top cited among traditional economies, accounting for increasing shares of the best cited articles when going from the top 10% to the top 1% in the five years from 2006 to 2010. However growth rates of citations and shares of excellence are increasing for nations like China and Brazil, indicating that they may well reverse the observed trend and start concentrating resources and increasing their ownership of highly influential research in the near future.

Figure 31: World shares of papers in top 10%, 5% and 1% cited articles



Source: BIS (2011), International Comparative Performance of the UK Research Base, Elsevier, report to BIS

ROLE OF THE UNIVERSITY SYSTEM

Universities should not simply be seen as a source of scientific discoveries that may or may not be relevant to innovation. They contribute to a range of innovation-relevant functions, the most relevant of which are as follows:

- Universities create knowledge in two broad economically relevant domains. These are firstly, generic scientific types of knowledge that are broadly applicable across fields, such as mathematics; secondly, there are ‘industrial sciences’ such as electronic engineering or chemical engineering; and social sciences, including business studies;
- Universities create capabilities in teams and individuals, both in terms of particular areas of expertise as well as wider abilities to identify and address problems; that is, they are a major channel of investment in high-level skills;
- Universities maintain knowledge bases via teaching, via data storage and transmission, and via the maintenance of libraries and databases;
- Universities develop innovation-relevant technologies, especially in fields such as instrumentation and software development. This includes user-initiated modification of existing processes and instruments;
- Universities develop new forms of problem-solving and search heuristics that enable firms to address new problems in new ways; that is to say, they not only solve problems, they develop new ways to address them.

- Universities engage in reactive problem-solving via a wide range of formal and informal collaborations with firms. This is often done via informal contacts rather than formal collaboration agreements, and therefore does not normally show up on the usual indicators for university-industry interaction.
- Universities have direct impacts on production via the creation of spin-off companies, and via the general creation and exploitation of intellectual property.

It is common to think of the impacts of universities in terms of the direct effects of knowledge discoveries. These tend to involve either the transfer of knowledge (via the licensing of a patent or via some type of formal agreement), or the creation of a spin-off company. These effects are real, although as noted above they are far from being the only channel of impact. The value that the private sector puts on collaborative and contract research with UK universities reached £3Bn in 2009/10,[99] up 4% since the previous years. In the same year, UK HEIs filed 2,012 patents and had 827 patent applications granted (some from previous years' applications); 273 spinoff companies were created, some of which will add to the 969 university spinoffs that remained active 3 years after creation. Cross-sector linkages between academia and the corporate sector are further strengthened with people moves between the two sectors. These moves are increasing for all countries and increasingly occur both ways.

The UK creates many spin-off companies: for example, in 2009-10, 273 spin-off companies were created (Table 5).

Table 5: Academic spin-off firms in the UK

	Number established	Number surviving after 3 years
2005-6	186	746
2006-7	226	844
2007-8	219	923
2008-9	215	976
2009-10	273	969

Source: HESA (2009/10)

We know relatively little about the overall economic value of these companies in terms of their capitalisation or contributions to GDP. One thing we do know, however, is that relatively few academics engage in spin-off company creation, while large proportions of academic staff in UK universities are involved in other forms of interaction with business.

The relevant evidence on these issues comes from the UK Innovation Research Centre which has conducted two important surveys on academic interactions

99 Higher Education Business and Community Interaction Survey 2009/10 (HESA).

with industry.[100] This research occurs against the background of a wide range of studies of academic participation in industry-relevant activities conducted across at least 8 countries.[101] These all suggest that academic entrepreneurship is a relatively minor element of academic-business engagement.

Table 6: Academic participation in spin-outs in the UK

	% of respondents (n=1902) who formed a spin-out in the last three years
All disciplines	3.5
Arts and Humanities	1.8
Biology, chemistry, veterinary science	3.9
Engineering, materials science	11.2
Health sciences	2.8
Physics, mathematics	4.9

Source: Abreu, M., Grinevich, V., Hughes, A., and Kitson, M. (2010), Knowledge Exchange Between Academics and the Business, Public and Third Sectors, UK Innovation Research Centre.

On the other hand, collaborative research, consulting, and informal problem solving are by contrast major activities (Table 7).

Table 7: Academic problem-solving activities in the UK

Problem-solving activities	% responding
Setting up physical facilities	9.0
External secondment	9.9
Prototyping and testing	10.2
Hosting of personnel	27.0
Research consortia	34.8
Contract research	36.8
Consultancy services	43.4
Joint publications	46.1
Joint research	49.2
Informal advice	56.9

Source: Abreu, M., Grinevich, V., Hughes, A., and Kitson, M. (2010), Knowledge Exchange Between Academics and the Business, Public and Third Sectors, UK Innovation Reseearch Centre.

100 The first survey, led by Alan Hughes and Michael Kitson and conducted by the Centre for Business Research in Cambridge, is a census of all UK academics, with a realised sample of 19029 respondents. The second survey, led by Ammon Salter at Imperial College Business School, known as the IGPC survey, covers 6106 researchers who were recipients of EPSRC grants after 1995. See: Abreu, M., Grinevich, V., Hughes, A., and Kitson, M. (2010), *Knowledge Exchange Between Academics and the Business, Public and Third Sectors*, UK Innovation Research Centre; and Salter, A., Tartari, V., D'Este, P., and Neely, A (2010)., *The Republic of Engagement. Exploring UK Academic Attitudes to Collaborating With Industry and Entrepreneurship*, UK Innovation Research Centre, and Advanced Institurte of Management.

101 See also Bruneel J, D'Este P, Salter A, '*Investigating the factors that diminish the barriers to university-industry collaboration*', *Research Policy*, 2010, Vol:39, Pages: 858-868.

Looking at different types of interaction across surveys, we find quite close accord across a range of business-relevant activities with high levels of academic participation (Table 8).

Table 8: Degree of engagement across types of interaction in the UK

Type of Interaction	Cambridge survey (At least once)	IGPC survey (At least once)
Attendance at conference with industry and university participation	87%	78%
Attendance at industry-sponsored meetings	n/a	59%
A new contract research agreement (original research done by university alone)	37%	54%
A new joint research agreement (original research undertaken by both partners)	42%	53%
A new consultancy agreement (provision of advice that requires no original research)	43%	44%
Postgraduate training with a company	33%	44%
Training of company employees (through course enrolment or through temporary personnel exchange)	33%	27%
Creation of new physical facilities with industry funding (e.g. new laboratory of buildings on campus)	9%	15%

Source: Salter, A., Tartari, V., D'Este, P., and Neely, A. (2010), The Republic of Engagement: Exploring UK Academic Attitudes to Collaborating With Industry and Entrepreneurship, *UK Innovation Research Centre, and Advanced Institute of Management.*

These results are important for our understanding of the role of universities in the innovation system. On the one hand, if we think of innovation as the commercialisation of research discoveries, either by technology transfer or by spin-off, then universities appear to play a relatively small role. On the other hand, if we take a more diffused view of innovation, seeing it as a complex set of problem solving activities that are not necessarily set in train by research, then the data suggests that UK academics are heavily involved in innovation processes.

PUBLIC SECTOR RESEARCH ESTABLISHMENTS (PSRES)

PSREs support both industry-level knowledge bases and the more general scientific knowledge base. They are part of a broader system of Public Research Organisations (PROs), often located in universities, and private-sector Research and Technology organisations (RTOs) that perform a wide variety of support services to firms. Support to these organisations comes partly direct from Government departments, but more significantly through the Research Councils. These organisations have formal or informal collaborative relationships that lead to flows of knowledge that are crucially important for the performance of the UK innovation system. There are at least three primary ways through which PSREs/PROs/RTOs support industry-level innovation and knowledge:

- Support to industrial innovation, comprising: scientific support to industry knowledge bases; problem solving and advice for commercial firms; innovation-relevant knowledge services; specific product and process outcomes; spin-out companies; user-initiated innovations. Case studies illustrating the influence of PSREs in the health sector are presented in Box 6 below.

Box 6: Research Councils activities and healthcare applications

In the MRC, research played a key role in the development of 10% of the monoclonal antibody drugs currently approved for use. The first therapy to reach blockbuster status was Humira with $1bn in sales in 2005. By August 2009 Humira was being used in 80 countries in the treatment of 370,000 patients, and it is now estimated to be the world's top earning pharmaceutical product, with sales predicted to reach $10bn by 2016. Other MRC activities included a series of medical trials, completed in 2010 that demonstrated that bowel cancer can be prevented with a simple, once-in-a-lifetime, five-minute screening test. Among 40,000 people screened, the test cut the incidence of the cancer by a third and the death rate by 43 per cent over a decade.

Outside of the MRC, case studies show that research carried out by the other councils, often adapted from its original function, has spilled over into the field of healthcare. A new core technology, originally developed by EPSRC-supported student Dr Mark Grubb to monitor the health of workers in metal foundries is being used to monitor the heart beats of newborn babies who need resuscitation, with an expected annual commercial EU and US market for the device of around £18 million.

BBSRC-funded researchers are continuing to work with the pharmaceuticals industry in leading research programmes in Streptomyces, which have huge significance for the production of novel antibiotics: an increase of just 1% in revenue streams from new antibiotics would generate revenue potential of c£300M. While impacts from past BBSRC research include a new molecular test for Blue tongue, developed and commercialised at the BBSRC sponsored Institute for Animal Health (with colleagues at the French Laboratoire Service International), which is estimated to have avoided losses of around £400M.

Looking at the STFC, UK advances in particle physics technology not only supported important experiments at CERN but pioneered early developments in superconducting magnets, which in turn led to the development of MRI scanners. The MRI industry supported around 4,000 jobs in 2007, with an estimated value added contribution to UK GDP of £195 million. MRI technology has revolutionised healthcare. There are more than 20,000 MRI scanners installed around the world performing 60 million examinations every year. Around 500 scanners in the UK carry out more than a million examinations every year, making a huge contribution to government targets for the diagnosis and treatment of cancer.

Source: UK Research Councils (2010): Economic Impact Reporting Framework, Reports 2009-10

- Infrastructure creation and maintenance, comprising: provision of top-level ‘general purpose’ technological capabilities; physical and knowledge infrastructure provision; personnel training, development and mobility. Case studies illustrating the contribution of PSREs in the technical and environmental fields are presented in Box 7 below.

Box 7: Research Council activities in technological developments

A number of the Research Councils provide evidence showcasing the technological impacts of their research. Among these EPSRC have invested in Innovation and Knowledge Centres, (IKCs) aimed at accelerating and promoting business exploitation of emerging research and technology fields. Each of the five centres funded receives up to £6.95 million funding over 5 years with a further £2.5 million from the Technology Strategy Board. The Centre for Secure Information Technologies (CSIT) at Queen’s University Belfast, is an IKC set up to exploit the university’s international research expertise in high performance data and network security and intelligent surveillance.

While a consortium comprising of the German company HB Systems and Surrey Satellite Technology Ltd (SSTL), a company spun out by EPSRC-funded researchers from the University of Surrey in 1985, has secured a contract worth £510 million to supply the first operational spacecraft for Europe’s Galileo satellite-navigation system. One recent study found that between 2006 and 2025, Galileo is likely to bring cumulative economic benefits to the nation of over £18 billion, from such benefits as transport safety improvements and environmental benefits from shorter journey times.

Other technological investments have been made in the field of environmental research, NERC has provided essential research and advice to government regarding experimental carbon capture and storage technology (CCS). The UK government estimates that the value of the North Sea Business could be £2-4bn per annum by 2030 and sustain between 30,000 and 60,000 jobs over the period 2010-2030. While other research funded by NERC and HDB-Horticulture and undertaken by scientists at Lancaster University and Stockbridge Technology Centre discovered that treating tomato seeds with jasmonic acid (JA) resulted in protection against pests for up to eight weeks after germination. Jasmonic acid is involved in controlling a plant's natural defences against pests, but it had not been anticipated that it would provide protection for so long.

Source: UK Research Councils (2010): Economic Impact Reporting Framework, Reports 2009-10

- Public policy development and implementation, comprising: contributions to policy development; information for policy implementation; contingency planning and monitoring for accidents and natural disasters. Case studies showing PRSEs activities in the cultural, historical and economic policy developments are given in Box 8 below.

Box 8: Research Council activities in public policy development

The AHRC's activities are primarily cultural. Recently the council explored the experience of migration from the Bengal delta region from 1947 onwards made new connections through working with local communities, engaging with public policy, and by providing new educational resources. As part of this project a website and educational resource pack was developed in collaboration with the Runnymede Trust to support teachers and children undertaking Key Stage 3 in the UK to encourage young people to engage with their family histories, their communities, and society more broadly.

ESRC funded research and researchers contributed to the design, development and implementation of the Pathways to Work initiative largely through indirect interventions, for example, by supporting leading researchers and research centres, and developing new methodologies and data sources. An 'ESRC impact ratio' was developed, suggesting an estimated ESRC contribution in the order of £2m over the period 2003-09.

By undertaking a cost-benefit analysis of the Education Maintenance Allowance in terms of increased attainment levels and participation in post-compulsory education, it was possible to estimate the benefits of the policy outcomes in terms of increased lifetime earnings of the target population. The study calculated the benefits associated with these efficiencies and used them as a baseline for the assessing of the value of ESRC's contribution to the EMA, estimated to be around £10m.

Source: UK Research Councils (2010): Economic Impact Reporting Framework, Reports 2009-10

The innovation information infrastructure

The innovation information infrastructure offers specialised, but widely accessible, knowledge to the science infrastructure and businesses, and to wider society. This information acts as a set of pervasive resources that reduce the costs of innovation and enable efficiency and connectivity through a range of common languages, best practices and reference sources. It takes both codified forms (written, formalised) through agreed standards, frameworks and guidance, and tacit forms (based on know-how/experience, education and skills) through expert advice and networking activities. **Both codified and tacit knowledge is part of the informational glue that enables the innovation system to work effectively.**

INFORMATION INSTITUTIONS

Here we describe five central organisations in the information infrastructure, and the functions they fulfil with respect to innovating firms.

- *The British Standards Institute (BSI)* provides technical, managerial, environmental, design agreed codes of best practice that improve safety, efficiency, and interoperability and that facilitate trade. Well designed standards reduce the costs to businesses and consumers as they can adopt products and processes with confidence. It also provides expert advice on the use of standards. Standards are a good measure of codified knowledge of new and improved technological information that firms can economically acquire and apply.
- *The UK Accreditation Service (UKAS)* reduces bureaucracy and increases efficiency by moderating the need for legislation through assessing and ensuring conformity with applicable standards and requirements, focussing on providing an independent evaluation of an organisation's technical competence, thus maximising the value of standards.
- *The National Measurement Office and the National Measurement Institutes (NPL, LGC, TUV, NEL)* provide standards of measurement for use in trade, industry, academia and government. These enable the benefits of new products and processes to be measured and stimulate new product development in the instrument sector. Measurement standards underpin a wide range of public goods, including consumer protection, forensic science, environmental controls, medical treatment, and food safety regulation. Agreed measurement standards are a key element in almost all modern innovations and technologies.
- *The Design Council* supports the application of good design in business and, importantly, the public sector through best practice guides, contribution to design standards making, networking activities and expert advice.
- *The Intellectual Property Office (IPO)* promotes innovation by providing an IP framework that enables creators, users and customers to benefit from knowledge and ideas. It also provides expert advice on the use of IP in business. This Intellectual Property System is developed in the section on protecting property rights, also in this Chapter.

PERFORMANCES OF SOME INFORMATION TYPES

Over the recent years Government, in partnership with the partner bodies and external experts, has attempted to better quantify the economic impacts of information infrastructure provision. These studies make important steps towards a solid evidence base on the effects and impacts of the innovation information infrastructure, although the synergies between several parts of the information infrastructure are still not well understood.

The evidence rests on one series of studies conducted by the DTO and BIS in recent years.[102] Emerging findings suggest that:

- Standards make a significant contribution to innovation performances
  - They contribute some £2.5 bn per annum to today's economy;
  - They have a significant role in promoting the transfer of technology across countries, especially in major manufacturing sectors. Technology dissemination via standards has contributed 12% pa to UK labour productivity growth since 1945;
  - The propensity of business to see standards as valuable knowledge inputs for innovation was positively related to the size of the net standards stock available in an industry, within a range. But new and older standards can inhibit innovation, the former by not providing enough information and the latter by promoting out-of-date technologies. The relationship depended crucially on the age of the stock, with a high proportion of either "old" or "new" standards having a negative effect on their informational value.
- For some industries and user groups the need for accurate measurement is critical:
  - It is especially a requirement in high tech manufacturing. For example, companies manufacturing precision engineering components used in aero engines will be working to tight specifications. Public services such as healthcare and forensics also make a critical use of measurement;
  - Recent research finds a positive relationship between the extent of measurement knowledge available to business sectors and the types and degree of innovation carried out by firms in those sectors. A striking result is that measurement knowledge is more strongly associated with novel than with 'catch-up' innovation; that is, it underpins leading-edge product and process innovation;
  - Metrology science is part of the public science base and private sector research and development. Recent research shows that metrology is deeply embedded in the national research effort with a growing number of publications jointly with university researchers, while metrology papers are heavily cited in other scientific publications;

102 Major contributions are: Lambert, R. (2010) *Economic Impact of the National Measurement System*. Evidence paper of the UK Department for Business, Innovation and Skills. July 2010; Vinodrai, T. Gertler, M and Lambert, R. (2008) "Capturing Design: Lessons from the United Kingdom and Canada," Chapter 5 *in Science, Technology and Innovation Indicators in a Changing World: Responding to Policy Needs*, OECD; Lambert, R. "Economic Impact of the National Measurement System", An evidence Paper prepared for the Measurement Advisory Board, 2010; Lambert, R. and Temple, P. (2008). *The Economics of Weights and Measures in the UK*, (Report prepared for the National Measurement Office); Swann, G. M. P. (2009*) The Economics of Metrology and Measurement,* Report for the National Measurement Office; Swann, G. M. P. (2010) *The Economics of Standardization: An Update*. Report for the UK Department of Business, Innovation and Skills. May 2010; Swann, G. M. P. (2010) The Economic Rationale for a National Design Policy, BIS Occasional Paper 2; Goncalves, J., and Peuckert, J., (2011), *Measuring the Impacts of Quality Infrastructure: Impact theory, empirics and study design*, Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin.

  - Measurement knowledge indicators make a positive and statistically significant contribution to productivity and growth that is complementary to that of product and process innovation, reflecting the pervasiveness nature of measurement. The implied elasticity of performance on increases in the stock of measurement knowledge, especially for more advanced user groups is high, at around 8%.

- Design is an important category of intangible investments:
  - The estimate of design expenditure in the pilot NESTA index suggests that design investment amounts to around £20 bn annually in the UK, which can be compared with £14 bn on formal R&D activities by business;
  - A recent survey of intangible investment by business, carried out by the ONS as part of the NESTA Index project, estimated design spending related to new and improved products and processes to be under £2 bn, which is consistent with the results from the UK innovation survey;
  - Surveys of the design industry carried out for the Design Council estimated the turnover of the industry to be of the order of £15 bn.[103]

- Little, if any, research has been undertaken into the specific effects of the way that the accreditation system has innovative effects. Work is in progress to fill this gap as part of an exercise to build a firmer evidence base.[104] However, there is an argument that accreditation can become even more important when used with lower regulation as an efficient way of managing risks.

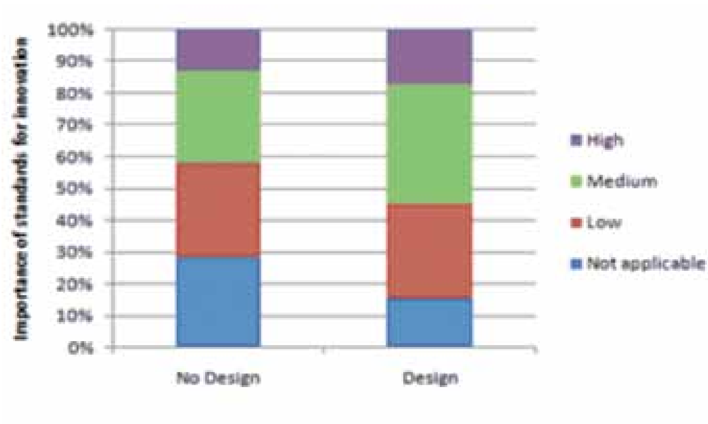
The codified and tacit knowledge generated and distributed by the infrastructure are complementary – that is, they can have more powerful effects in joint applications. Research suggests that there are complementarities between infrastructure information sources.[105] Figure 32 shows the joint importance to innovating firms of design (design investment for product and process innovation) and standards as a source of information for innovation. Standards and strategic investment in design are interdependent. For example, some 65% of innovators with design investment rate standards as medium or high importance as information, against 45% of innovators without design investment.

103 Notably the industry as defined for the survey was heavily weighted towards product, communications, branding/marketing and other aesthetic aspects, and excluded are parts of engineering design and architecture sectors that feature in the indirect estimates produced for the NESTA index project.

104 An Infrastructure Partners Project led by BIS is underway.

105 UK Innovation Survey (2009).

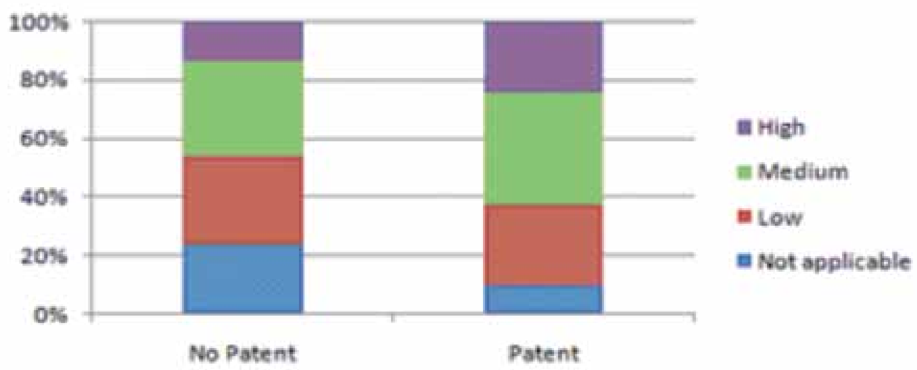
Figure 32: Standards and design in innovating firms



Source: UK Innovation Survey 2009

Similarly, Figure 33 shows a significant degree of complementarity between patents and standards amongst innovating firms.

Figure 33: Standards and patents in innovative firms



Source: UK Innovation Survey 2009

A better understanding of the complementarities between parts of the information infrastructure would allow the provision of better and more easily accessible services to innovative businesses. This is an area for both better research and policy development.

Conclusion

The interactions between the institutions examined in this Chapter and businesses play a central role in advancing innovation capacities. They are a source of sustained competitive advantage through problem solving, capacity building, reducing uncertainties and accelerating the transfer of new knowledge. They contribute to the growth of innovative enterprises located in the UK. They also actively contribute to the visibility and reputation of the UK as an attractive economy for investment.

Taken as a whole, these infrastructures facilitate investment, and are important because **innovation unavoidably requires large investments**. Investors are open to the erosion of the worth of their assets by innovations made by others. Assembling and financing new assets, and managing risk and uncertainty are complex challenges for businesses. In the aftermath of the recent economic crisis, uncertainties have significantly increased and the consequences for the willingness of businesses to make innovative investments in this context are difficult to anticipate. Creating an environment which maximises the ability to meet these challenges is a fundamental objective of public policy, as Chapter 5 will show.

Encouraging Business Investment in all Forms of Innovation

This Chapter shows that all sectors and industries innovate but that they do so in different ways:

- Innovation is not exclusive to a small group of high-technology businesses or industries but extends to services and low tech manufacturing. Services in particular represent a very large part of the UK economy.
- High growth firms are particularly important for output growth and employment creation. These are innovative businesses, and are distributed across all sectors of the economy.
- Innovation depends on the development of innovation-related assets. The mix of input investments differs across industries, but five core innovation 'modes' can be identified.

This Chapter points to the importance of a more differentiated policy approach taking into account inter-industry variations, and barriers affecting the ability of managers and entrepreneurs to invest:

- Innovation involves both large technological and economic risks and uncertainties. Investing over uncertain and sometimes long-term futures poses serious challenges for management and government.
- Financing investment is a major issue, both for new firms (where both bank and venture finance play roles) and for existing firms (which must allocate their own resources to innovation).
- Appropriate skills, both in terms of research and technical skills and those of organisation, coordination and management, are costly to acquire and change over time.
- Transforming existing physical infrastructures, in particular integrating high communication networks into all the other infrastructure networks, is crucial in cities in which a large part of the innovation system tends to be concentrated.

In all these areas providing the right framework conditions are essential to incentivise business investment in innovative assets, on which future growth depends.

In this chapter, recent data and studies are used to first demonstrate that all industries invest in innovative assets, and that this is not confined to high-tech sectors. This is a crucial point that has to assume a more prominent position on policy agendas, especially in advanced economies. Some major challenges in investment in innovation are then examined. The most important of these are:

- Management of high level of risk and uncertainties, especially for long-gestating investment programmes involving complementarities;
- Ensuring sustained financial commitments to innovation within businesses over time;
- Developing generic and firm-specific skills of employees, a necessary form of intangible asset for businesses because it is complementary to investment in other tangible and intangible assets.
- Building a physical infrastructure based on new information and communication technologies to encourage businesses to make complementary investments and develop new assets.

Encouraging innovation across the economy

Many approaches to innovation policy, both in the UK and other OECD economies, have favoured particular sectors or technologies. The emphasis has often been on research-intensive activities that produce ‘high tech’ products: ICT technologies and activities, biotech and pharmaceutical applications and industries; aerospace and nanotechnology. In some cases there is a strong argument for this. Generic technologies, such as the digital complex, can have powerful cross-industry impacts, and are therefore very important in the policy agenda. However, **diverse innovative assets, which are the defining features of advanced economies, can be found across all sectors and all industries**.

VARIETY OF INNOVATIVE BUSINESSES

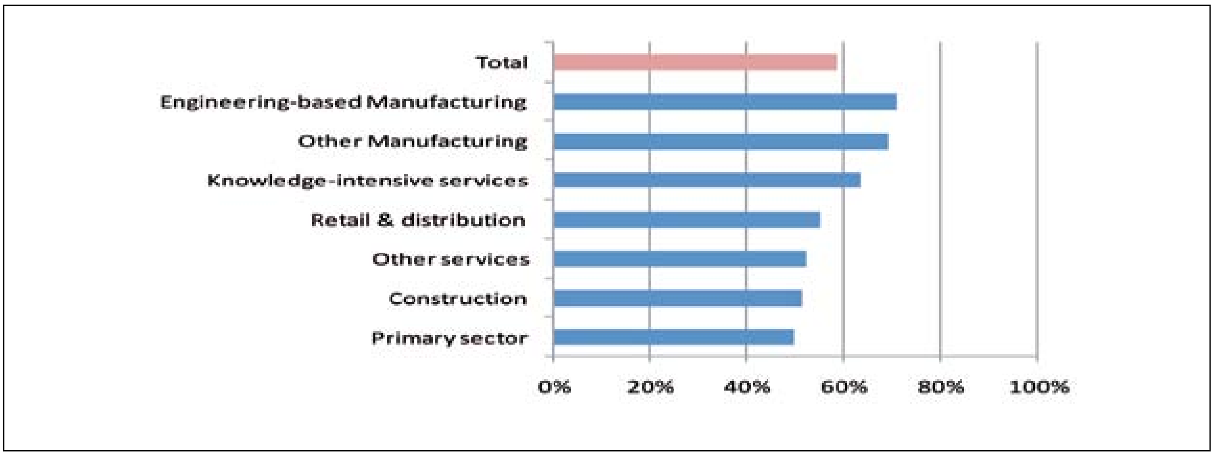
High tech manufacturing sectors are, in themselves, small. A policy focus only on these sectors therefore excludes a very large part of the economy.

High tech activities mainly produce inputs that are used elsewhere – so **the success of high tech industries, and their impact on productivity, depends on the extent to which they are adopted by other, lower-tech, industries**. The output of high-tech sectors are only of value when used in conjunction with the outputs of other, less research-intensive sectors. Conversely, innovation in low and medium tech sectors often involves the serial incorporation of high-tech components into existing products and production processes. Quite apart from these considerations, low and medium tech industries are innovative, often on the basis of non-R&D inputs. A large body of evidence support these claims.[106]

106 Robertson, P., Smith, K., and von Tunzelmann, N, (2009), *Innovation in low- and medium-technology industries*, Research Policy, 38, (3) pp. 441-446; Robertson, P and Patel, PR, (2007), *New Wine in Old Bottles: Technological Diffusion in Developed Economies*, *Research Policy*, 36, (5) pp. 708-721.

Figure 34 shows that in the UK 58 per cent of businesses were innovation active between 2006 and 2008 and that innovation activity is not confined to high-tech sectors.[107]

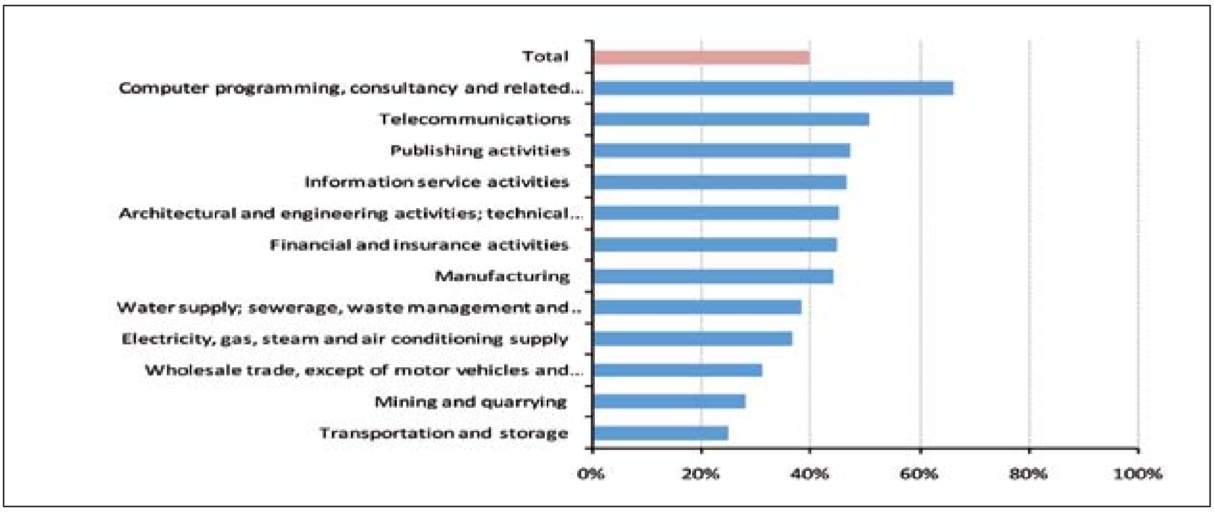
Figure 34: Proportion of innovative active enterprises in the UK, by sector (2006-2008)



Source: UK Innovation Survey, 2009

This is confirmed by Figure 35, which looks at similar data for the EU as a whole, and shows that innovation active enterprises cut across sectors in Europe.[108]

Figure 35: Proportion of innovative enterprises in Europe (excl. UK) by sector (2006-2008)



Sources: Eurostat Community Innovation Survey (2009)

107 The UK definition of innovation active is that the business must either be a product or process innovator, had ongoing or abandoned innovation projects, or had engaged in activities (such as R&D, training) related to innovation.

108 Eurostat use a more restricted definition of innovation activity than the UK and define innovation activity as enterprises with technological innovation (product, process, ongoing or abandoned), regardless organizational or marketing innovation.

However, different sectors use different inputs. Data from the UK Innovation Survey shows substantial variation across sectors in terms of input investments. This can be readily seen in Table 9. For some sectors, such as primary sectors, construction and retail distribution, the acquisition of machinery, equipment and software from outside the firm is a primary innovation investment (a significant part of this is output from the high tech sectors, as noted above). For two sectors, engineering and knowledge-intensive services, internal R&D is a key input. But *all* sectors require a mix of inputs.

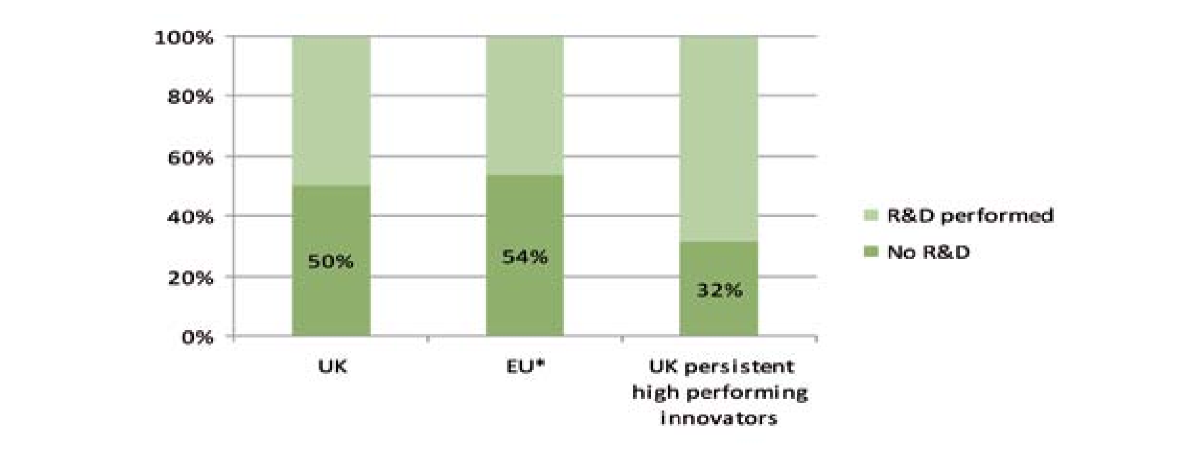
Table 9: percentage of innovative expenditure by sector, 2008

	Primary sector	Engineering-based Manufacturing	Other Manufac-turing	Construction	Retail & distribution	Knowledge-intensive services	Other services
Internal R&D	6.0	44.0	19.2	7.6	16.9	45.7	5.1
Acquisition of external R&D	6.4	15.7	6.2	4.2	4.1	16.4	2.4
Acquisition of machinery, equipment and software	78.2	21.3	44.7	65.3	45.3	27.1	35.0
Acquisition of external knowledge	4.4	2.2	3.8	9.4	3.5	1.9	20.7
Training for innovative activities	2.3	2.3	4.9	3.3	2.0	2.3	28.0
All forms of design	1.3	12.1	8.5	7.8	4.9	2.8	3.1
Market introduction of innovations	1.5	2.5	12.7	2.5	23.3	3.9	5.8
All	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: UK Innovation Survey, 2009

There are many forms of innovation that do not rely on the relatively small group of high tech sectors for inputs. Innovation is not at all a matter of research-intensive sectors producing radical changes, while low tech sectors engage in smaller-scale innovation. Major, world-changing innovations can and do emerge from relative simple technological shifts in low tech manufactures and services. Perhaps the most dramatic example of this in the modern era is containerisation, a logistics innovation with deep consequences. This innovation, like for example refrigeration in food handling, did not necessarily involve R&D. This is a significant point in modern innovation, because many innovators simply do not do R&D. Figure 36 below shows that half of the innovative companies in the UK innovate without specialised research activities. For the EU as a whole the proportion is even higher. Absence of R&D might conceivably be an effect of low-innovative firms; however within the UK Innovation Survey data it is possible to isolate the top ten percent of innovating firms in the UK. It is important to note that about a third of these high innovation performers use this kind of no-internal-R&D innovation model.

Figure 36: Proportion of innovation active enterprises with no R&D, 2006-2008



Sources: Eurostat CIS6; R.J. Adams, 'The distribution of innovation activity across UK industry', BIS (2010)[109]

It is noteworthy that companies in the services sector use innovation models that are highly reliant on intangible assets. The growth of services in advanced economies has amplified their importance, given that many service-sector firms are highly reliant on intangibles and less reliant on traditional tangible capital.

MODES OF INNOVATION ACROSS INDUSTRIES

Innovation is a cross-sectoral phenomenon but modes of innovation differ. A recent project under OECD auspices, carried out by researchers across OECD member countries, has made extensive use of the micro-data from innovation surveys across the world to develop analytical and econometric models of how innovation operates across countries in terms of the behaviours of businesses and their systemic connections, including with the knowledge infrastructure.[110] Five core modes of innovation emerge from the analysis:

1. **IP/technology innovating** – largely representing use of in-house R&D, and formal appropriation methods i.e. Intellectual Property Rights.
2. **Marketing based innovating** – this broadly combines new-to-firm product innovation with investment or initiatives in the distribution and marketing of innovations
3. **Process modernising** is characterised by the introduction of a new process, together with buying in of machinery, equipment or IT, and external (supplier) contributions to the innovation mode.

109 * EU – excludes UK, internal R&D only. Innovation active as enterprises with technological innovation (product, process, ongoing or abandoned), regardless organisational or marketing innovation.

110 For methods and results, see: Lambert, R. and M. Frenz (2008)' Innovation modes and productivity in the UK.' Report to the Science and Innovation Analysis Unit, UK Department for Innovation, Universities and Skills; Frenz, M and Lambert, R (2008) 'Mapping closed and open innovation practices: a comparison across nine countries based on micro-level innovation survey data', Dynamics of Institutions and Markets Discussion paper, no. 64; Frenz, M and Lambert, R. (2010) 'Mixed modes of innovation in national and regional systems of innovation: some comparative analyses'. Presented at the Conference in honour of Nick von Tunzelmann, University of Sussex. OECD (2011); a similar model (with fewer modes) is set out in OECD (2009). This section uses the results of one strand of this project, which develops typologies of innovation modes in each participating country.

4. **Wider innovating** modes link together managerial and organisational innovations.
5. **Networked innovating** links internal R&D with bought in R&D, closeness to the knowledge base and cooperation on innovation.

This work can be used to compare differences in innovation modes across broad industry groups and to some extent look at similarities and differences in innovation modes in industries across countries.

Differences across industries are significant:

- For example, 'IP/technology innovating' mode appears most relevant for firms in high-tech manufacturing sectors and least relevant in services, as would be expected.
- 'Process modernising' mode has the lowest difference across industries.
- Financial services generally focus on the 'wider (managerial) innovating' mode but also record a perhaps surprising orientation to the 'marketing based innovating' node.

Interestingly, while there are some similar patterns of specialisation of industries across countries, patterns unique to individual countries also emerge. They largely reflect the features of the domestic innovation system within which industries innovate (see Chapter 2). **Similarities in industrial orientation are mediated by strategies and external opportunities that are local and national.** For example, in the case of Austria, the vehicles sector specialises in technology based innovation, in conjunction with 'networking'. In Germany, on the other hand, networked activity is the main mode, supported by technology and externally oriented process modernising. In Belgium and South Africa, 'external process innovation' is the leading modality. In general, 'wider innovating' (based on managerial and strategic change) is less favoured in the vehicles sector in most countries except in Korea and Chile, where it is one of the leading modes.

There is considerable inter-country heterogeneity in business services, with alternative patterns of strategic combinations of the innovation modes. In the case of the UK, for example, 'wider innovating' shows the highest relative score, but this is close to the other modes. In Italy, 'networked innovating' is the leading orientation of the sector. In Spain and South Africa, 'process modernisation' is more heavily represented in the sector, although this mode is a less prominent part of the innovation strategy of the sector in most countries.

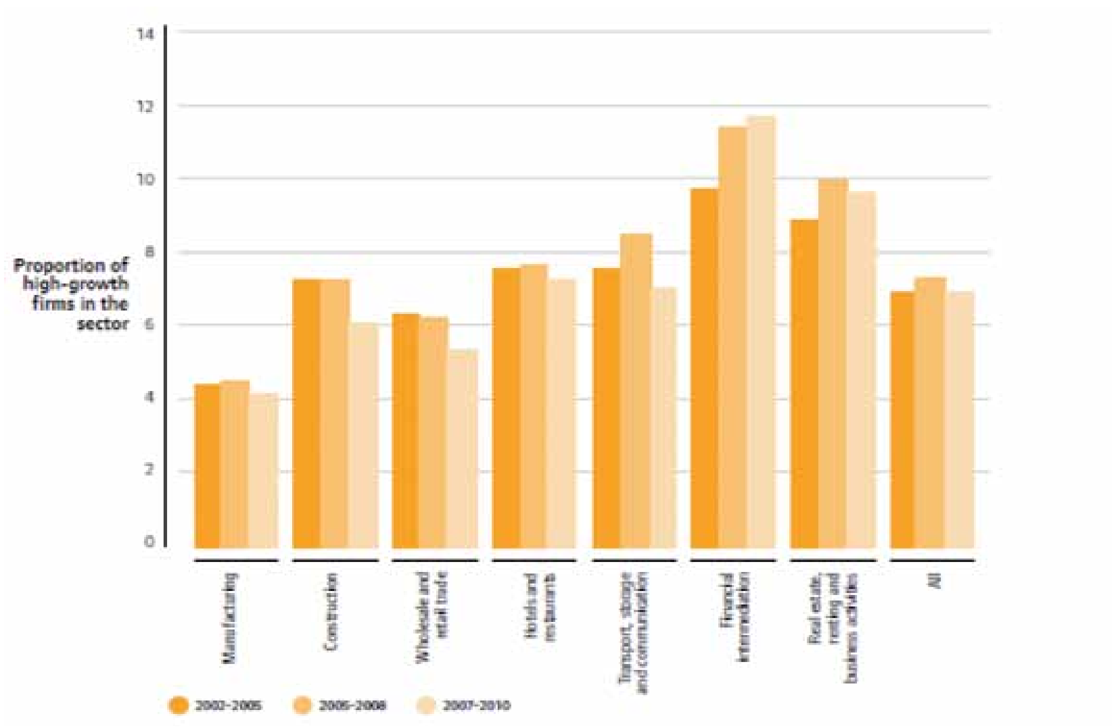
These considerations showing the broadness of innovation, and its pervasive presence across all sectors, suggest a need for a more differentiated policy towards innovation across sectors of the economy. **The mix of inputs for innovation differs across sectors, so the risk profiles of innovation differ, the financing aspects of innovation differ, and the supply of skills and infrastructure needed differ.** All are major issues for government; but it now seems clear that the mix of these conditions needs to take inter-industry variation more fully into account.

HIGH GROWTH BUSINESSES

NESTA's 2009 research into high growth firms confirms the evidence presented in the previous sections.[111] The records of all UK companies between 2002 and 2008 were analysed. 11, 000 businesses generated 20% or higher average annual employment growth over a three-year period and created 54% of new jobs. In the period 2007 to 2010, the number and share of UK businesses growing at over 20% per year remained broadly similar to that in the periods 2002-2008. Some key findings from this research are that:

- High growth businesses are not just high tech companies **but are distributed across the economy, from mining to banking,** as in Figure 37. Alongside high-tech companies, high growth firms are logistics providers, facilities managers, professional services firms and manufacturers.

Figure 37: Share of high-growth firms in the UK by sector



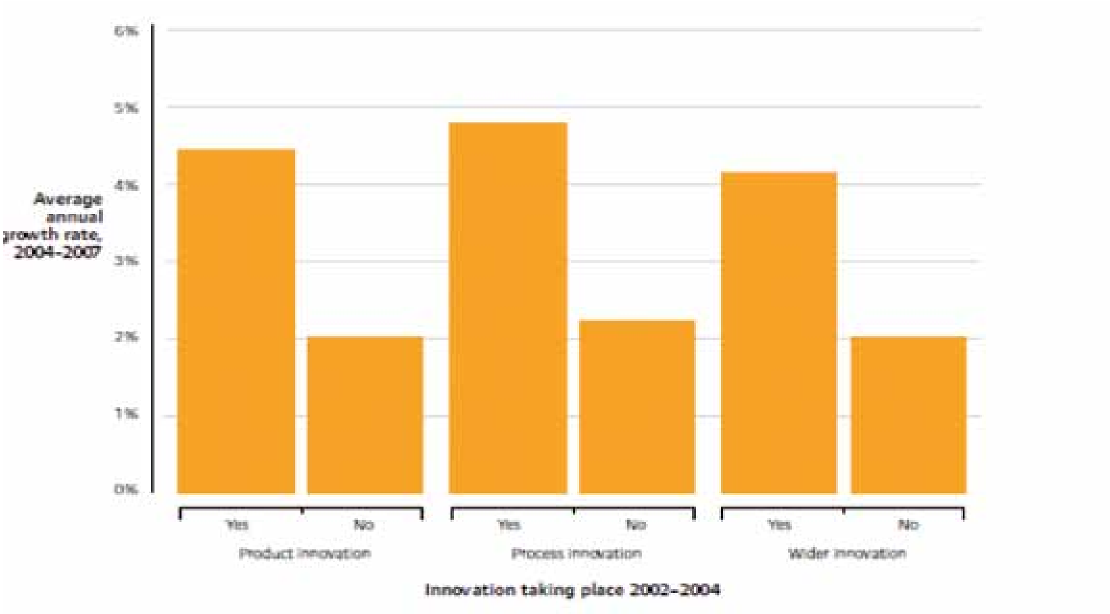
Source: NESTA analysis of the ONS business structure database (2009)

111 NESTA (2011), *Vital Growth: The Importance of high-growth Businesses to the Recovery*, London: NESTA. See also A. Bravo-Biosca (2011), '*A look at business growth and contraction in Europe*', London: NESTA, 2011; Paper to 3rd European Conference on Corporate R&D and Innovation.

- **High growth businesses are not just start ups.** New companies are not the only ones that grow rapidly, some of these companies built the foundations of their growth over many years. Of the 221, 731 businesses founded in 1998, for instance, two thirds had vanished by 2008, and of those that remained only 10% had more than 10 employees and achieved at least one year of growth. High growth is not an intrinsic characteristic of some businesses, but a stage that some companies will go through and others will not.

- **High growth businesses are innovative firms.** Earlier work by NESTA and NIESR[112] shows that being innovative is associated with high growth, with innovative businesses growing twice as fast as non-innovative ones, as shown in Figure 38.

Figure 38: Innovation and business growth



Source: "Innovation patterns in Small and Medium size Enterprises (SMEs)" on page 100ESTA (2009)

INNOVATION PATTERNS IN SMALL AND MEDIUM SIZE ENTERPRISES (SMES)

Small firms are often regarded as driving innovation, as opposed to large incumbents, usually because the small-firm population contains new entrants. But this view needs to be qualified. **SMEs perform less innovation than large firms** across a range of dimensions covering product innovation, process innovation, non-technological innovation, new-to-market product innovations and collaboration in innovative activities.

Very few SMEs undertake Research and Development activities. Table 10 below sets out the percentage of small businesses that were engaged in research and development in the manufacturing and services sectors in each year since 2005.

112 Mason, G., Bishop, K. and Robinson, C. (2009), *Business growth and innovation: the wider impact of rapidly-growing firms in UK city-regions"*, Research Report BGI/36, London: NESTA.

Table 10: Percentage of SMEs* engaged in R & D

	2005	2006	2007	2008	2009
Manufacturing	2	2.4	2.7	2.6	2.7
Services	0.5	0.6	0.6	0.6	0.6

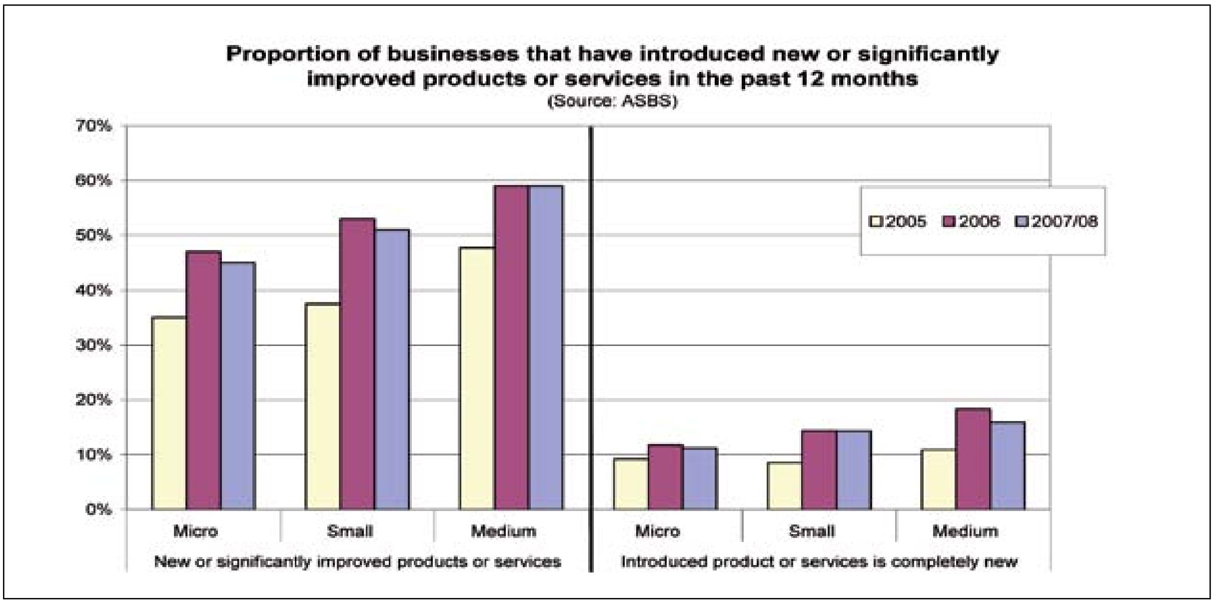
Source: ONS 2011, Business Expenditure on R&D *2009*

** A small business is defined as one with 0 – 49 employees and the percentages are of the total population of small businesses.*

It is important to note however that the difference in innovation between SMEs and large firms is due to a lower proportion of small firms innovating rather than a lower intensity of innovation in those that do innovate. In certain high technology sectors (semiconductors, biotechnology), emerging sectors (green industries) and creative industries (film production, publishing, architecture) innovative SMEs have been important drivers of innovation based on a combination of intangibles, new technology and design skills. There is a smaller gap between large firms and SMEs in share of turnover due to new-to-market product innovations compared with the amount of innovation.

This suggests that **SMEs who do innovate achieve a higher average return on investment** and tend to have a better commercial success rate with bringing innovation to the market. The rapidly increasing power and declining cost of information technology and the spread of online content have reduced SME barriers to innovation and facilitated new models of collaboration such as Open Source Technology (see Chapter 3). The combination of new technologies with increasing consumer demand for bespoke products and labour market flexibility has allowed SMEs to narrow the innovation gap versus large firms with the innovation gap falling from 11 percent in favour of large firms in 2004-06 to 2 percent in 2006-08. Figure 39 shows that within SMEs, size still matters, while medium size firms. Innovation rates in Micro and Small firms though rising, are still lower. Therefore, recent trends have reduced rather than eliminated economies of scale and minimum efficient size.

Figure 39: Proportion of businesses that have introduced new or significantly improved products or services in the past 12 months



Source: BIS 2009, Annual Small Business Survey

It nonetheless remains that **innovation requires a riskier and greater investment in human capital and physical capital than reproducing an established product and these barriers are more acute for SMEs**. In Chapter 3 the difficulties that innovative SMEs face regarding the infringement of intellectual property has been emphasised. In this Chapter the other barriers to investment for SMEs' managers will be analysed.

Managing risks and uncertainty

Risk (in the sense of the probability of certain outcomes) and genuine uncertainty (in the sense that we do not know what the possible outcomes might be) are defining features of innovation. After all, innovation by definition is novelty, and we do not know in advance what the nature and impacts of novelty might be. Therefore the identification and management of risk and uncertainty is a key function of any innovation system and systems differ in how well they approach and manage risk. **Incentivising businesses and investors to invest in innovative projects over long term investment horizons is a central challenge for policy.**

RISKS AND UNCERTAINTIES ASSOCIATED WITH NEW TECHNOLOGIES

Where technologies are radically new, and therefore involve disruption of existing knowledge bases, they tend to involve significant risks and uncertainties, and this is a central problem for innovators. **The future of new technologies is inherently uncertain in part because success often depends on an extended process of multiple innovations, which shapes and expands new application areas and generates returns.** Increases in productivity growth tend to be produced over time by the cumulative effect of a series of improvements within a new technological system, rather than by a single innovation. It is very challenging to foresee the trajectory of future improvements and quantify in advance the economic benefits those improvements will generate: [113]

- New technologies often work imperfectly, and have little or no performance advantages over the technology they might replace (jet engines did not initially perform better than prop engines, for example). Long periods of post-innovation improvement can be necessary.
- Identifying uses for new technologies can be very problematic. The economic impact of an innovation often depends on clusters of complementary inventions, and this reshapes the application environment. The time frame over which these complementary inventions could be developed can vary considerably.
- Major technological innovations entail profound organisational changes, and also product design development. A period of gestation is necessary before the opportunities they embody are properly understood and exploited. This period can be long for radical innovations as the tendency is to conceive them in terms of the old technologies that they will eventually replace. This can explain both why spectacular breakthroughs usually lead to only slowly rising productivity growth initially and why many new technologies take long periods to replace an established technology.
- A new technology can turn out to have applications in totally unexpected contexts. Innovations often arise as solutions to specific problems in particular industries and in some cases may have a significant economic impact in other industries. Society often finds uses for new technologies that were unanticipated by innovators (such as SMS texting in mobiles, a function that was intended by developers to compete with pagers).
- The introduction of new technologies often tends to accelerated improvements in old technologies, leading to a competition between different technologies. Innovations can turn out to complement an existing technology and not necessarily replace it.

These points are supported by a very large number of case histories, some of which are briefly described in Box 9.

113 This section draws in particular on the ideas of Nathan Rosenberg. See for example Rosenberg. N (1995), *'Innovation's Uncertain Terrain'*, The McKinsey Quarterly, Number 3.

Box 9: Case histories on the development of technological innovation	
Laser	The patent lawyers for Bell Labs were initially unwilling to apply for a patent for the laser, believing it would have no relevance to the telephone industry. Yet, in 1966, the best transatlantic telephone cable could carry only 138 conversations simultaneously. The first fibre-optic cable, derived from laser technology and installed in 1988, could carry 40,000. Those installed in the early 1990s can carry nearly 1.5 million. Even more unexpectedly, the laser has become central in ICT, and has become the instrument of choice in many surgical procedures, including eye, gynaecological and gall bladder surgery. Overall development of lasers from invention to widespread application took many decades.
Computer	In 1949, the computer was thought useful only for carrying out rapid calculations in certain scientific and data processing contexts. Thomas Watson, then president of IBM, rejected the idea that the computer might have a much larger market, on the basis of well-informed advice from a body of experts on the technology. The prevailing view at that time was that world demand could be satisfied by just a handful of computers.
Radio	The inventor, Marconi, thought radio would mainly be used between two points where communication by wire was impossible, as in ship-to-ship or ship-to-shore communication, or over difficult terrain. He envisaged the users of his invention as steamship companies, newspapers and navies. It is only later, during the 1st World War, that Sarnoff appreciated the commercial possibilities of radio and how the new technology could be employed to transmit news, music and other forms of entertainment and information.
Walkman	Batteries, magnetic tape and earphones had all been around for some time. Akio Morita's innovative breakthrough was to have the idea of providing entertainment in unexpected settings, thereby identifying a market opportunity for Sony that had previously been overlooked.
VCR	The American pioneers, RCA and Ampex, gave up long before a usable product had been developed. Matsushita and Sony, by contrast, went on to make thousands of small improvements in design and manufacture. The initial concept of the VCR had been of a capital good for use by television stations. Progress came with the realisation that there might be a mass domestic market for the product if its performance, and especially its storage capacity, could be enhanced. The VCR became Japan's largest export product.

Source: Rosenberg (1995), Innovation's Uncertain Terrain, The McKinsey Quarterly, Number 3

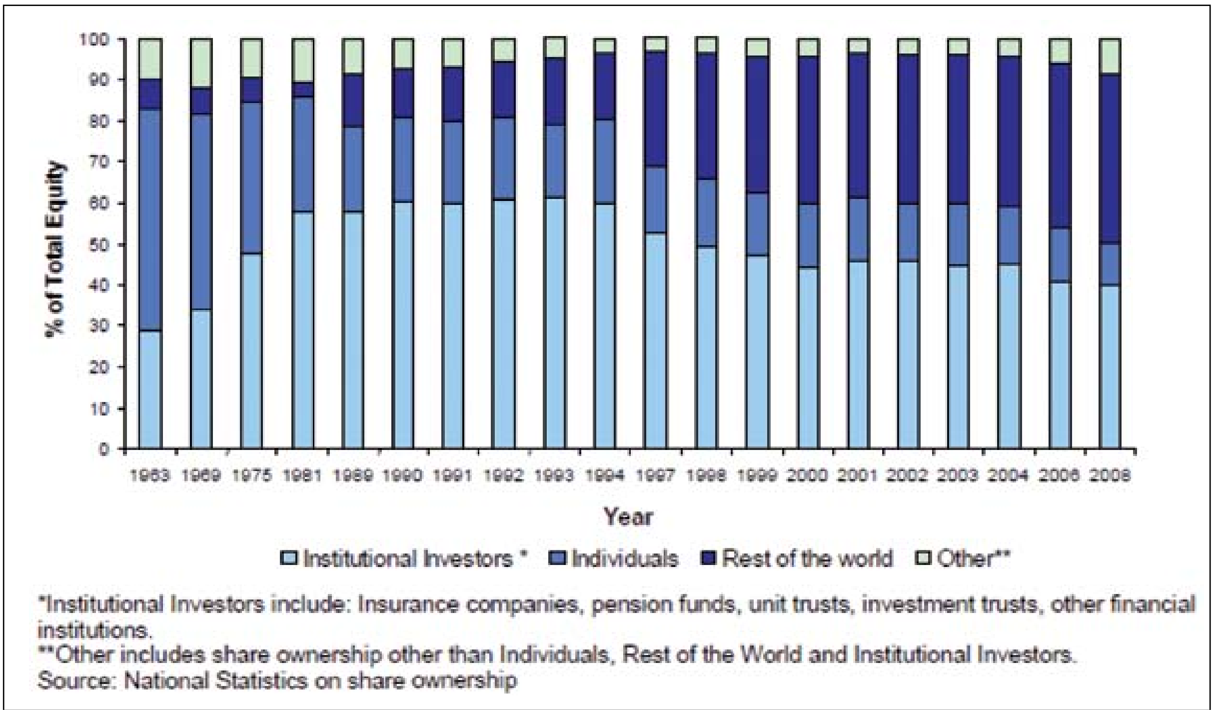
The benefits of innovation therefore are hard to predict and commonly accrue over the long term and this is especially the case for radical innovations.

THE 'SHORT-TERMISM' DEBATE

In recent years there has been a controversy regarding the rise of short-term behaviours among investors in capital markets – so-called 'capital markets myopia'. This controversy is in large part a debate about corporate governance. The corporate governance framework comprises the processes, customs, policies, laws and institutions that shape the way a corporate operates and delivers the long term success of the company. This includes procedures for allocating resources to innovation. Engagement by shareholders is important as it allows understanding and guiding the company strategy more effectively. It has been argued that capital markets are increasingly focused on short-term returns and that this may be having a detrimental effect on their efficiency, on the return on investment and on company behaviour. There is increasing evidence to support this view. A recent study finds that the market-based governance systems characteristics of the UK create greater pressure towards the reduction of R & D than other European countries, which are characterised by less developed financial markets and lower takeover pressures. Remuneration systems for executives that attempt to incentivise them by linking pay and a bonus to the financial performance of the firm has 'a particularly strong negative impact on R&D'.[114] This point has been made by a number of commentators,[115] to the extent that BIS recently organised a consultation on this topic.[116] The costs of an increased focus on short-term returns by businesses would be under-investment in activities such as research that are central for innovation and therefore in the growth potential of the economy over the long term.

The 'short-termism' argument stems from changes in the nature of shareholders in the UK companies. Figure 40 shows that the proportion of individuals in total ownership has been declining over the years. By the 1980s share ownership was dominated by domestic institutional shareholders. More recently, there has been a relative decline in the share of UK institutions and a corresponding rise in the share of non-UK ownership.

Figure 40: Main share ownership categories in the UK, 1963-2008



Source: BIS (2010), A Long Term Focus for Corporate Britain: Call for Evidence, October

114 Honoré, F., Munari, F., and Van Pottelberghe de la Potterie, B. (2011) '*Corporate Governance Practices and Companies' R&D Orientation: Evidence From European Countries'*, Breughel Working Paper 2011/01.

115 For instance, Greenspan (1996), Francis Boyer Lecture, The American Enterprise Institute for Public Policy Research, Washington D.C., December 5; Rappaport A. (2005), The Economics of Short-term performance obsession, May, Financial Analysts Journal; The Aspen Institute (2009), Overcoming Short-termism: A call for a More Responsible Approach to Investment and Business Management; Lazonick W. (2007), The US Stock Market and the Governance of Innovative Enterprise, Industrial and Corporate Change, Volume 16, Number 6, pp. 983–1035.

116 BIS (2010), *A long Term Focus for Corporate Britain: Call for Evidence*, October, BIS.

However, most holdings are aggregated into bigger 'institutional' managed pools of capital. Institutional shareholders therefore remain prominent. They currently account for 77% of the Investment Management Association's (IMA) members' assets under management in the UK, which is estimated to manage about 40% of total UK equities. In this context, the role of investment managers who invest on behalf of a range of institutional and retail clients is pivotal. It is argued that investors and managers increasingly focus on share prices and short-term indicators (resulting from easy data access from the widespread use of ICTs) to make decisions. This may create agency problems, where companies' directors would be discouraged from taking a long-term view of the business, and fund managers would generate income through fees related to the number of portfolio changes rather than increased long-term value for their clients.

Such issues are very difficult to isolate and quantify, and therefore the evidence base to support these views is not strong enough at this time to draw robust conclusions. However, the Bank of England has recently highlighted evidence showing that increased liquidity and information availability have led to increased trading and share price volatility in the UK, with high dividend payouts being maintained despite variation in profits. Holding periods of shares have reduced from 5 years in the 1960s to less than 8 months in 2007 and high frequency of trading now accounts for 30-40% of European trading in equities and futures. A recent piece of research[117] suggests that there is significant evidence of short-termism among UK companies over the past few decades. It shows that long duration cash-flows and projects are penalised particularly severely by excess discounting and argues that this is a market failure. It concludes that reducing the effects of short-termism involves supporting greater transparency about long-term performance, improved governance, and better contract design and tax/subsidy measures.

The basic issue is that profit-seeking companies often have relatively short time horizons for investment, and this may or may not been aggravated by recent trading practices. Income-contingent loans e.g. the launch-aid system for Airbus, research institute funding e.g. for the world-wide web, or the independent labs of state-owned companies e.g. for mobile telephony, have all been important – though often ad hoc –mechanisms for handling these problems. **These functions of risk and uncertainty management are central to innovation systems, and have to be openly acknowledged and addressed.** One way policy can support business investment is by developing and communicating strategic frameworks over the longer term, especially in areas where Government is a major consumer such as health, or urban development. Another way is by putting in place mechanisms and initiatives to 'de-risk' some investments, for instance through a smarter use of procurement. We will look at these issues in the rest of this Chapter and in the following Chapter.

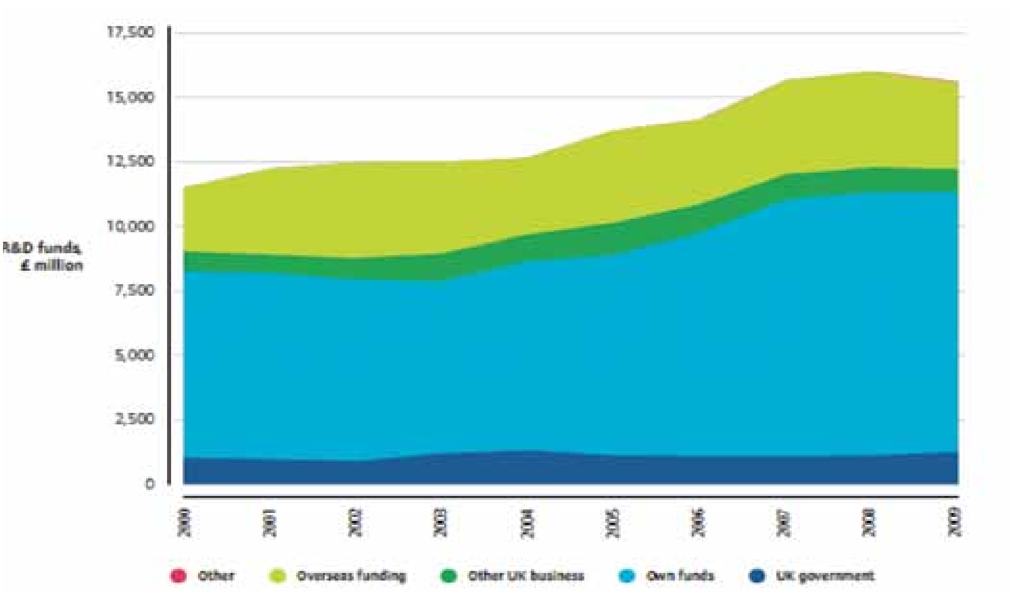
117 Andrew G Haldane and Richard Davies, '*The Short Long*', Speech to 29th Société Universitaire Européene de Recherches Financières Colloquium: *New Paradigms in Money and Finance*, Brussels, May 2011.

Financing innovative businesses

Since the returns on innovation are highly uncertain and assets can take an intangible form it can be difficult for investors to assess companies' market value. In addition, in the event of failure, this intangibility limits resale value. **This is even more pronounced for innovative SMEs**, which makes it more difficult for them to access external finance.[118]

Businesses fund a significant amount of their innovative activities through retained earnings. Figure 41 shows that 60% to 65% of R & D is funded internally by firms.

Figure 41: Source of funds for UK business expenditure on R & D, 1990-2009

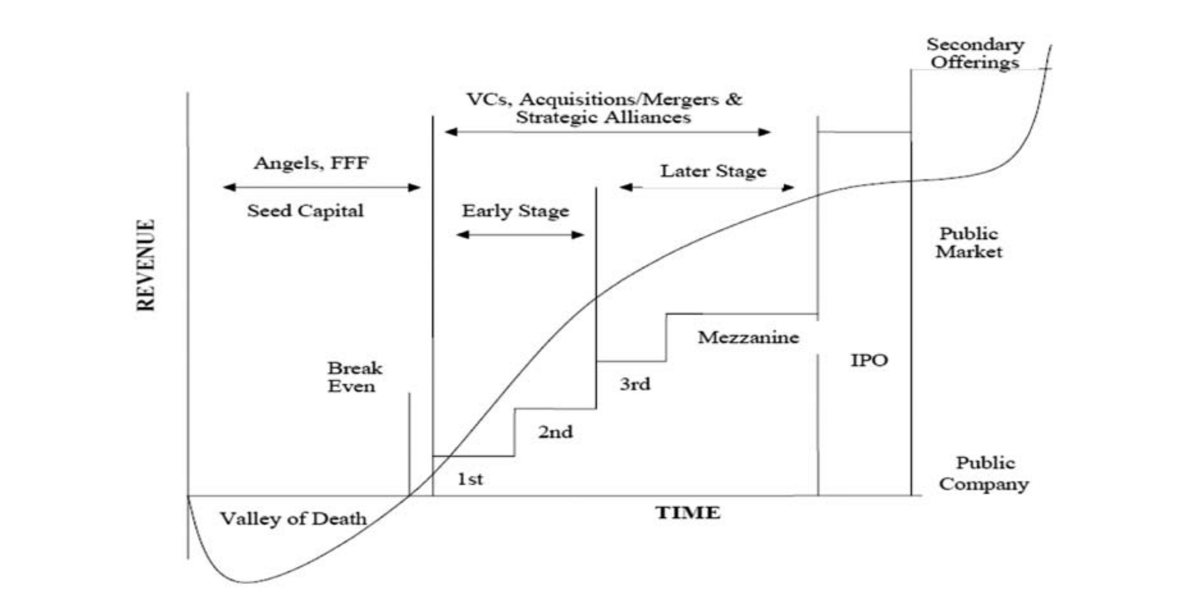


Source: ONS 2011, Business Expenditure on R&D *2009*

However, they also receive funding from a variety of sources, especially SMEs. The financing requirements of innovative SMEs vary throughout the product cycle and during these different phases they can be met by various sources. An illustration of this is presented in Figure 42 below.

118 Other factors that can also impede the successful financing of innovative SMEs are: a lack of management skills, absence of adequate accounting history and limited market power.

Figure 42: Product cycle financing



Source: BIS 2009, Annual Small Business Survey

Personal savings (plus, for example, mortgages on houses) are often important sources of funding for start-ups due to their inherent risk excluding them from bank loans. As personal funds diminish and more capital is required, Business Angels can play an important role, if they are still prohibited from bank loans and are considered to be too small for venture capital investment. Along with capital, Business Angels can also offer expertise, knowledge and contacts.

After firms have passed the early stages, second round funding can come from venture capitalists. Venture capitalists reduce the uncertainty and information asymmetries characterised by innovative SMEs by spending time actively scrutinising and familiarising themselves with the company before and after providing the funding.

However, data from the Community Innovation Survey (Figure 43) show that costs and availability of finance are seen as high barriers to innovation by enterprises.

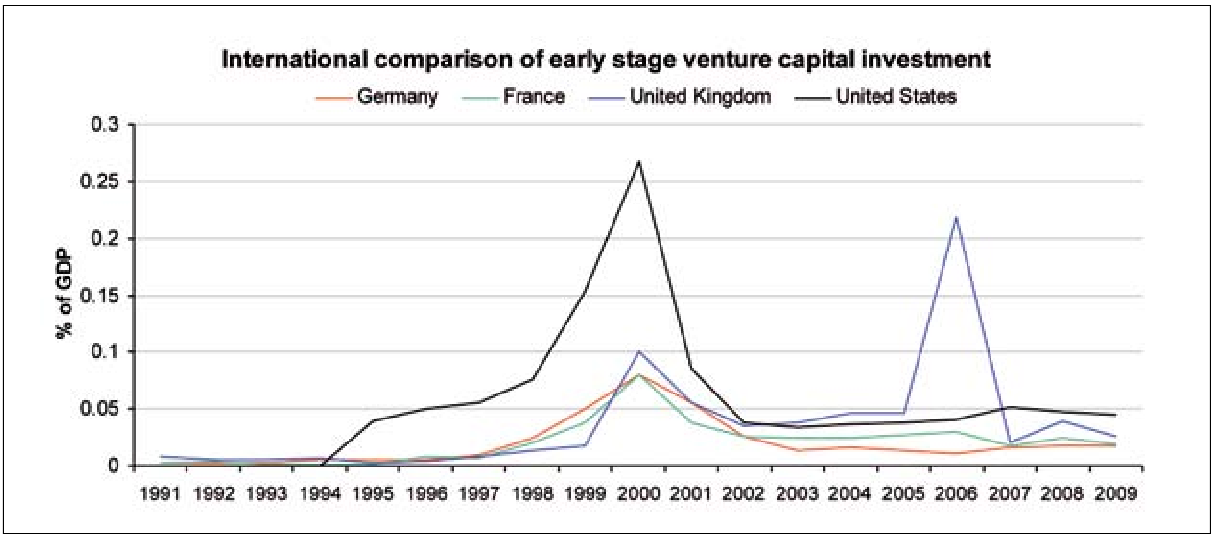
Figure 43: Percentage of enterprises regarding potential barriers to innovation as 'high'

Barrier to entry	Size of enterprise		Per cent
	10 – 250 employees	250+ employees	All (10+ employees)
Cost factors			
Direct innovation cost too high	*17*	*13*	*17*
Excessive perceived economic risks	*15*	*12*	*15*
Cost of finance	*17*	*10*	*17*
Availability of finance	*16*	*8*	*16*
Knowledge factors			
Lack of qualified personnel	*7*	*4*	*7*
Lack of information on markets	*3*	*2*	*3*
Lack of information on technology	*3*	*2*	*3*
Market factors			
Market dominated by established businesses	*9*	*6*	*9*
Uncertain demand for innovative goods or services	*8*	*7*	*8*
Other factors			
UK Gov regulations	*8*	*5*	*8*
EU regulations	*7*	*4*	*7*

As early-stage innovative SMEs with high-growth potential fit the profile for equity investment from business angels and venture capitalists, the restrictions on the supply of these sources may be considered a factor in determining the availability of finance.

Figure 44 shows that in the run up to the crisis, the UK was performing relatively well in relation to French, German and US levels of venture capital investment. But this culminated in a sharp rise followed by a precipitous fall, in 1999-2001 and 2005-2007.

Figure 44: International comparison of early stage venture capital investment



Source: Eurostat 2010

More recent data from the BVCA shows that the supply of early-stage venture capital investment to SMEs decreased by 31% in 2010 from 2009 as a result of the credit crunch.[119] Many private sector venture capital funds have continued to focus on managing their existing portfolio due to difficulties in raising new funds, and constraints affecting exit routes such as public equity markets like AIM. Lower levels of venture capital investment could thus significantly constrain innovation and growth if high growth potential firms are unable to access the required levels of funding from other appropriate sources.

Business angels have become more significant over the past decade as a source of early stage venture capital.[120] Part of the market is organised and visible, comprising angel networks and syndicates, while in the wider market angel investing is largely a private activity and its investment activity can not be easily measured. The investment activity of UK angel networks and syndicates has grown quite considerably since 2000, with the total amount of finance raised through these groups increasing from around £50m to around £125m[121]. Co-investment both amongst angels and with other investors has increased in significance. Recent research shows that the total amount of investment raised through angel networks and syndicates remained broadly unchanged between 2008/09 and 2009/10 despite the difficult economic conditions, and there was a slight increase in the number of investments. The amount invested by angels themselves declined by 13%, while the amount of finance attracted from other investors increased. The estimate for the total value of investments made by the whole of the UK business angel market in 2009/10 is £318m. This, however, is a decline of 25% compared with 2008/09.

Financial markets are important for innovation for reasons wider than simply the supply of finance. Financial markets have complex interactions with the real economy because they feed into governance mechanisms, markets for corporate control, and they affect not only the allocation of resources for innovation but also the distribution of rewards that flow from innovation success. There remain many under-researched issues, but in recent years important steps have been made in the analysis of financial-real connections and their impacts on innovation.

One of the most important steps has been the European Commission-supported project *Finance, Innovation and Growth* (FINNOV) involving six teams across Europe led by Professor Mariana Mazzucato at the Open University. This project, still under way, has asked a series of questions about whether or not financial markets reward or penalize innovation, about whether innovative firms are adequately financed, and about how returns are distributed. The main conclusions thus far include a number of policy relevant results, notably:[122]

119 BVCA: British Venture Capital Association.

120 NESTA (2008) *Shifting Sands: The Changing Nature of Early Stage Venture Capital Market in the UK*, London: NESTA.

121 BIS (2010), *Annual Report on the Business Angel Market in the UK*, June, BIS.

122 European Policy Brief, Socio-Economic Sciences and Humanities Research, *Do Financial Markets Reward Innovation?*, Brussels: DG Research, 2011.

- Success in markets depends on more than innovation performance – it depends on size, persistence in innovation effort and alliances, for example. The complex mix of success factors incidentally suggests that any single firm rating method is likely to mislead.
- The 'credit crunch' tended to penalize the most innovative firms, and this is something that needs attention in the post-crisis recovery.
- In the US, share buybacks have been at the expense of innovation investments. Business models that link executive pay and bonuses to the stock-market performance of the firms need to be carefully considered in terms of their innovation impacts.
- There is no single optimum method for financing innovation-active firms – there is a mix of relevant financial instruments and firm behaviours, and policy needs to take account of heterogeneity in the population of firms.

Developing human capital

Innovation skills are the integrated totality of person-embodied capabilities that are necessary to create, adapt and operate changes. It can be argued therefore that human capital subsumes most intangible assets: patents, R & D, software, design etc. are the outcome of human expertise. **Innovation performance is dependent on technical skills but also organisational, managerial and marketing skills**, depending on industries and business models. In an innovating economy the overall balance of skills change with the dynamics of innovation. Skills are evolving inputs, risky and costly to develop, especially in a context of uncertainty in their future relevance. **Skills shortages reported by employers in the UK are significant.**

DEFINING SKILLS FOR INNOVATION

The measurement of human capital is challenging and commonly based on proxies of education and occupation. There is also no agreed understanding of the concept of skills for innovation and the range of skills it encompasses. As a result indicators on the importance of various skills for innovation are imperfect and the evidence in this area is rather patchy. However, research by the ESRC[123] and OECD[124] converge in showing that there is no one specific mix of skills that is conducive for innovation. It is difficult to disentangle the skills that drive innovation from those that are demanded as a result of change brought about by innovation. Instead **the required skills vary across the type and stage of innovation concerned, the industry and the strategic business model the firm pursues**:

123 ESRC Centre for Research on Innovation and Competition (2005), A Literature Review on Skills and Innovation. How Does Successful Innovation Impact on the Demand for Skills and How Do Skills Drive Innovation? Report to the Department of Trade and Industry, September.

124 OECD (2011), *Skills for Innovation and Research*, Paris: OECD.

- **Innovation requires the supply of well trained scientists and engineers.** These skills tend to be deployed in the industries where new services and products are science-based and designed by relatively small teams such as pharmaceuticals or electronics, which require working with universities and/or have their own R & D laboratories. These skills are also found in industries where innovation is based on small professional elites such as high value added manufacturing and, perhaps more surprisingly, financial services. These 'elite' skills are crucial for certain forms of technological innovation. In this area, the rapid development in science and engineering of the East Asian countries, like South Korea, Singapore and China poses new challenges, with a growing number of graduates. Technological innovation activities are likely to become more dispersed.
- However, firms' competitiveness depends not only on their capacity to innovate in products, but also on their capacity to transform managerial practices, internal and external resources and capabilities. **Organisational, managerial and marketing skills are increasingly found to be complementary to technical skills and necessary to innovate successfully**, although research in this area has lagged far behind research on technical skills. In industries that are more focused on product and technological innovation, marketing skills and client interfacing are important to meet complex customer needs. In the services sector where the boundaries between process and product innovation are rather ill defined, organisational and managerial skills are needed to re-design work flows.[125] The growth in outsourcing, value chain interactions, and external intellectual property for example, mean that activities that were previously undertaken within firms are now being undertaken by others, or in collaborative arrangements between firms. This requires new ways of working, managing suppliers and agreeing contracts.
- Beyond that, it is also paramount that the general workforce is able to engage, and adapt to, innovation. Good levels of basic competence in language, sciences, maths and information technology form 'platform skills' that are pivotal for workers to learn new skills, adapt to changing global circumstances and allow the redeployment of the labour force displaced by global competition across the economy.

CHANGING SKILL REQUIREMENTS

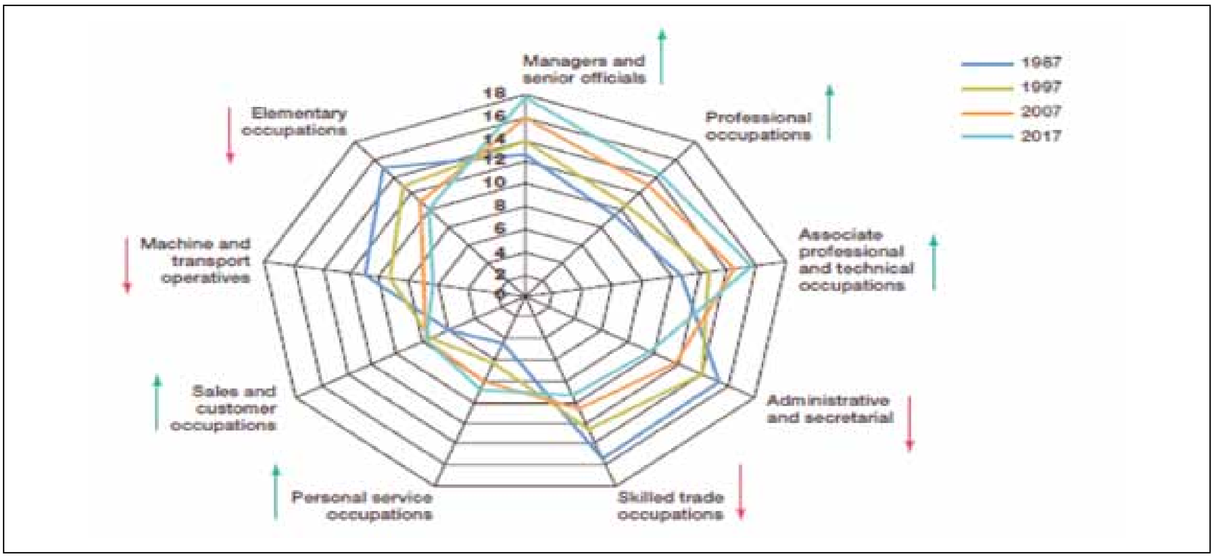
Innovation implies changing skill requirements. It has in the past been argued that the basic dynamic of innovation has led to 'deskilling' of large parts of the workforce, especially those in operative tasks. Others have argued that modern innovation has resulted in skill 'polarisation' with the emergence of very high-end skills coupled with significant decline (or off-shoring) of low skilled jobs. Finally there have been arguments proposing much more complex models of changing skill composition over time.

125 Miles, I D. (2005), *Innovation in Services*, in The Oxford Handbook of Innovation, ed. J Fagerberg, D Mowery & R Nelson, Oxford University Press.

The UK has a strong evidence base in this area. The UK Commission for Employment and Skills (UKCES) currently collects and analyses data on a wide range of sectors, as well as on prospective skills needs. There is good data over time, deriving from ESRC-supported surveys, including: Social Change and Economic Life Initiative (SCELI) (1986); Employment in Britain (1992);1997 Skills Survey; 2001 Skills Survey; and 2006 Skills Survey.[126] These surveys have clearly suggested a steady rise in skills needed across most jobs, though growth slowed after 2001. This has been indicated also by increases in necessary training time and the amount of time required for on-the-job learning. The necessity of learning new skills on the job has grown over the two decades of these surveys. Taken together **this evidence suggests no diminution of skill requirements as innovation proceeds**.

The changing occupational categories reflect shifts in industrial structure and hence in demand for skills. The National Strategic Skills Audit[127] provides a long term view into both the past and the future shown in Figure 45. The substantial growth in managerial, professional and technical occupations is marked, as is the substantial growth in the personal service occupations. The decline in administrative/secretarial and skilled trades is also clear. Such changes are paralleled in European labour markets more generally. This tends to confirm the 'polarisation' theory[128] in which the relative demand for well-paid skilled jobs is rising together with that for low paid least-skilled job, while the demand for 'middling' routine jobs is falling in advanced economies.

Figure 45: Changes in occupational structure in England 1987-2017



Source: UKCES (2010) Skills for Jobs: Today and Tomorrow – the National Skills Audit for England 2010 – Vol.1, Key Findings

126 These sample about 4,500 individuals across employed households, looking at aspects of work experience in terms of broad skills use, job discretion, complexity and work-based learning. Respondents are asked to rank the importance of about 40 generic forms of skill needed for tasks, and these are aggregated into about ten major skills types (literacy, physical, numeracy, technical know-how, influence, planning, client communication, horizontal communication, problem-solving, checking, aesthetic and emotional). Information was also collected on skills in computing, foreign languages and management.

127 UKCES (2010), *National Strategic Skills Audit*, Vol 1- *Key Findings*, Vol 2 – *The Evidence Report*, UKCES.

128 Goos, M.and Manning, A. (2007), Lousy and lovely jobs: *The Rising Polarization of Work in Britain*, Review of Economics and Statistics, Vol. 89, issue 1, MIT Press, Pages 118-331.

These changes in occupational structures are associated with estimates of high growth occupations by sector (Table 11):

Table 11: High growth occupation

High growth occupations in large sectors with expanding employment	High growth occupations in sector with expanding employment
• Corporate managers and STEM professionals in computing and related services, and other business services • Corporate managers in the health and social work sectors • Business and public service professionals, associate professionals, health associate professionals, culture/media/sport occupations, caring/personal service occupations	• Teaching and research professionals and business/public service professionals in hotels and catering • Teaching and research professionals and business/public service professionals in computing and related services
High growth occupations in large sectors	**High growth occupations in multiple sectors**
• Corporate managers in distribution related to motors and wholesale distribution, transport and storage, professional services, public administration/defence and education • Teaching and Research professionals in education • Business/public service (associate) professionals in health and social work, and banking/insurance	• Teaching and research professionals • Culture/media/sports occupations • Caring occupations • Customer service occupations

Source: UKCES (2010) Skills for Jobs: Today and Tomorrow – the National Skills Audit for England 2010 – Vol.1, Key Findings

The UKCES work identifies significant future demand for technology professionals in the computing sector, emerging skill gaps related to digitalisation amongst managers and professionals, continued high demand for highly-skilled, specific STEM-related occupations, widespread demand for associate or 'para' professional and technician roles and expansion of demand for skills in the care sector. This leads UKCES to identify a set of high-priority skills where relatively rapid action is required: in management skills, in computing and software, and in health skills (including science and technology professionals in pharmaceuticals and medical technologies). A wide range of skills, with lesser degrees of urgency, are also required.

SKILLS SHORTAGES AND PROVISION

There are concerns that, despite the increase in educational attainment in advanced economies, the supply of skills will not keep pace with future demand and various surveys of firms have identified the existence of shortages, although with important differences across industries and countries. The most recent evidence from the National Employer Skills Survey[129] shows that **UK employers report high levels of skills updating needs and skill gaps**:

129 UKCES (2011), *The 2011 Employer Skills Survey* (ESS11), UKCES.

- Almost three quarters of private sector organisations surveyed reported having skill updating needs in 2009, compared to 30% who reported internal skills gaps and only 3% who were experiencing skill-shortage vacancies at the time of the survey. Table 12 ranks skill needs by sector of the economy; one hypothesis that might emerge is that skill gaps and updating needs appear to be greater in low-tech activities: agriculture, food, transport etc.

Table 12: Sector rankings on skill-shortage vacancies, internal skill gap and updating needs

	Skill-shortage vacancies	Internal skill gaps	Skills updating needs
	Sector ranking on skill deficiency measure		
Agriculture, forestry and fishing	12	22	16
Food, drink and tobacco	11	12	23
Printing, publishing, recorded media	16	19	19
Chemicals, rubber and plastics	23	14	24
Fabricated metal products	14	7	25
Electrical, electronic and instrument engineering	6	5	15
Mechanical engineering, vehicles and other engineering	15	6	21
Other manufacturing industries	25	20	26
Building of complete constructions; civil engineering	21	18	10
Building installation, building completion and other construction activities	18	8	8
Sales of motor vehicles, parts, fuel	19	13	7
Wholesaling	26	24	22
Retailing – specialised stores	20	9	9
Retailing – non-specialised stores; other retail and repair	22	2	5
Hotels, motels and other accommodation	4	1	18
Restaurants, canteens, catering	2	3	14
Bars	5	4	12
Transport services	9	26	20
Postal and telecommunications services	24	21	4
Auxillary transport activities, travel agents	17	17	17
Financial services, including insurance	10	11	2
Computer services	1	23	1
Legal, accounting, auditing, business and management consultancy, etc.	3	16	3
Architectural and engineering activities and related technical consultancy; technical testing, analysis	8	15	6
Other business services	13	25	13
Personal and other services	7	10	11

Source: UKCES(2011), The 2011 Employers skills survey (ESS11)

The most important factors driving skills updating and improvement needs are new legislative or regulatory requirements, the introduction of new goods and services, new work practices and new technologies, and increased competitive pressure in general. The types of skills that need updating cover a wide range of generic skills (such as customer-handling, team-working, problem solving and communication skills), technical, practical and job-specific skills and managerial skills.

- Some 30% of organisations with skill updating needs reported that managers were the single most important occupations affected.
- Organisations engaged in high-value added activities and complex business models are more likely to report skill-shortage vacancies and skills updating needs. They appear to be indicators of high standards set for skills and a more dynamic approach to skills resourcing in those organisations. UKCES evidence supports the view that innovative business models and skills are interdependent in nature. It points to the importance of seeing skills shortages and gaps in a wider context, particularly relating to the practices and ambitions of firms.

Skills gaps inhibit innovation in firms in three ways:

- Employees with less training will be less aware of other methods of production and products and as a result less able to recognise the limitations of existing products and the scope for innovative improvement;
- Even if the scope for innovation has been identified, less skilled employees will have less capability to develop better products or produce new products in through an innovative method;
- A less skilled firm will be more subject to information failures where they will be less aware of external expertise to assist the innovation process in cases when there is insufficient internal capability. Less skilled firms also suffer from greater absorptive capacity limitations which limit the extent to which the firm is able to benefit from external expertise.

The severe deterioration of labour market conditions following the impact of the downturn has created concerns about human capital depreciation in the economy as a whole. Experience from previous recessions shows that the extent of skills scrappage will depend on the speed with which people can find new employment and on their opportunities to maintain or augment their skills through training. Continuing to support the acquisition of a wide range of skills is crucial for future innovation performance.

However, skills provision is a costly and risky investment for firms. Skills are provided via a complex set of decisions and agencies. In part, individuals make decisions based on conjectures of the links between skills acquisition and future payoffs; this is essentially the approach reflected in human capital theory, which sees individual decision-making as central. A problem here, in part reflected in the theory, is that payoffs may require complementary investments by others, either in skills or equipment. A large literature demonstrates the presence of externalities and provides a strong rationale for the public funding of education and training.

Skills are also importantly developed via decisions in firms, and as we have seen above, this is a major element (and in some industries *the* major element) in intangible investments for innovation. A key problem for skill development then becomes the ability and willingness of managers to make the requisite investments. A distinction can be made between 'specific skills' i.e. skills or knowledge that is useful only to a single employer, and 'general skills' i.e. skills or knowledge that is useful to other, and even many employers. The 'free-riding' problem is that if an employer invests in general skills the risks are that after qualifying the employee will leave for another employer who has not incurred the training expense and as a consequence is able to offer higher wages. Specific skills, on the other hand, are only of value in a particular employment and therefore should fall on the employer. Innovation, however, creates complications. If the employer is unable to fully appropriate the returns on innovation and rates of return on new skills are very difficult to calculate and subject to error. Skills provision is therefore a very risky investment. This helps understand why the investment in skills for innovation are often in short supply, especially in flexible labour markets where people are encouraged to switch between jobs in response to offers of higher pay from alternative employers. The training issue is particularly acute for SMEs. Across the OECD SME employers participate in skills and training to only half the extent of employees in large firms OECD (2008).[130] A major strength of the Japanese innovation system is the significant investment made by businesses in skilling employees in an environment where employees are attached to large companies for life (see Appendix).

Finally, there is the publicly available skilling system, via the organisations that provide vocational and educational training. A major issue for this system, in any innovating economy, is how well forecasts of change can be made, and how adaptable and flexible the system is in the face of change. In large part this is an issue of information provision. As UKCES has emphasised,[131] it is not possible or desirable to plan precisely future demand for skills and mismatch between supply and demand. However, providing intelligence to the market can contribute to enhance signals and allow the different players, firms and individuals, to make-better informed decisions. This is especially efficient if information is supplemented by other policy levers providing financial and/or behavioural incentives.

Building and managing physical infrastructures

Much innovation is infrastructure-dependent: it relies on the creation and use of physical and knowledge infrastructures. Infrastructures pose special problems for public policy, and particularly public finance, for three reasons: they tend to be very large in scale, they tend to be systemic in character, and they tend to be long-lived. They also must be constructed in an integrated rather than an ad hoc way, and their long lifetimes mean that normal investment appraisal techniques are often unsuited to evaluating their costs and benefits.

130 OECD (2008), *Leveraging Training and Skills Development in SMEs*, Paris: OECD.
131 UKCES (2010), *National Strategic Skills Audit, Vol 1- Key Findings, Vol 2 – The Evidence Report*, UKCES.

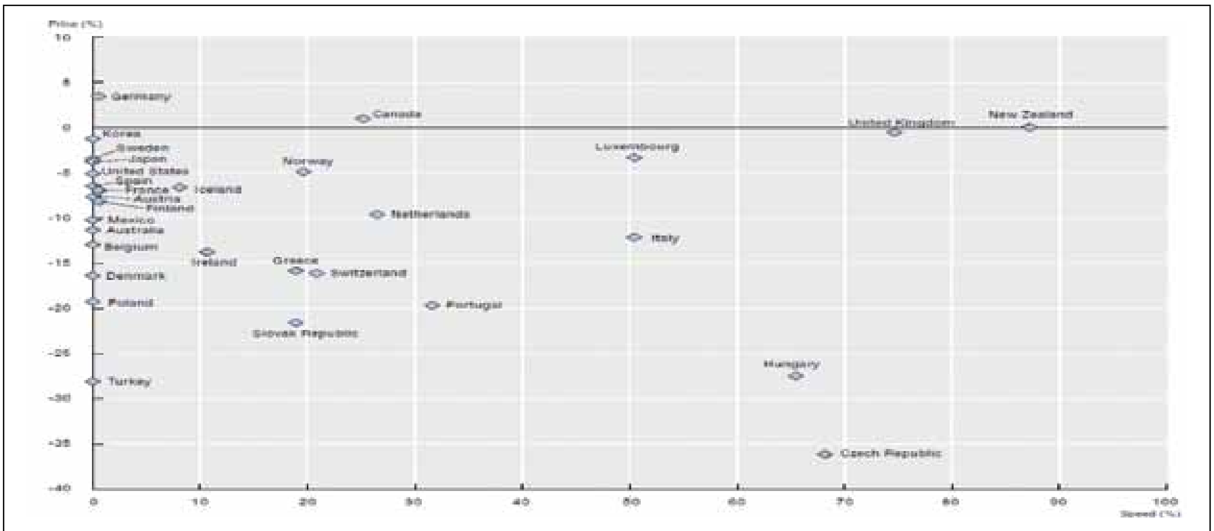
Historically, the characteristics above explain why governments have typically played major roles in decisions to establish and operate infrastructures. Much of modern economic reform has involved either privatisation or deregulation of infrastructure operations, or attempts to change the incentive structures and financing for the private sector to invest. A key concern at the moment is that **a gap may be opening up in the UK, and also in some other OECD countries, between the infrastructure investments required for the future and the capacity for the public sector to meet those requirements** from traditional sources of finance.

COMMUNICATION NETWORKS

A major development is that ICT technologies are leading to particularly far-reaching changes. They are the most innovative and rapidly changing infrastructure sector, and they drive innovation throughout the economy today. **ICT and high speed communication networks are radical forms of innovation and they therefore have a major impact on the innovation system as a whole.**

High-speed broadband access has increased dramatically over the last few years, particularly in the UK where the speed of DSL offer increased by about 75%, as show in Figure 46.

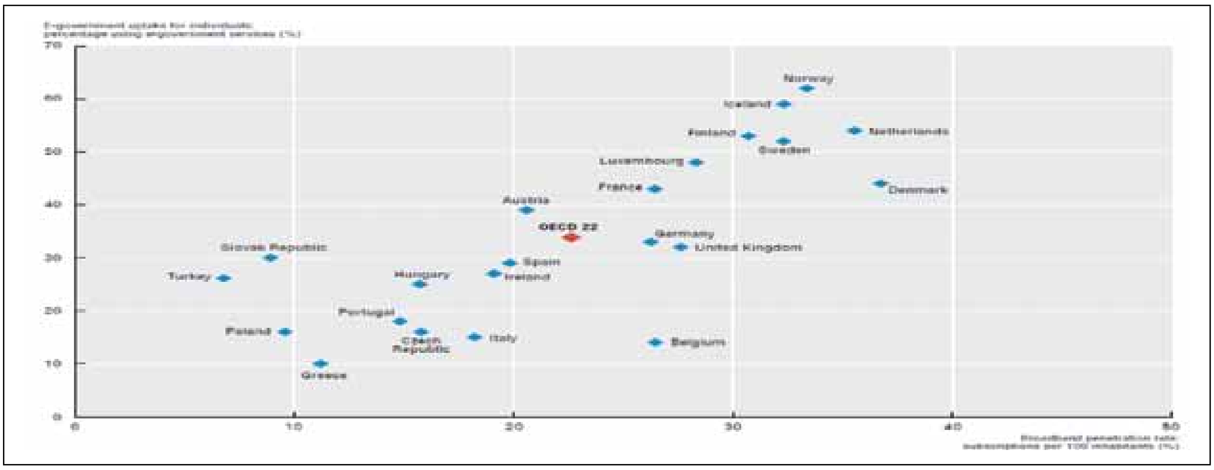
Figure 46: Evolution of a representative DSL broadband subscription over time, 2005-09



Source: OECD (2010), Measuring innovation: A New Perspective, Paris: OECD

High speed broadband is rapidly changing consumer and business practices, enabling broader participation in the innovation process by opening it to suppliers, competitors, universities and consumers across the world. It is leading to new forms of collaboration for innovation (as seen in Chapter 3). Recent research suggests that investment in ICT has become the dominant driver of growth in services, with an average growth rate in computer hardware investment of 22.5% p.a. between 1985 and 2005, and ICT as a whole increasing by an average of 9.2% p.a. during the period[132]. It is also fostering innovation in the public sector at all levels of government and enhancing the delivery of public services. OECD countries' capacity to develop and implement e-government services is based on an extensive broadband infrastructure. Scandinavian countries lead in harnessing the potential efficiencies of ICT, as Figure 47 shows.

Figure 47: Relation between broadband penetration and citizen uptake of e-government services



Source: OECD (2010), Measuring innovation: A New Perspective, Paris: OECD

Convergence between communication and physical networks

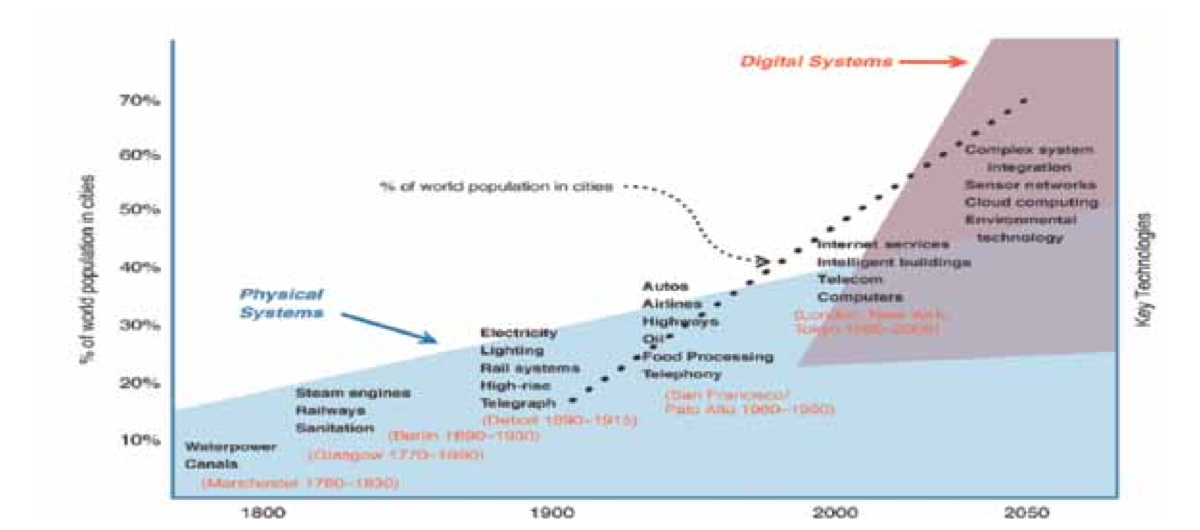
But ICT technologies are likely to have a profound impact by being the foundation of much innovation in all the other infrastructure sectors in the future. For example, the integration of physical infrastructures and digital technologies are likely to largely influence the economic development of large cities, where much innovation is concentrated.[133]

Figure 48 shows the long period of capital investment in physical infrastructure and much shorter period of rapid investment in digital assets. It also plots growth in the percentage of world population living in cities as a proxy for the rise in demand for infrastructure.

132 Barras, R. (2010), *Building cycles: Growth and Instability*, Wiley, John and Sons.

133 Gann, D. M. Dodgson, M. and Bhardwaj, D. (2011) *Physical-digital Integration in City Infrastructure*, IBM Journal of Research and Development, Vol:55, Pages:8:1-8:10.

Figure 48: Key technologies affecting city development



Source: Gann, D. M. Dodgson, M. and Bhardwaj, D. (2011) Physical-digital Integration in City Infrastructure, IBM Journal of Research and Development, Vol:55, Pages:8:1-8:10.

Traditionally transportation, water and waste recycling, energy and electricity, and buildings have been developed and operated independently, although since the 1980s they have been increasingly interdependent. Sustained investments in digital technologies will intensify the ability to interlink them. This offers wide opportunities for improving existing services and creating completely new types of services, some of these are already emerging such as smart traffic systems (see Box 10), telemedicine, intelligent transport networks, interactive learning, cloud computing etc.

Box 10: Smart traffic systems

Massive volumes of data (sometimes called ‘big data’) can be collected from sensors, radio-frequency identification devices, mobile telephones etc. interconnecting subsystems to provide real-time information about how infrastructure is performing and how people and organisations are using it. This leads to improving knowledge about complex systems, their design and operation. The development of the **London** traffic-congestion charge depended on novel data analysis and resulted in improvements in many cities. Traffic congestion charges in **Milan** have a scale depending on the level of pollution emitted by individual vehicles. **Stockholm**’s traffic system uses cameras and lasers to identify and charge vehicles according to the time of day and has reduced congestion by 25%. **Chinese cities** are looking to optimise traffic flows based on positional data automatically provided by drivers’ mobile phones.

Source: Gann, D. M. Dodgson, M. and Bhardwaj, D. (2011) Physical-digital Integration in City Infrastructure, IBM Journal of Research and Development, Vol:55, Pages:8:1-8:10.

Physical-digital integration is also pivotal to improving environmental efficiency. It is likely to lead to new models of energy generation, transmission, distribution and consumption. The smart electrical grid is a good example. It provides consumers with information on their electricity consumption in real time allowing consumption based on price signals. But it is more than simply metering since it allows monitoring of the overall supply and demand situation, and thus integration of very different combinations of renewable and non-renewable inputs. The smart grid will therefore be a key element in reducing emissions in years ahead. Other technologies also have significant potential in this respect: biotechnology in water treatment, fuel technologies in land transport, carbon sequestration in power generation, and nanotechnology applications in almost all of these sectors.

The scope for innovating through the application of ICTs remains large and will depend on the ability to transform complex systems like the energy system and the transport system. Simply fitting new technologies into existing systems will not lead to fundamental changes. However, entirely new systems are difficult to develop and introduce, and often require significant organisational and institutional changes. This is all the more challenging in advanced economies like the UK where new infrastructure is overlaid on older, whereas in emerging economies new cities are being developed with integrated systems already in place. The challenges facing the convergence of infrastructures are so broad that individual investors are unlikely to capture the full benefits and therefore will tend to under-invest in it. It is incumbent on policy makers to play a role in providing strategic planning and vision for physical infrastructure and adapting the regulatory and institutional framework accordingly. This is necessary to provide more certainty for investment and build a platform for innovation in all sectors of the economy.

Conclusion

There is a danger that businesses and investors can become risk-averse in the wake of the crisis, which would clearly be detrimental to innovation and growth. The recent crisis is an opportunity to raise UK trend growth and make it more knowledge driven and sustainable. This requires scaling up private investments that extend beyond R & D to also cover non-R&D innovation inputs, human capital and infrastructure. It requires financing levels and provision of other incentive mechanisms or reward systems for innovation. The policy context which guides private investment in innovations can help address these challenges and maximize their economic impact.

The recent crisis is also an opportunity to reconsider the role of the public sector within the innovation system. Innovation is not the exclusive realm of the private sector and is not only generated through market mechanisms. Indeed, through its actions the public sector has a major impact on the development and diffusion of innovations. These issues are discussed in the last Chapter.

Improving the Innovative Capacity of the Public Sector

Government has long played a central role in innovation. Fostering technological breakthroughs is a fundamental role of Government. As a major and early user of goods and services, the public sector itself is an essential part of the innovation system. It shapes the direction of innovation in the wider economy through:

- Being a source of demand via public procurement, especially in areas such as health, transport and urban development;
- Sponsoring a substantial research effort in support of public goals and supporting the development of radically new technologies. The case of government-led innovation to support green growth is more particularly discussed in this Chapter;
- Setting market incentives, for instance through a renewed interest for inducement prizes and challenges;
- Producing innovations related to its own activities of public service delivery and defence.

There is potential to improve performances in this part of the innovation system. However, the complexity and diversity of the public sector creates operational barriers that can hamper innovation, in particular:

- In public procurement there is a very complex array of procuring organisations without coordination or consistent considerations of innovation impacts;
- Weak innovation culture and practices in public services inhibit user-led innovations at significant scale.

The Chapter points to the importance of tackling some of these barriers so that the public sector can play a bigger role and have a more positive impact on innovation across the system. These are important new innovation challenges particularly given the tight financial constraints in most advanced economies.

We looked in Chapter 4 at how organisations that are related to the private sector generate new knowledge and produce assets that are vital for the innovation system to function. In this chapter we analyse in which ways central and local government and their delivery bodies can influence the innovation performance of the system as a whole. We will look at four areas that are particularly important:

- Forms of public procurement are examined, including public procurement from SMEs, and the use of procurement in the creation of lead markets. The main challenges to a better use of public procurement are identified;
- Government creates new innovation trajectories by seeking to address pressing societal needs. Many radical technological innovations have been fostered by Government. The strategic priority of green growth, which has emerged over the last decade or so, will be analysed as an important case of this at the present time;
- Government has also successfully fostered new inventions through setting incentives in the research market, and the wide diffusion of digital technologies has been leading to a renewed interest in inducement prizes and challenges;
- The delivery of better public services at lower cost will unavoidably require public organisations to innovate, and the tight financial context is putting additional pressure on traditional ways of organising public services. Recent results from NESTA's pilot public sector innovation index provide an insight into how innovation happens in public organisations.

Procuring or commissioning in ways that encourage others to innovate

The public sector plays a leading role in responding to changing public expectations of services and long-term social demand. The Government – meaning central Government, support departments and agencies – is the largest customer in the UK, with the potential to provide a major stimulus for innovation. **The size of the government's procurement budget at roughly £220 billion a year, about 15% of GDP, dwarfs most innovation policy instruments by many orders of magnitude, even if only a fraction is spent on innovative activity.**[134] Table 13 below gives the share of demand derived from government in sectors of the economy. Table 13 shows that, in addition to education, the pharmaceutical and medical instrument industries are also heavily reliant on government as a customer. Government is also a major customer for legal activities and aerospace manufacture.

134 OGC (2010) *Policy through Procurement Action Plan*, Norwich: OGC.

Table 13: Government as purchaser by sector

Sector	Government demand as a share of total demand, 2008
Education, including training	60.8
Pharmaceuticals	35.2
Medical and precision instruments	29.1
Legal activities	16.4
Market research and management consultancy	16.4
Aircraft and spacecraft	13.2
Pulp, paper, paper products, printing and publishing	10.7
Owning and dealing in own real estate	10.5
Computer services	10.0
Post and telecoms	9.2
Architectural activities and technical consultancy	6.8
Advertising	6.8
Accountancy services	5.5
Whole Economy	**15.6**

Source: ONS (2010)

A strategic approach to public procurement would not aim to select firms or technologies, but rather whole market areas that are important for the economy and ripe for innovation.[135] The principle of fostering innovation through public procurement has become more prominent over the last decade or so as part of a greater awareness of the importance of feed-back linkages between supply and demand in the innovation process. Furthermore, current pressures on fiscal budgets mean that demand-side innovation policies to boost innovation performance while increasing the productivity of public spending have to receive renewed impetus. However, data reflecting the links between public procurement and innovation is limited and there is a strong need for effective measures.

FORMS OF PROCURING ACTIONS FOR INNOVATION

The public sector acting as an intelligent and demanding customer has a blend of benefits: enabling innovative solutions to effectively address social challenges and improve service delivery, supporting the development and growth of innovative businesses and stimulating wider economic growth.[136] The public sector can thus foster activities within firms and firms benefit because procurement can help them recuperate the sunk costs of large and sometimes risky investment over a pre-determined period of time.

135 Edler, J., Georghiou, L., Uyarra, E., Yeow, J., *Procurement and Innovation: Underpinning the Debate*, Manchester Institute of Innovation Research, Background Paper, October 2011.

136 Uyarra, E. (2010), *Opportunities for innovation through local government procurement: A case study of Greater Manchester,* London: NESTA.

Four levels of targeted actions can be identified:[137]

- **Direct procurement of R & D** to support the activities and decisions of Government and public authorities, with no guarantees that the public sector will buy the goods and services developed. This type of action has been implemented for many years, for instance it is a tool traditionally and successfully used in the USA in the area of defence to generate spillovers.
- **Standard procurement for ready-made products can be made 'innovation-friendly'** by incorporating innovation-related criteria in the tender specifications and in the assessment of tender documents so that innovation becomes an essential criterion. To ensure coherence and consistency this type of procurement requires some structures that allow the sharing of best practice.
- **Strategic procurement for the purchasing of not-yet-existing products,** services or systems, which could be developed within a reasonable amount of time based on novel technological development work from the companies responding to the call for tender. It can include the assessment of pre-commercial products and services in areas where public organisations are lead customers to share risks between procurers and suppliers, or de-risk investment to support the leveraging of funds from the private sector.
- **Co-operative procurement occurs when government agencies buy jointly with private purchasers** and both utilise the purchased innovations. A particular form is **'catalytic' procurement**, where the Government is involved in the procurement or even initiates it, but the purchased innovations are used ultimately exclusively by the private end-user. It is a means to support private purchasers in the decision to buy. Sweden has been using this type of procurement to boost the production of energy-efficient technologies. The European Commission is currently looking into options for a catalytic form of procurement.

INNOVATIVE PROCUREMENT FOR SMES

Innovative procurement can also be targeted towards the stimulation of SMEs. Venture capital is often thought of as the primary funding mechanism but in reality it is only viable for a small proportion of technology companies, and when access to finance is tight, such funding becomes even more limited[138]. Increasingly common are 'soft start ups' – when technology companies establish themselves through consultancy contracts for clients requiring help with specific problems. This contract model can lead to growth itself, or it can result in demonstrators and prototypes that will create a far more appealing investment prospect for venture capital.[139]

137 Edler, J. and Georgiou, L. (2007), *Public Procurement and Innovation: Resurrecting the Demand Side*, Research Policy, Issue 36, pages 949-963.

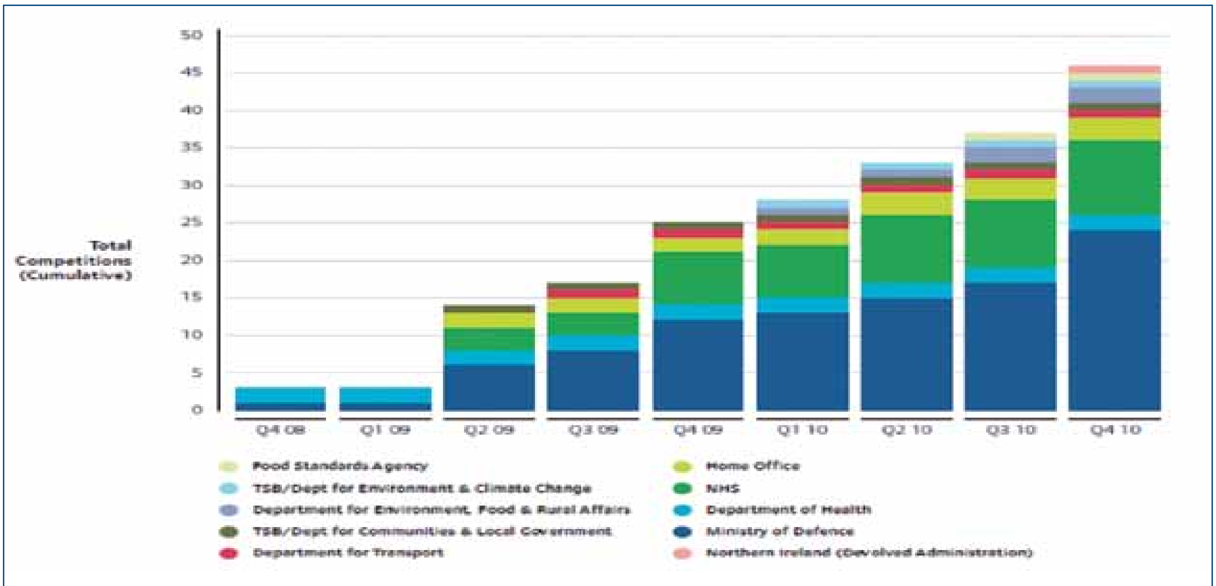
138 For instance, whilst 205 technology companies raised venture capital in 2005, only 80 did so in 2009 (source: Dow Jones Venture Source 2010).

139 Connell, D. (2006), '*Secrets of the World's Largest Seed Capital Fund: How the United States Government uses its Small Business Innovation Research (SBIR) Programme and Procurement Budgets to Support Small Technology Firms*', Centre for Business Research, University of Cambridge.

The US's Small Business Innovation research Program (SBIR), upon which the UK's Small Business Research Initiative (SBRI) was modelled, demonstrates the impacts that can be achieved over a longer period. Established over 30 years ago and issuing contracts worth $2 billion annually, surveys have found that that one quarter of SBIR funded projects received at least one patent[140], and over 300 SBIR award winners have public market listings.[141] One independent study found that over ten years, SBIR-funded companies generated five times more growth than other companies.[142]

NESTA research into the UK's SBRI, re-launched in 2009, found that nine in ten SBRI competition entrants had never worked with the NHS before, suggesting that there are innovative solutions in the SME community to transform public service delivery that can potentially be tapped into[143]. Figure 49 shows that from April 2009 to September 2010 there have been 46 competitions resulting in 519 contracts awarded to the value of £35.6 million. The competitions have helped small and micro businesses to engage with Government Departments and the validation effect of having a government contract has helped a number to raise venture capital or additional financing.

Figure 49: SBRI competitions by government institutions, April 2009-September 2010



Source: Technology Strategy Board (2010)

LEAD MARKETS

Domestic demand is a prime channel for enhancing the competitiveness of locations and the enterprises therein. Sophisticated and challenging demand

140 Lerner, J. (1999), '*Public Venture Capital: Rationale and Evaluation*', in Wessner, C. (ed.) The Small Business Innovation Research Program: Challenges & Opportunities, Board on Science, Technology & Economic Policy. National Research Council, National Academy Press.
141 Connell, D. (2006) ibid.
142 Lerner, J. (1999) ibid.
143 NESTA (2010), '*Buying Power? Is the Small Business Research Initiative for procuring R&D driving innovation in the UK?*' June, London: NESTA.

is one of the key variables determining the attractiveness and performance of locations for investment from innovative companies according to the World Economic Forum annual reports. Countries are more internationally competitive in the areas in which they display challenging, future-oriented and international leading demand – so called 'lead markets'.

Lead markets require early adoption of an innovation so that it becomes widespread through multiple users or through a single user with sufficient purchasing power to constitute a market on its own. In such case the learning benefits are supplemented by a reduction of risk of the investment necessary to innovate. The expectation is that other markets would then adopt the design thereby. **Public procurement can make a difference in supporting lead markets through being the lead user** (strategic procurement) **or encouraging multiple users** (co-operative or catalytic procurement). In Finland, for example, it has been shown that consumers and government tend to act as lead users and as prime movers when it comes to buying and applying new products and services. This has made the country for decades now a prime location for the introduction and diffusion of consumer electronics and consequently has created a fruitful environment for the production of such products.[144] However, to be successful lead markets must also include, in addition to general conditions favourable to innovation, customers willing to pay a premium for a particular characteristic of the innovation, compatible physical infrastructure and sufficient scale for the costs of innovation to be viable.

PROCUREMENT CHALLENGES

Over recent years the European Commission has been particularly active in trying to identify and develop successful procurement actions for innovation.[145] The Commission has identified a number of procurement challenges that have to be overcome:

- **Procurement is a selective instrument and the potential risks of this selectivity such as capture by some firms must be handled.** There are also additional risks such as non-completion risks stemming from the technical features of the good or service to be procured, or no response to the tender. An important feature of successful innovative procurement [146] is that the rules should enhance collaboration rather than maximise competition (see Chapter 3) and therefore be separate from the rules for ordinary procurement.

144 Ebersberger, B. Lööf, H. and Okansen, J. (2005), *Does Foreign Ownership Matter for the Innovation Activities of Firms in Finland?'* VTT Working Papers 26, VTT.

145 The Europe2020 Flagship Initiative Innovation Union published on 6 October 2011, includes initiatives to support Public Procurement of Innovation Action n°17. Under the Lead Market Initiative, it has developed an approach to support thematic networks to help procurers to be more innovative in their purchasing. This followed a public consultation held in Summer 2008 and a workshop on Lead Markets and Public Procurement organised "within the INNO-Views framework programme in The Hague. Reports include European Commission (2007), *Guide to Dealing withlinnovative Solutions in Public Procurement*, Pro-Inno Europe paper N.1, Commission staff working document; European commission (2005) *Innovation and Public Procurement: Review of Issues at Stake*, study by Fraunhofer Institute Systems and Innovation Research.

146 Edquist, C. Hommen, L. and Tsipouri, L. (1999) *Public Technology Procurement and Innovation*, Springer.

- **The prevalent culture in many organisations of the public sector encourages risk aversion and low cost as the main drivers of contract award, not innovation.** A culture change towards innovation involves a strategic commitment to modify rationales across and within administrations to integrate the innovation rationale and subsequently a strong co-ordination of efforts to create inter-administrative win-win situations. Innovation often is not in the mind of regulators when new regulations are made.
- **Public sector's complexity makes governance, coordination and strategic planning more difficult.** The Office of Government Commerce reported that although public procurement often constitutes between 10% and 15% of any given supply market this is spent in over 44,000 organisations right across the UK in every sector in which government operates. This substantial effort is therefore organised through a very large number of procuring organisations, without any general consideration of innovation impacts. In countries like the US or Japan, which have applied pre-commercial procurement more systematically and comprehensively, this co-ordination need is met through building competences. For instance, in the US mission-oriented approaches facilitate co-ordination of ministries and in Japan, METI has a broader portfolio and wider responsibilities than traditional ministries of economics. In the EU public procurement networks aim to improve coordination between procuring organisations in specific areas, see box 11 below.

Box 11: Public procurement networks	
Three EU Public Procurement Networks became operational in September 2009.	
ENPROTEX	ENPROTEX seeks to spark innovation of protective textiles through public procurement to meet the future needs of fire and rescue services using a number of methodologies including: establishing and sustaining a specialized platform of European Network of Public Procurement Organisations; developing cooperation among public procurers; providing an interface with both end-users and manufacturers. In particular, the project will aim to provide industry with forward commitments for the procurement of protective textiles products so as to encourage innovation in the sector.
SCI-NETWORK	The Sustainable Construction and Innovation Network (SCI-NETWORK) brings together a strong group of public authorities and other key stakeholders wishing to drive sustainable innovations in public construction and regeneration projects across Europe. The network hopes to help combat the cross-border fragmentation of the sector and ensure the spread of good ideas. Specific working groups focus on 5 topics: application of environmental standards in renovation; new technical solutions; procuring innovation; whole-life costing; financing & contracting.
LCB-HEALTHCARE	The Low Carbon Building (LCB) – Healthcare network seeks to stimulate innovative low-carbon building solutions for the healthcare sector. A platform for a network of public procurement stakeholders that wish to be proactive in stimulating innovative low-carbon building solutions for the healthcare sector will be created. Demonstration pilots will be done in all consortium countries aiming at collating, testing and developing further the tools created and enabling the spread of best practices.

Source: http://ec.europa.eu/internal_market/publicprocurement/index_en.htm

- **Inadequate absorptive capacities and lack of relevant skills in procuring institutions and competencies in the public sector can be an issue.** A further requirement for innovation procurement is to define which markets to tackle. Governments can put in place structures that include potential suppliers so that the likelihood is high to define demands concretely enough that can be met by industry in the future. One approach to inform about the future direction of technologies as well as future needs is the use of foresight strategies to develop common visions between producers and users. The European Construction Technology Platforms summarised in Box 12 is an example of such initiatives.

Box 12: The European Construction Technology Platforms

The European Construction Technology Platform (ECTP) seeks to raise the sector to higher level of performance and competitiveness. This is achieved by analysing the major challenges that the sector faces in terms of society, sustainability and technological development. Research and innovation strategies are developed to meet these challenges engaging with and mobilising the wide range of leading skills, expertise and talent available to us within our industry over the coming decades, in order to meet the needs of the Society.

The ECTP gathers appropriate members necessary to achieve its Mission. The members come from a range of stakeholder organisations including contractors, materials and equipment manufacturers, designers, architects, engineers, owners / operators / clients, users / consumers, service and technology providers, research centres and universities, cities and regions and financial institutions.

A number of initial focus areas have been identified: underground construction, cities and buildings, quality of life, materials, cultural heritages, processes and ICT.

Typical outputs of strategic importance include:

- Vision 2030 for the European construction sector, signed and committed to by leading representatives of major stakeholder groups
- Strategic Research Agenda (SRA), outlining how the Vision 2030 will be achieved including roadmaps and strategies
- Detailed Priorities to be implemented at short and medium terms in R&D programmes or schemes (FP7, Eranet, Eureka, National ones...)

Source: http://ec.europa.eu/internal_market/publicprocurement/index_en.htm

Procurement is a complex area and presents challenges that are difficult to tackle. However, in one of the few efforts to compare the innovation effects of different policy activities, it was concluded that procurement policy 'is a far more efficient instrument to use in stimulating innovation than any of a wide range of frequently used R&D subsidies'.[147] To illustrate this, it is worth pointing out that **global innovation leaders such as the USA, Japan or Sweden have been particularly inventive in developing public procurement initiatives** to support innovative efforts in their economies (see Appendix).

Fostering technological breakthroughs

Government has been at the origins of many technological breakthroughs. Indeed this is a fundamental role of Government as radical innovations raise major economic problems. One area where Government is currently shaping the environment for technological innovation is green growth.

GOVERNMENT ROLE

Governments have historically played important roles in the development of many of the most visible technologies of the modern world. These include computing, large aircraft and engines, radar, mobile telephony, satellite communications, modern pharmaceuticals, high speed rail, biotechnology, and global positioning, to name only some of the most visible.[148] These technologies have not emerged in any uniform way. However they have usually been outcomes of purposive efforts aimed at securing pre-envisioned outcomes.[149]

The main evidence for the role of government has been the histories of the technologies in question. **Many of the core technologies of the modern era appear to have their origins in mission-oriented programs that involve firms as participants but not as initiators.**[150] They result from attempts to solve specific socio-technical problems, some civil but others notably military, as exemplified by the role of the US government (see Appendix on the US innovation system). Public-private interactions in the development of major technologies can be found earlier in European history. For example, much electricity development was initially private in character, but governments increasingly intervened to

147 Edler, J (2010), *Demand-Based Innovation Policy*, in R.Smits et al *The Theory and Practice of Innovation Policy*, Cheltenham: Edward Elgar, p. 281.

148 For account of government roles across a number of technologies see, for example, Computer Science and Telecommunications Board, Funding a Revolution. Government Support for Computing Research (Washington USA: National Academy Press), 1999. On mobile telephony, Sven Lindmark, Evolution of techno-economic systems: an investigation of the history of mobile communications, Chalmers University of Technology, 2002, ISBN 91-7291-194-8 and Johan Hauknes and Keith Smith, Corporate Governance and Innovation in Mobile Telecommunications: How did the Nordic Area Become a World Leader? Report to the European Commission, DG-Research, Corporate Governance and Innovation Project; on GPS, S. Pace et. al, The Global Positioning System: Assessing National Policies, (Rand Corporation, 1995), especially Appendix B, 'GPS History, Chronology and Budgets'.

149 This does not at all mean that *innovators envision all of the outcomes*. Society has a persistent habit of using new technologies in ways that cause great surprise to innovators. For example, the innovators behind mobile telephony envisioned a world of mobile communications primarily for business users, and were very surprised when predominantly young users first began using mobiles, and then sending text messages (which were originally seen as a pager substitute useful for business) in large volumes. This shifting of use is a major source of technological risk and uncertainty. See Nathan Rosenberg, "Uncertainty and technological change", in T. Landau, T.Taylor and G. Wright, *The Mosaic of Economic Growth* (Stanford, Ca.: Stanford University Press) 1996: 334-353.

150 The concept of "mission-oriented" technology policy derives from H. Ergas, "*Does Technology Policy Matter?"*, Technology and Global Industry, (Washington: National Academy of Sciences) 1987, 191-245.

create the network integration through which the economic benefits of the underlying innovation were realised.[151]

Why has the government role been so pervasive? Radical innovations involve many problems that are exceptionally difficult to solve for profit-seeking potentially innovating firms. These problems are not necessarily market failures as conventionally understood. They relate to information failures, to institutional failures, to coordination failures, and to more general investment obstacles related to innovation. Six broad problems are:

- *Long time horizons and financial commitments.* The long time horizons and circuitous search paths involved in radical innovations make it virtually impossible for rational investment appraisal around these technologies, which also require long-term financial commitments that are frequently beyond the ability of any profit seeking firm to undertake.
- *Risk bearing and the management of uncertainty.* These technologies tend to involve serious technological risks (in the sense that there are serious risks of technological failure), and economic risks (in the sense of very high probabilities of capital loss for particular projects). Uncertainty also relates to how technologies are likely to be used, an aspect of innovation that often cannot be predicted.[152]
- *Indeterminate outcomes and multiple search paths.* It is usually necessary not to undertake a single search path in the case of radical technologies: overlapping and multiple paths are often a key feature of success in these fields (demonstrated most sharply in the cases of nuclear weapons, nuclear energy and computing technologies).
- *Social adaptation.* Society does not simply adapt to new technologies, it also shapes them. But there are often social adjustments and adaptation that need to be made for a radical innovation. These may include regulation, training, changes in physical infrastructures etc.; they are beyond the capabilities of individual investing firms.
- *Coordination failures.* Innovations occur as complex systems, which require system coordination. In some cases a dominant large firm can achieve this, but it can also be addressed by public agencies.
- *Overcoming lock-in.* Overcoming lock-in to a currently dominant technology typically requires the protection of niche markets, public procurement, and patronage that tend to be provided only by interested and wealthy elites or by government.

These considerations apply to very large-scale technologies, but they are also relevant to technologies on a smaller scale. Many governments maintain more

151 Robert Millward, "*Business and Government in Electricity Network Integration in Western Europe*, c.1900-1950", *Business History*, Vol. 48 No, 4, 2006, 479-500.
152 Historically, this has been a major economic function of government: David A. Moss, *When all Else Fails. Government as the Ultimate Risk Manager* (Cambridge: Harvard University Press), 2002.

or less large organizations aimed at developing and organizing such patterns of innovation, often involving close links to private-sector technology firms. For the USA, Mariana Mazzucato has stressed the importance of the Defense Advanced Research projects Agency (DARPA), the Small Business Innovation Research, the National Nanotechnology Initiative, and the National Institutes of Health.[153] In Germany, the Fraunhofer Institutes have developed such technologies at the MP3 music compression system (see Appendix on the German innovation system). In the UK the list is also long. So the challenges of identifying and developing key technologies remain a serious issue for public policy.

INNOVATION FOR GREEN GROWTH

An important area where Government is currently shaping the innovation environment for economic actors is in the development of efficient renewable energies and green technologies for a low-carbon era. Achieving the transition to green growth requires a transformation of the whole economy, affecting both what is produced and how it is produced, which could have major implications for industrial competitiveness. **Innovative activity is vital in ensuring that the transition takes place in the most cost-effective way** through providing innovative alternatives to compete with non-green products, opening up new potential markets and helping to lead to a more efficient allocation of resources between different economic activities.

New source of growth

The UK is committed to a legally binding target of reducing greenhouse gas emissions by 80% below 1990 levels by 2050 and has aspirations to 'green' other core components of economic activity, such as reducing waste to landfill and improving resource efficiency more generally, and improving water and local air quality. A green economic transition will affect all sectors across the economy, having an impact on market opportunities available, market pricing and structure, efficiency and competitiveness:

- **Some industries will face increased market opportunities for new products, services and technologies** to deliver reductions in environmental damage directly or indirectly through 'greener' alternatives to existing products and technologies. Recent analysis estimates that the global low-carbon and environmental goods and services sector (LCEGS) was worth £3.2 trillion in 2009/10 (an increase of 2% on the previous year). The UK market contribution to this market was estimated to be approximately £116 billion (around 3.6% of the global market), employing around 914,000 people and supporting a net positive trade position of £4.7 billion (exporting £11.5 billion in 2009/10). Further, the UK sector is forecast to grow at an average of just over 5% per annum to 2015/16;

153 M. Mazzucato, *The Entrepreneurial State*, London: Demos, 2011, Ch 4.

- **Some industries will need to transform their goods, services and energy/ resource use**, although the ultimate purpose of their outputs may remain very similar. This includes a very broad range of sectors including aerospace, automotive and construction and a number of 'enabling' technologies/ sectors, such as ICT, electronics and financial services;
- **Some industries may face both rising investment needs and demand.** The challenge of decarbonisation and the need to 'green' sectors more broadly, will require high levels of investment in capital-intensive goods, particularly in infrastructure. This will increase demand in the supply chain for materials for these sectors, which are often simultaneously likely to be the most exposed to increased energy costs since they are energy intensive industries (for example, steel, cement, glass and chemicals); and
- **Some industries will have to innovate to be viable.** The reduction of environmental damage across industry may reduce the viability or substitution of production processes for energy- or resource-intensive industries. These sectors and others will also face competition from more sustainable products and technologies.

Capitalising on the new markets and business opportunities created by this transition and the speed at which industries that are able to transform will be critical. The extent and success of investment in innovation undertaken, both by final products producers and throughout the supply chain, will be a key determinant of both the speed and success for the transition.

Incremental innovation such as improving the energy and wider resource efficiency of existing technologies (for example, increasing the fuel efficiency of internal combustion engines in vehicles, or improving the use of natural resources in production) and more radical innovative steps such as the development of technologies that could be direct substitutes for high-carbon incumbents (for example, renewable energy technologies seeking to replace conventional fossil fuel generation, or ultra-low-carbon technologies substituting for petrol- or diesel engines in vehicles) will be required to transform every aspect of the economy. **In some cases, substantial infrastructure investment could also be required to support these 'transformative' innovations**, for example the development and full commercialisation of electric-powered vehicles will need an extensive supporting network of charging points.[154]

In its review of the adequacies of the UK's innovation frameworks for delivering the technologies required meeting the UK's climate change objectives, **the Climate Change Commission (CCC)[155] highlighted innovative areas where the UK was particularly strong or had the potential to be strong**:

154 BIS (2009), *Towards a Low Carbon Economy: Economic Analysis and Evidence for a Low Carbon Industrial Strategy*, BIS Economics Paper No 1, June.

155 Climate Change Commission (2010), *Building a Low Carbon Economy – The UK's Innovation Challenge*: Supporting Analysis and Review of Evidence, CCC.

- **Develop & Deploy:**[156] offshore wind, marine, carbon capture and storage (CCS) for power generation, aviation technologies, smart grids, and electric vehicle technologies;
- **Deploy:**[157] nuclear power, advanced insulation materials, heat pumps and CCS for energy intensive industries (highlighting that there may be scope for UK participation in demonstration of industry CCS); and
- **Research and develop:**[158] hydrogen fuel cell vehicles, technologies in agriculture and industry, third generation solar PV technologies, energy storage and advanced biofuels technologies.

Developing low carbon technologies

Market power and dominant designs can create a greater barrier in the green space. Many green innovative alternatives are not cost competitive in their early phases; this is a common problem for new technologies. Additionally, they face significant set-up or capital costs on top of more natural market barriers such as economies of scale. In addition, green alternatives have to contend with barriers to entry imposed by the prevalence of dominant incumbent technologies in areas where they are attempting to compete, and where current infrastructure has evolved to meet the needs of the existing technology suite. For example, energy and transport systems have dominant designs that are well-supported by established, fossil-fuel-based, infrastructure. As such, new technologies that do not conform can be locked out because the high fixed costs attached to developing new infrastructure can potentially act as a significant barrier.[159]

Uncertainty is likely to be higher for green investments, since the existence (and strength) of the market is almost wholly reliant on government regulation for its maintenance. There is no single path to achieving green objectives and lack of information about aspects of the longer-term policy and regulatory framework[160] creates additional uncertainty about the potential rate of return from investment in innovation. This higher level of uncertainty can increase the level of risk attached to a project and hence affect the decision about whether to proceed with the investment.

156 The UK will be better placed to accelerate the development of new technologies where it has a particular advantage – for example where the UK has a the full range of manufacturing and business R&D facilities. UK-based companies will lead international collaborations and the technology will be significantly developed, demonstrated and deployed in the UK. Government policy should offer the full range of RDD&D support.

157 Where the UK appears to lack an advantage in production, its influence on the development of technologies is likely to be much less. UK-based suppliers may develop important components and may participate in international collaborations but the pace and scale of development will be determined elsewhere. Appropriate public support is likely to be targeting demonstration projects and, if necessary, adapting technologies to local conditions and building the skills required for operation and maintenance.

158 Some technologies may be further from market and it is unclear which country has, or will have, a particular advantage. Here, the UK has a significant research capability and the potential to develop a leadership role. Public support should not direct academic research, but should ensure that the results of R&D programmes are widely disseminated.

159 Foxon et. al (2007), *'Energy Technology Innovation: A systems perspective'*, quoted in CCC (2010), *Building a Low Carbon Economy – the UK's innovation challenge: Supporting Analysis and Review of Evidence*, CCC.

160 For example, the future price of carbon under the European Union's Emissions Trading Scheme, EU ETS, is determined in part by agreement across Member States about the level of the cap placed on emissions produced.

There are a number of different levers available to the Government, the effectiveness of which will vary depending on the relative strength of different failures, the sector where the investment is being undertaken, and the technology itself and its stage of development. CCC (2010), among others, highlighted the **importance of both supply-push and demand-pull policies in encouraging investment in low-carbon innovation, particularly stressing the importance of taking a whole systems approach** to providing sufficient incentives and certainty for companies:

- The current innovation system in the UK provides a range of non-technology specific and more targeted interventions that aim to support green innovation from basic research and development through to commercial deployment. Many of the levers that government wields more generally such as public procurement, fiscal incentives to undertake core R&D and direct grant support are as important green innovation.
- The TSB is a key institution in helping to deliver key technological developments that will support the transformation to a greener economy. In addition, while TSB's remit extends much broader than the 'green' agenda, agencies such as the Carbon Trust and Energy Technologies Institute have specific objectives around helping to bring forward particular technologies that deliver cleaner alternatives for heat, power and transport.
- The Low-Carbon Innovation Group is made up of representatives of all key departments and delivery agencies (such as TSB and Carbon Trust) in order to improve coordination of programmes and resources among the key players in this space, and reduce duplication.
- In addition the Government has worked to ensure that, in order to minimise barriers to technology development that arise from the often capital-intensive nature of these technologies, gaps that had been identified in the provision of technology support have been closed. For example, the provision of capital support to build open-access testing facilities in offshore wind, marine and nuclear is important.
- Finally, the Government has attempted to strengthen incentives that reduce the risk attached to potential returns from investment. Available levers range from involvement in the EU ETS which helps companies internalise the price of carbon into investment making decisions (and hence levelling the playing field with high-carbon competitors), to implementing national incentive frameworks to encourage the deployment of green technologies (such as the Renewables Obligation, fiscal incentives such as fuel duty) and wielding the potential power of public procurement (through, for example, commitments to 'green' the government estate and employing the Forward Commitment Procurement model) to help markets grow to deliver a critical mass that enables economies of scale and cost reductions to be delivered.

In addition to ensuring that the support for innovation in this area is delivered in a timely way, additional challenges centre on the uncertainty of the path to achieving a greener economic base. **There are multiple routes available to**

delivering the necessary green growth outcomes and as such the innovation system in the UK must maintain sufficient flexibility to look out to the longer-term and deliver a range of technology options, given that it is not possible in many cases to assess ex-ante what will succeed. Providing the necessary support for development of a range of options is a considerable challenge, particularly in the context of a constrained fiscal environment. A number of organisations have recently considered the innovation institutional landscape in the context of the green agenda; the OECD is currently working on a green innovation strategy, for example. Table 14 below presents a summary assessment by the CCC on the UK's current position against key themes considered vital to deliver an institutional framework for innovation that is sufficient to meet the demands of the low-carbon (and by analogy the broader green) challenge.

Table 14: Assessment by the Committee on Climate Change of the UK institutional framework for green innovation

Key Theme	Current UK position
Overarching objective and long-term focus	Considerable uncertainty about the path from 2020, the technologies that this will require, and implications for technology support over the next few years.
Clear alignment between overarching objective and objectives of delivery bodies	The number of bodies and differences in approach mean that the landscape lacks clarity and is considered complex. Objectives of delivery bodies need to be fully consistent with government objectives
Strong links between all stages of the innovation process	Scope for strengthening links in designing research programmes related to low-carbon. Within this, need for appropriate balance to allow academics freedom to develop new ideas at the earliest stages of research.
Monitoring frameworks with feedback to objectives	Little evaluation evidence on the effectiveness of spends and a lack of resources dedicated to the long-term monitoring of measures.
Integration with international programmes	Need to increase UK influence over the design of EU programmes and take advantage of the scope for collaboration with other countries in developing key technologies.

Source: CCC (2010): Building a low carbon economy: the UK's contribution to tackling climate change

The Government is currently undertaking a review of the UK delivery landscape supporting low-carbon innovation, considering both the short-term needs (including making technological improvements to existing devices) and new technologies to support longer-term goals.[161]

Incentivising innovation through prizes and challenges

Public incentives in the market for research can take the form of patents, prizes or grants. In this section we will focus more particularly on prizes. A prize sets a goal for innovation in concrete terms along with a reward for the achievement of that goal without specifying the means of achieving it.This form of incentive is not recent since it dates back to the 1700s when prizes were a fairly common way of rewarding innovation. Eventually prizes began to be replaced by research grants that awarded money upfront to allow scientists to buy expensive equipment and hire staff. However, the massive extension of reach through

161 http://www.decc.gov.uk/en/content/cms/funding/funding_ops/innovation/deliv_review/deliv_review.aspx

the diffusion of digital technologies has been leading to a recent resurgence in the use of prizes. For instance, NASA has sponsored technological prizes since 2004. The question is whether prize awards can be a powerful mechanism for accelerating technological development.

THE REWARD STRUCTURE IN SCIENCE

Historic case studies suggest that prize awards, which have been used to address challenges faced by the society of the time, have at times led to major technological breakthroughs. Most famously, the British Parliament offered the £20,000 longitude prize to anyone who figured out how to pinpoint location on the open sea (see Box 13).

Box 13: Case histories of scientific prizes	
The Longitude Prize (1714)	A £20,000 prize was offered by the British government for a means of determining a ship's longitude within roughly 35 miles. English carpenter John Harrison invented and constructed a marine timekeeper that won the prize in 1773. Harrison's timekeeper was a predecessor to the modern marine chronometer.
Napoleon's Food Preservation Prize (1795)	Napoleon's Society for the Encouragement of Industry offered a 12,000-franc prize for a new method of food preservation. Nicolas Appert created a solution which marked the beginning of the canning industry. He was awarded the prize in 1810.
The Liverpool and Manchester Railway Locomotive Prize (1829)	This £500 prize was awarded to the winner of the Rainhill Trials, held to determine what type of engine should be used to pull trains on the nearly completed Liver to Manchester Railway. George Stephenson won the prize for his Rocket locomotive and was awarded the contract to produce engines for the railway.
The English Channel crossing prize (1909)	The Daily Mail offered a £1,000 prize for the first pilot to fly across the English Channel. Louis Blériot made the crossing on 25 July 1090 flying from Calais to Dover. Blériot went on to become a leading aircraft pilot and manufacturer.
Ansari X Prize (1996)	The Ansari X Prize set out a challenge was to use private funding to build and launch a spacecraft capable of carrying three people on two journeys within two weeks to a distance of 100 kilometers, or 62 miles, above the earth's surface. It offered a $10m prize and was won in 2004 by Mojave Aerospace Ventures, with two flights by the aircraft SpaceShipOne.

Source: BIS (2011)

Competition and awards play a central role in today's organisation of the science community.[162] Rewards set up races for scientific discoveries. They are based on the public disclosure of performances and the greater the achievement, the larger the rewards. The winner is awarded all for the discovery – so called 'rule of priority' – and there are benefits associated with this rule:

- It is economically efficient since social-value added is only associated with the first discovery (there is none when the same discovery is made more than once).

162 Dasgupta P., and David, P. (1994*), Towards a New Economics of Science*, Research Policy, Volume: 23, Issue: 5, University Of Chicago Press, Pages: 487-521.

- It elicits public disclosure of new findings, which widens the span of application in the search for new knowledge and lowers the likelihood that it will reside with persons or groups who lack the resources or ability to exploit it. It also enables peer groups to screen and evaluate the new finding.
- The autonomous governance system that characterises Western academic science tends to reward discoveries that are turned towards a goal that is widely recognised as worth achieving, either at the outset or subsequently. It is the disclosure of knowledge that aids other scientists in generating new findings that are usually rewarded.

However, the reward structure sets up a tension between cooperative compliance and individualistic competitive urge to win priority races. This can potentially lead to wastage of resources allocation in different ways:

- Competition among researchers may encourage duplication of research efforts e.g. rival teams may undertake an unduly risky set of research projects; too many projects may be discontinued by those who perceive that they have lost the race; rival teams may choose overly similar projects.
- The reward structure can have an opportunity cost by attracting too many researchers to a given race, to the possible neglect of other areas in which the entry of even a few competitors might be socially beneficial.

Economic theory of science therefore points to benefits but also the limitations of using a reward structure.

Innovation prizes can be beneficial to society. They allow the specification of technical output required without prescribing how that output should be achieved. This can give rise to the inclusion of both emergent and radical innovations to address the same challenge, as well as to the development of new collaborations and partnerships in tackling the challenge. An economic model[163] suggests that in the context of imperfect information, the range of situations where a patent system dominates prizes and contractual research may be narrower than previously thought. However, in areas where there are high entry barriers innovation prizes are not suitable forms of incentive as participants receive no upfront financial support.[164] The duplication of effort that prizes generate can be efficient if the social benefit of the innovation is sufficiently large. The design of the prize is therefore important and especially the appropriate specification of the technological target, the size and nature of the prize and the method for selecting the winner.

163 Wright, B. (1983), *The Economics of Invention Incentives: Patents, Prizes, and Research Contracts*, American Economic Review 73(4):691.707.

164 Newell, R. G. and Wilson, N. E. (2005), *Technology Prizes for Climate Change Mitigation*" Resources for the Future Discussion Paper 05-33.

DESIGNING PRIZES

There are few empirical analyses focusing on how prize incentives actually work 'on the ground' to change the level of activity of innovators.

A study of a large data set of prizes awarded for inventiveness by the Royal Agricultural Society of England (RASE) between 1839 and 1939 concludes that prizes can be a very effective mechanism to foster innovation.[165] This study shows that the contests organised by the RASE attracted a large number of inventors so the prizes did act as an important inducement incentive. The results point to a significant proportion of inventions (around 20 per cent) that were patented, usually within one year of the announcement of prizes. Significant effects of prizes on patent counts emerge which become much larger when lower quality patents are parsed out using patent fees. A doubling in the monetary prize was associated with a 6-7 per cent increase in patents in the targeted area of the show. An additional medal was associated with a 33 per cent increase in patents. The study also indicates that the monetary awards did not offset all the costs of technological development (covering around a third of the total cost of the implements and machinery exhibited by successful entrants). This is because exhibiting an innovation was a powerful form of advertising and winning a prize could strongly reinforce this effect. The awards encouraged not only competition through entry into the target areas but also through the diffusion of knowledge across innovators.

NESTA's experience of running the Big Green Challenge indicates that a large number of people from a range of backgrounds, including rural communities (the winning team came from the Scottish Islands), were motivated by the race. There was also evidence that the Challenge brought together groups that had not previously collaborated and groups that had usually not applied for public sector funding. 80% of the groups that weren't successful in the early stages of the competition continued to implement their plans anyway.

The consensus among contest organisers is that to be suitable for a prize a problem must be able to be very well defined and the parameters for winning very clear.[166] An important point however is that prize competitions do not replace the large public and private investment in R & D and intangible assets that is necessary to foster technological breakthroughs. Rather they can complement, extend and inform it in specific areas by extracting ideas from untapped sources in society.

Innovating in public service delivery

Changing expectations from users of public services and the more recent tight financial context have combined to put significant pressure on traditional ways

165 Brunt L., Lerner J. and Nicholas T. (2008), *Inducement Prizes and Innovation*, Center for Economic Policy Research, Discussion Paper No. DP6917, July.

166 Burke, A (2011) *How Open Innovation Can Help Solve Scientific Puzzles*, New York Academy of Sciences Magazine, February.

of organising and delivering public services. Innovating in the delivery of public services can support better outcomes at significantly lower cost. **Implementing user-led innovations at a scale in public services is a major challenge.**

USER-LED INNOVATION IN PUBLIC SERVICES

NESTA's work has explored the potential for more **user-led innovation in public services as a route to developing better, more cost effective approaches**. In this context, open innovation means ways of inviting and supporting new approaches to social challenges from different types of actors. User-led innovation in public services means innovation with and by the users of services, rather than innovation done for them.[167] This sort of innovation in public services involves users more closely, works with the behaviours and resources of communities and maximises the potential of online or digital tools. Many policymakers and those who work in public services would agree with the need for a shift to preventative approaches and drawing more on people's own capabilities to solve problems. Working more closely with citizens, communities and frontline staff is an effective way to achieve better prevention and behaviour change.

We have seen in Chapter 5 that scandinavian countries have better exploited the new opportunities offered by ICTs to be more responsive to users in their public services. In the UK there are many examples of innovations involving users (including those led by civil society organisations) whether in health, justice, education or local government. As just one example, Local Area Coordination is an innovative approach in practice in Scotland, Middlesbrough and Yorkshire and the Humber to act as a point of contact for people living with disabilities, to plan and organise care services around the user. Local Area Coordinators are effective in supporting independent living and helping people stay out of residential homes, with a dramatic impact on cost of care provision.[168]

Contrary to the stereotype, the problem is not necessarily a lack of 'good ideas' or innovative practice in the public sector or public services more widely. There is actually a lot of innovation activity in some areas of public services but, in the main, these approaches remain marginal. In order for these approaches to realise their potential and tackle the financial and social challenges facing public services, the issue is **how to 'scale' them to achieve a bigger impact. Scaling means that, over time, the best innovations become the dominant new approaches**. In public services, this might mean the growth of particular provider, the adoption of the approach by other providers, or inspiring many more providers to develop similar approaches.

167 For an in depth discussion of the potential of user-led and open-innovation in health, see NESTA (2009), *The Human Factor: How Transforming Healthcare to Involve the Public can Save Money and Save Lives*. London: NESTA.

168 For further examples see Boyle, D., Slay, J., and Stephens, L. (2010), *Public Services Inside Out: putting coproduction into practice*, NESTA; and, Gillinson, S., Horne, M., and Baeck, P. (2010) *Radical Efficiency: Different, Better, Lower Cost Public Services.* London: NESTA and the Innovation Unit.

Generally, the innovation system in public services has problems, due in part to a number of operational, cultural and systemic barriers to innovation in the public sector that can inhibit transformation:

- Innovation in public service delivery is often highly centralised, with small upfront R&D. The average R&D 'intensity rate' (R&D expenditure as a percentage of total sales) in the public sector is lower than in the private sector. The NHS dedicates 0.9 per cent of its budget to innovation, the Home Office 0.73 per cent and the Department for Work and Pensions just 0.14 per cent. In comparison, R&D intensity rate across all manufacturing sectors is around 4 per cent, rising to 15 per cent in sectors such as pharmaceuticals. Innovation tends to be associated with large-scale, technology-led projects with significant upfront costs.[169]
- At an operational level, the scale and complexity of the public sector, including siloed departmental responsibility, makes it difficult to innovate across service areas. Legitimate aversion to risk, over-specified regulations and procedures and a lack of funding and commissioning for new approaches can inhibit initiative, discretion and appropriate risk taking, coupled with a lack of incentives to act in innovative ways.[170]
- NESTA's research and practical work has identified further structural barriers to the spread and scaling of new approaches: an 'incumbency bias' that makes it difficult to change existing organisational and managerial practices, a lack of evidence to support the selection of innovation, and a lack of effective processes for decommissioning and redirecting resources towards better approaches.[171] NESTA's focus is on how to select, fund and grow the best innovations.[172,173]

NESTA'S PUBLIC SECTOR INNOVATION INDEX

A pilot approach to measuring innovation in the public sector has been recently produced by NESTA.[174] It provides some initial insights about how innovation is happening in the public sector and how public sector organisations are managing innovation.[175] The approach is based on a framework of public sector innovation developed from NESTA's Innovation Index and broader public sector innovation research, which is displayed in Figure 50 below.

169 Harris, M., and Albury, D. (2009), *The Innovation Imperative*, London: NESTA.

170 These barriers have been frequently discussed in relation to innovation in public services: see National Audit Office (2009) Innovation Across Central Government. National Audit Office; Cumming, L. (2010) 2020 Vision: *A Far-sighted Approach to Transforming Public Services*, Accenture; Mulgan, G., and Albury, D. (2003), *Innovation in the Public Sector*, working paper version 1.9, Strategy Unit, UK Cabinet Office.

171 For further discussion see Bunt, L., Harris, M., and Westlake, S. (2010) *Schumpeter Comes to Whitehall,* NESTA.

172 NESTA's functional model is explained in more detail in the summary report for NESTA's Innovation Index; see NESTA (2009) *The Innovation Index: measuring the UK's investment in innovation and its effects*, NESTA.

173 Developing an evidence base for social policy and research on decommissioning and innovation both form part of NESTA's ongoing research programme, outputs from which are forthcoming.

174 NESTA (2011), *Innovation in Public Sector Organisations*, March, London: NESTA.

175 The project developed and piloted a telephone interview-based survey-based approach during the summer and autumn 2010 over 175 organisations across the NHS and Local government.

Figure 50: Framework for innovation in public sector organisations

Source: NESTA (2011), Innovation in Public Sector Organisations, March.

The overall index scores suggest that:

- Innovation is stifled and **the key opportunity to improve innovation lies in the conditions in which organisations operate** (incentives, autonomy, leadership and culture, enablers). Scores are better for NHS organisations where innovation has been an explicit part of the NHS Strategy.
- **Mechanisms to encourage effective sharing of ideas should be improved.** Levels of reported innovation activity in 'accessing new ideas' is relatively low, especially in Local Government, and most ideas are sourced from outside the organisation. Access to best practice information from similar organisations is viewed as the most important enabler of innovation and mechanisms to encourage effective sharing can be improved.
- **A key incentive to innovate is customer feedback** and competition is yet to take full effect as an incentive. The impact of regulation is viewed as a double-edged sword, acting as both a barrier and a driver of innovation for Local Authorities, and more as a driver in the NHS.
- 37% of the surveyed organisations (28% of Local Authorities and 53% of NHS Trusts) reported having an innovation strategy as part of the overall strategy of the organisation. **Those organisations with innovation strategies have consistently higher innovation indices.** This is mostly due to higher 'leadership and culture' factors (including the prioritisation of innovation) but also capabilities in the 'management of innovation'.
- **Senior leadership is expected to drive innovation**, but results also suggest that managers give high priority to developing new ways of working and supporting the trial and error testing of new ideas, and staff also understand the value of innovating.

- **Critical organisational enablers of innovation should be recognised and improved when necessary.** They are management information, connectedness (internally and externally), access to support and skills, the use of incentives and rewards, and the quality of ICT infrastructure.

Based on the lessons from this pilot, NESTA intend to develop an online benchmarking tool.

Conclusion

The considerations addressed in this chapter suggest that there may be considerable scope for improving innovation performance by improving the focus and methods of public procurement, market incentives and public sector activity.

An effective innovation policy requires recognition that innovation is not the exclusive realm of the private sector and is not only generated through market mechanisms. The public sector is a major player in the innovation system and at the origins of many radical technological innovations.

In times of fiscal constraints there is also scope to better use the innovation potential of the public sector. However, this is a challenging task as the public sector is a complex customer. **Mobilising public administrations in favour of innovation requires establishing strong incentives** to increase collaboration and communication, administrative reforms and standards that go wider than cost considerations and also integrate innovation objectives, and upgrading competencies of human resources. This comes to developing an enhanced innovation culture in the public sector, which will have beneficial effects on the innovation potential of the economy as a whole.

Appendix: Global Innovation Leaders[176]

The US innovation system

The size of US markets provides a major advantage to the US innovation system. It allows US innovative businesses to grow, delivering high returns from successful marketing or technological innovation. But it is also the case that the US Government plays a major role, perhaps greater than recognised, in shaping innovation.

The cold war years saw significant investment by the Federal Government in supporting Research & Development activities in industries and universities, especially in defence-related technologies, life sciences, and energy. It provided a powerful impetus to the development and commercialisation of new civilian technologies in commercial aerospace, semiconductors, computers, and computer software. These then attracted increased private investment into the development of civil technologies with wide commercial applications.

The Defence Advanced Research Projects Agency (DARPA), created in 1958, remains instrumental in fostering these spillovers by developing technological initiatives, providing funding but also skills and management support to businesses, and providing a brokering function between university research, businesses and the public sector. This budget of this Agency is about $3 billion per year and funds exclusively challenge-led schemes in high risk-high reward areas of life sciences, physical sciences and engineering.

US federal research funding for academic and business institutions is distributed by governmental departments and agencies, including the Department of Defence, the Department of Energy, the National Science Foundation, or the National Institutes of Health (NIH). The NIH has an annual budget of $32 billion and is the largest civil agency.

The Small Business Investment Company Program (SBIC) was created through the Small Business Administration to bridge the gap between entrepreneurs' need for capital and traditional sources of financing. The program invests long-term capital in privately-owned and managed investment firms.

Over the last couple of decades, faced with more intense foreign competition, more limited financial resources and the growth of regional US clusters, federal policymakers launched more decentralised programmes spread across a number of agencies. These programmes sought to strengthen civilian technological capabilities by subsidising and promoting joint research, encouraging

176 Information about these innovation systems have been compiled with the help of the Science and Innovation Network (SIN) based in UK Embassies in Washington, Tokyo, Oslo and Berlin. Special thanks to Sarah Mooney, Kevin Knapett, Ursula Roos and Hazel Gibson.

collaboration between U.S. universities and industry in technology development, and supporting collaboration between U.S. industry and the federal laboratories. In the late 1980s programmes such as the National Center for Manufacturing Sciences (NCMS), the semiconductor research consortium SEMATECH, the Advanced Technology Program (ATP) of the Department of Commerce, and the National Science Foundation's Engineering Research Centers all represented a new technology policy and relied on expanded funding from the private sector.

Public procurement is a lever effectively used by the US Government. The Small Business Innovation Research Programme (SBIR) required Government Departments and agencies with large budgets to use 2.5% of their research procurement to support small businesses initiatives. SBIR funding is about $2 billion annually with additional contributions at local levels. For instance North Carolina matches all federal SBIR funds dollar for dollar.

Other U.S. initiatives in technology policy were to reduce antitrust restrictions on collaboration in research and improved intellectual property protection.

Today's US Innovation System has some strong characteristics:

- Integrated innovation systems within US Government Departments (e.g. Department of Energy (DoE), Department of Defence (DoD), National Institute of Health (NIH)). This includes support for research and proof of concept work, as well as support for product development and public sector organisations acting as a lead customer for innovative products and services through programmes such as the Small Business Research Initiative (SBIR).
- Public funding to undertake long-term, challenge-led research and R&D activities with universities and businesses. These programmes have played a significant role in the development and commercialisation of major innovations, e.g. telecoms and the internet. Increasingly the funding of these programmes is linked to international collaborations.
- An exceptionally strong public and university research base, supported through federal agencies like the Department of Energy (DoE) and National Institute for Health (NIH) provide a bridge to commercialisation and help to de-risk private investment providing a significant incentive for universities to commercialise innovations e.g. ownership of all IP arising from Federally-funded research), which has encouraged US institutions to invest in their technology transfer and exploitation capability.
- The existence of diverse and large companies that are investors in R&D and also in wider forms of innovation, ranging from ICT companies such as IBM, Microsoft or Cisco, to aerospace and defence companies such as Boeing, and Life Science companies such as Pfizer, Amgen, and Johnson & Johnson. Large companies in non technology-based sectors are also important customers for innovative products, notably Amazon and Wal-Mart, whose investment in logistics and supply chain management technologies in the 1990s had a significant impact on US retail productivity growth.

- A high acceptance of failure and a dynamic entrepreneurial culture, linked to strong clusters e.g. Silicon Valley, Boston, Austin, North Carolina. The combination of the availability of venture capital, business angels, and other forms of public and private investment alongside strong mentoring programmes, facilitate business start ups and rapid growth to large scale in high-technology sectors such as low carbon and convergent technology. The important role of new small businesses in commercialising technological advances appears to be unique amongst major economies.
- A successful government sponsored funding programme for small businesses (SBIC). For every $1 an SBIC raises from a private investor, the Government provides $2 of debt capital, subject to a cap of $150 million. This attracted $840 million of private capital in 2010/11. Since its inception, the SBIC program has helped finance thousands of small businesses, including Costco, Amgen, Staples, Apple, AOL, FedEx, Intel etc.

The Japanese innovation system

Although the Japanese economy faces major problems of an ageing population, negative economic growth over recent years and a fragile environment, the Japanese innovation system still remains one of the most effective in the world. It continues to rely heavily on central government, large conglomerates and social and educational innovations.

The industrial and economic miracle of Japan was carefully orchestrated. In the 60s and 70s Japan was a big importer of technology through various mechanisms of technology transfer while simultaneously developing the basis for self-reliance and the ability to absorb technologies. Since the 1980s Japan has been at the forefront of many generic technologies. This transformation has been achieved on the basis of a national consensus in which central government played a leading role.

The Ministry of Economy, Trade and Industry (METI) shapes the long-term economic development of Japan. Technology forecasting and targeting is part of its the responsibility, which it performs in collaboration with the Ministry of Education, Culture and Sports, Science and technology (MEXT). METI creates 'technology strategy maps' through consultation with industry, academic institutions and government departments.

Research, development and innovation are seen as a strategic priority by the Japanese government as well as by industry. The capacity to mobilise very large resources in pursuit of strategic priorities is a feature of the Japanese innovation system. Research expenditure represents about 4% of GDP. METI supports innovative investment through research and funding agencies such as the National Institute of Advanced Industrial Science and Technology and the New Energy and Industrial Technology organisation. However large corporations provide about 80% of the national research expenditure.

Japanese large corporations have close links with central government. The strategic visions developed by MITI are used as guiding maps for future industrial developments by industry associations and large conglomerates such as Mitsubishi, Honda, Mitsui, Sumimoto. They allow for large strategic investments with long-term objectives. They also facilitate the access of the world markets through strong marketing strategies and networking. In the 1980s most of their research was conducted in in-house laboratories. More recently, they have been developing research collaborations with universities and research institutes.

Flexibility within Japanese companies and the dedication to quality of product design and development is also a feature of Japanese innovation. Thorough product design and aims for customer satisfaction are the main factors behind the constant quality improvements of the Japanese products. Companies often have the practice of rotating engineers from the R&D departments to the shop floors and back again which gives them additional customer knowledge.

Japan also has among the highest skilled workforce in the world. A high proportion of Japanese complete higher level of education and a significant share of them study science and engineering. On-site training is considered by companies to be the most important element in the formation of technical skills. In addition, companies often have established formal training courses and skill formation centres. This is favoured by an economic system where traditionally employment in a Japanese company is for life.

In August 2011, METI released a 5-year science and technology plan. It identifies innovative culture and funding for science and technology as a national priority. The plan includes a target of R & D of 4% of GDP, with corporations contributing 3% and Government 1% (about £190 billion).

The German innovation system

Germany built much of its economic growth over past decades through maintaining high-value added engineering and heavy industries. Almost 80% of R&D is channelled into automotive, electrical engineering, chemicals and machine tool industries, but Germany increasingly invests in advanced sectors like ICT, biotechnology and nanotechnology. Germany has a decentralised structure, strong SME networks, and cross-cutting technology and infrastructure policies.

Germany is committed to increasing R&D spend to 3.0% of GDP by 2015. Investment in education and research remained a priority through the economic crisis. R&D spend was 2.80% of GDP in 2009, two thirds of this provided by industry. Some federal states have their own innovation programmes which contribute to competition, regional differentiation and cluster development, with over 3% of GDP invested in R&D in Bavaria and Baden-Wuerttemberg. Germany's Laender are involved in joint policy co-ordination processes and co-fund research organisations and university infrastructure.

Germany has a well-funded research landscape. Some 70 Max Planck institutes specialise in basic research, while about 60 Fraunhofer institutes conduct applied research, collaborating closely with industry. About 80 Leibniz institutes and 17 Helmholtz large science centres engage in basic, strategic and applied research. The Federal and Laender Governments will increase base funding for Germany's research organisations by 5% p.a.

The High-Tech Strategy is Germany's cross-departmental mechanism to promote innovation. With a EUR 15 billion budget in 2006-2009, it promoted a mix of sectors and enabling technologies supporting national priorities and addressing global challenges: climate/energy, health/nutrition, mobility, security and communication. The second phase of the High-Tech Strategy launched in 2010 focuses on scenario-based innovation strategies and roadmaps. It places even greater emphasis on knowledge transfer, commercialisation, and strategic science-industry partnerships.

Industry plays an important role in defining priorities and in leveraging public-sector funding. The High-Tech Strategy has created long-term public-private partnerships in emerging technology areas. Industry is involved in road maps development and priority setting. Leading companies such as BASF, Bosch, Daimler, Deutsche Telekom, Siemens and Deutsche Post DHL contribute to Germany's High-Tech Startup Funds launched in 2005 and 2011, providing over EUR 500 million for start-ups. So far 250 start-ups have been supported, leveraging over EUR 300 million in private-sector follow-on finance.

It is the integration of high-tech into medium-tech products that forms the basis of German innovation. The influential Mittelstand – family-owned innovative SMEs – lies behind Germany's leading position in the export markets, from machine tools to laser systems. Recognising this, the German government actively promotes innovation in SMEs. The Central SME Innovation Programme (ZIM), launched in 2008 with an annual budget of EUR 300 million, funds research cooperation between SMEs and between SMEs and research institutes. As part of Germany's economic stimulus package a further EUR 900 million was provided in 2009-2010. The programme successfully secured and created jobs during the crisis.

The Swedish innovation system

The Swedish economy has a strong international orientation and this is reflected in its innovation system. The high performance of Sweden is also linked to the interplay between multinational companies, industrial policy, university research, and dynamic public sector organisations.

Around 4% of GDP is invested in R&D; 1% is government spending, and 3% from industry. The Swedish industrial system is characterised by a large knowledge-intensive and export-oriented manufacturing sector dominated by a small number of large multinational groups grown from traditionally strong domestic industries, such as Ericsson, Volvo, SAAB, AstraZeneca, Electrolux etc. With the growth of cleantech, digital and service sectors, and life sciences, SMEs are playing a strategic role but concerns persist about their ability to grow.

Most government funding goes to universities. A few universities (Karolinska Institutet, Lund, Uppsala, Goteborg, Chalmers and Stockholm) and the Swedish Royal Technical Institute dominate Swedish research. In 2009-2010 the Government released EUR 250 million to 21 national Strategic Research Areas for the first time.

The Swedish innovation system is made up of many organisations under the national innovation agency (VINNOVA) with a budget of around EUR 200 million per annum. For instance, the industrial research institutes' main mission is to provide research services to the business sector, the Government covering the costs of facilities and skills development. Their work is demand-driven and they act as an interface between academic research and product development in the business sector.

VINNOVA develops research and innovation strategies for specific sectors in close dialogue with businesses and key actors in the respective sector. It produces analytical work to try to understand the future needs for a specific industry, what type of competence is available at the Swedish universities, what the international competition is, and where growth areas are including information and communication technologies (ICT), services and IT implementation, biotechnology, manufacturing and materials, transportation, and working life science. This type of approach aligning industrial and research needs will continue to drive Government funding for both research and innovation in the next National Research Bill in October 2012. VINNOVA is also moving towards challenge led innovation as an overriding goal e.g. more innovative public sector procurement, maintaining its focus on four national priorities: sustainable cities; health wellbeing and medical; competitive industry; and information society.

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