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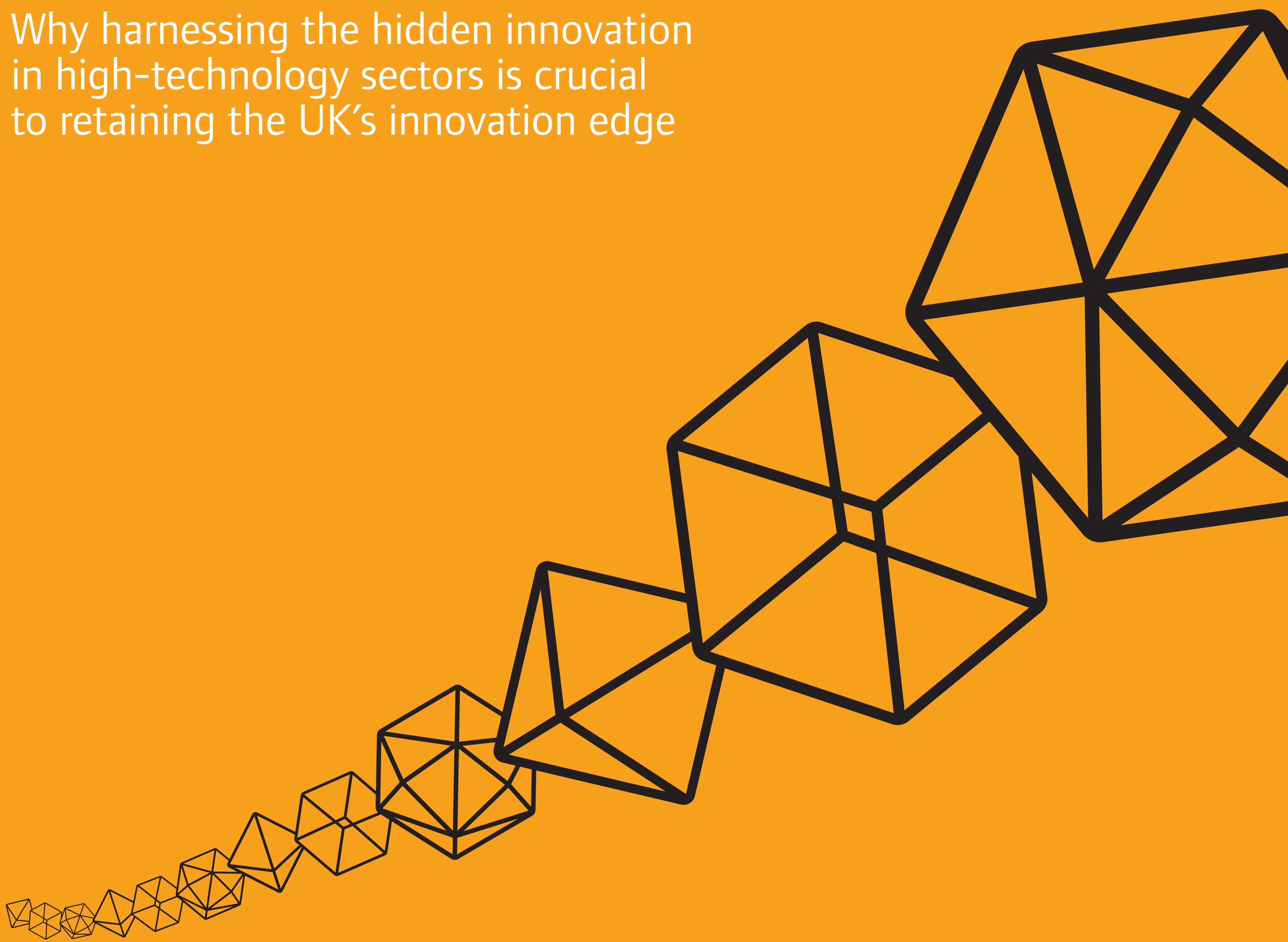
NESTA Making Innovation Flourish

Total Innovation

Why harnessing the hidden innovation in high-technology sectors is crucial to retaining the UK's innovation edge



Total Innovation

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Foreword

Innovation is vital to the UK's future economic prosperity and quality of life. So it is crucial that we understand where innovation comes from, who does it, what stimulates it, and how it benefits our economy and society.

In October 2006, we published the first in a series of reports on what we call 'hidden innovation' – the types of innovation that tend to be neglected by traditional indicators. We suggested that an 'innovation gap' had opened up between these indicators, the reality of innovation in the UK, and the policy intended to stimulate and support it.

Much has changed since then: a new UK government department for innovation; a White Paper that explicitly recognises the importance of hidden innovation; and the announcement of a major new effort to measure innovation in ways that more accurately reflect the UK's economy and society.

But much remains to be done. This report, the third in the series, focuses on high-technology sectors such as aerospace and pharmaceuticals. It reveals the increasing importance of hidden innovation in these sectors, and the surprising ways in which our most innovative firms have adapted to technological change and international competition.

What is clear is that, in this rapidly changing world, more of us need to be prepared to be innovative. We need, in particular, to rethink some of our most fundamental and long-standing assumptions about innovation, and to consider new, perhaps unfamiliar ways of responding. This is as much a challenge for our politicians and policymakers as it is for our firms and entrepreneurs.

We would greatly welcome your views on our proposals, and to hear your own.

Jonathan Kestenbaum
CEO, NESTA

May, 2008

NESTA is the National Endowment for Science, Technology and the Arts.

Our aim is to transform the UK's capacity for innovation. We invest in early-stage companies, inform innovation policy and encourage a culture that helps innovation to flourish.

Executive summary

There is both too much pessimism and too much complacency about the UK's high-technology sectors. Too much pessimism because the UK remains strong within major sectors such as aerospace, pharmaceuticals and automotive; too much complacency because the nature of innovation in these sectors is changing rapidly and may overtake UK industry and the policies designed to support it.

Innovation is about more than product breakthroughs resulting from scientific and technological research. It can be as much about new ways of doing things, or new business models. Such 'hidden innovation' enables UK firms to change and adapt in the face of rapidly increasing international competition.

Just as firms need to harness several different forms of innovation from new technologies to new business models – a process known as 'total innovation' – policy also needs to reflect this broader understanding of what innovation is and where it comes from. Most importantly, the UK needs to develop strategies to stimulate total innovation if it is to remain competitive in today's world.

The UK appears to perform poorly in innovation and the focus of policy has been on improving this performance

In an increasingly competitive global economy, innovation – the 'successful exploitation of new ideas' – is the major source of competitive advantage for mature economies like the UK.

But the UK performs poorly on traditional innovation indicators, such as public and private investment in formal research and development (R&D) and the number of patents registered.

Unsurprisingly, policy has focused on improving the UK's performance according to these indicators. The result has been a comprehensive range of initiatives that have focused on support for technology-focused innovation. These have included Knowledge Transfer Networks (KTNs), Knowledge Transfer Partnerships (KTPs), and R&D tax credits. Scotland, Wales and Northern Ireland have reflected a similar emphasis, as have initiatives in the English regions.

The UK has world-leading strengths in some high-technology areas but is up against rapidly increasing international competition

There has been too much pessimism about UK high-technology sectors

Aggregated figures for national investment in R&D fail to acknowledge the different patterns of specialisation in different countries. The UK retains strengths within the six sectors that represent the majority of R&D expenditure in the UK, from pharmaceuticals to electronics including:

- The second most significant pharmaceuticals sector in the world, home to globally-renowned firms such as GSK and AstraZeneca.
- The second largest aerospace industry in the world: Rolls-Royce is one of only three major manufacturers of civil aeroengines worldwide.
- Expertise in automotive engine development and manufacture, as well as the world's most successful motorsport industry.
- Major telecommunications firms such as BT and Vodafone that have pioneered new network infrastructures, products and services.
- Highly innovative UK-based software and IT services firms, such as Sage, Misys and Autonomy, and some of the most technologically advanced and creative games software developers in the world.
- World-leading electronics firms such as ARM, CSR and Wolfson.

Much of this has been achieved by moving successfully to higher-value-added activities in the face of competition from lower-cost countries.

However, international competition is intensifying
The increasingly distributed nature of innovation and the outsourcing of ever higher-value-added activities to firms in emerging economies is increasing their ability to compete with Western firms. This can be seen across many sectors: China, India and some Eastern European countries in pharmaceuticals, automotive and electronics; Brazil, Japan and China in aerospace; India in software and telecommunications.

The Indian software and business process outsourcing industry is expected to achieve $60 billion in exports of software and services by 2010; the UK is the second largest market for the Indian software sector after the US. Similarly, China is now the world's largest electronics manufacturer. In 1997, it accounted for 4 per cent of global electronics output; by 2005, its share was touching 20 per cent. Such rapid growth is not merely a matter of 'market forces'; it often also reflects concerted and coordinated efforts at building new national champions in these emerging economies.

In the face of this competition, UK firms need to harness 'total innovation'

We have neglected the 'hidden innovation' in the UK economy, including in manufacturing
Traditional indicators of innovation are based on a model that is increasingly irrelevant, especially to the UK. Indicators such as R&D expenditure and patent production assume that innovation is synonymous with scientific and technological invention born of new research-driven knowledge.

However, many forms of innovation are neglected by this traditional 'linear' model, for example new organisational forms and business models. These are examples of what we call 'hidden innovation'.

Recently, policy has begun to recognise this hidden innovation. Most importantly, *Innovation Nation*, the White Paper published in March 2008 by the UK's Department for Innovation, Universities and Skills (DIUS), gives a prominent place to hidden innovation and innovation in services. However, the White Paper has less to say about what policy mechanisms are required to stimulate and support this hidden innovation.

Much hidden innovation can be found in research-intensive sectors
UK high-technology firms, in sectors such as pharmaceuticals, aerospace, and telecommunications, increasingly recognise the need to innovate in new ways. Four types of hidden innovation can be seen in high-technology sectors.

- **Type I hidden innovation** is identical to traditional innovation but is not included in its measurement. For example, much technological innovation in aerospace firms is not captured in narrow R&D measures. The effective use of new composite materials in Boeing's new aircraft manufacture requires learning 'on the job' (not in the lab) about how to manufacture and tool such materials. Yet such practical research often lies outside formal R&D processes – particularly in small and medium-sized (SME) firms without formal R&D programmes. However, such innovations can save millions of pounds in increased efficiency and higher engineering performance.

- **Type II hidden innovation** happens in non-scientific and technological forms such as new organisational structures and business models. For example, in pharmaceuticals, some large firms have reorganised to reflect the structures of more entrepreneurial small biotechnology firms. GlaxoSmithKline (GSK) has created new semi-autonomous business units called Centres for Excellence in Drug Discovery (CEDDs). GSK now has many more – and more radical – drugs in development, and leads other large firms in the mid- to late-stage development of products. Organisational innovation can also markedly improve productivity (as with 'Lean manufacturing' to cut the costs and production time of cars and aircraft), and provide new services for customers (for example, firms such as Rolls-Royce are increasingly making the majority of their revenues from long-term maintenance and support contracts with customers).

- **Type III hidden innovation** comes from the novel combination of existing technologies and processes. Because some of these technologies aren't new-to-the-world, the innovation doesn't get counted in traditional metrics. For example, in software, official definitions of R&D only acknowledge software development that represents a 'scientific and technological advance'. Yet much software development involves the creative use of existing functions and routines to deliver new and sometimes innovative services.

- **Type IV hidden innovation** takes place 'under the radar' of many surveys. In many areas of engineering, there are small-scale problems and challenges that are dealt with outside R&D programmes. For example, the Toyota Production System (TPS) represents a highly successful approach to generating such 'micro-innovations'. TPS organises manufacturing and logistics to eliminate waste and inconsistency in products through an emphasis on continuous improvement, teamwork, and becoming a 'learning organisation'. Through this, Toyota implements one million new ideas each year (3,000 each day).

Without hidden innovation, there is a danger that established UK firms become 'locked-in' to existing technologies and business models
Technological R&D can become locked into existing 'platforms' and focus on incremental improvements to these platforms. This innovation can raise marginal performance or reduce costs, but is not going to lead to the fundamental change that is often needed to stay competitive.

This lock-in is often reinforced by the established organisational structures, business models and related investments made by firms around the existing platforms. For example, the large-scale manufacture and distribution systems required by steel car body structures in automotive, the 'blockbuster' drug development business model in pharmaceuticals, and the revenue charging model for mobile calls and data in telecommunications, all potentially prevent firms focusing on more transformative change.

The danger of such lock-in is that established firms fail to respond quickly or radically enough to the increasing international competition in these sectors. This is why much radical innovation often comes from new entrants; they are freer – organisationally and conceptually – to do so.

In this context, for incumbents the ability to develop new business models, organisational forms and processes becomes even more important. Doing so could help to free them to engage in new forms of technological development and to enter new markets.

Remaining competitive requires 'total innovation'
Some leading established firms – including Rolls-Royce, BT, Toyota and GlaxoSmithKline – are taking a broader approach to innovation. By seeking to integrate innovation in new technologies, products and processes with innovation in business models, organisational forms and market positioning, they create greater profits and protect their market position. This is 'total innovation'.

More UK high-technology firms need to develop the capability for total innovation. Too many firms are unprepared for the ways in which foreign competitors are developing wholly new approaches that are not limited to new technologies.

Recommendations: The UK needs Total Innovation Strategies for high-value-added sectors to retain its innovation edge

Innovation policy should be focused on supporting the types of innovation that contribute to business growth
Policy for high-technology sectors still focuses overwhelmingly on R&D and technology development. This focus should shift from supporting research to stimulating a wider set of innovative activities that can contribute to business growth.

Of course, the UK needs to remain an attractive place for major firms to locate their R&D activities, so policymakers rightly support R&D in these sectors. But this is no longer sufficient. Firms and entrepreneurs need to explore and experiment with new business models and different commercial strategies.

Extend sector-focused innovation policy
Focusing on total innovation reinforces the importance of sector-focused support. Technology 'roadmaps' which identify longer-term trends, support for specific emerging technologies, and strategic alliances within industries can all help to stimulate and support longer-term R&D. Some of this already happens (especially in aerospace and, to some extent, in electronics), but it rarely seeks to stimulate or support wider forms of innovation,

or to help in the development of new business models.

Better coordinate the 'non-innovation policy' that influences innovation
Typically, what is designated as 'innovation policy' does not encompass the wider set of policies that also influence innovation in businesses – from taxation and regulation to public procurement, intellectual property rights to education and skills. While innovation policy cannot be all-encompassing, these other areas of policy need to be aligned with the objectives of innovation policy – especially given the breadth of total innovation.

The demands of total innovation require stronger and broader skills
High-technology sectors need a strong supply of people skilled in science, technology, engineering and mathematics (STEM). More students need to be inspired to study these subjects, and STEM careers must present an attractive alternative to employment in other sectors.

However, narrow technical skills are not sufficient for total innovation. Education and training must develop the capabilities necessary for contemporary innovation, specifically more interdisciplinary skills and stronger strategic business skills.

The new UK Commission for Employment and Skills (UKCES) should build on the work of the sector skills councils to provide government with an analysis from the perspective of industry regarding the extent and quality of 'innovation-ready' skills in the UK, and advise on how the education, training and skills systems across the UK might be improved to ensure the better development of these skills.

Government and industry should develop Total Innovation Strategies for strategic industries
The UK needs to invest in its strategically important industries. These are the UK's current high-value-added industries and those that are identified as having the realistic potential to become high-value-added – our 'innovation edge'. 'Investment' in this context means economic and political commitment to their development.

The UK must develop comprehensive strategies for these industries. These strategies should be comprised of three main elements. They should chart likely changes in the environment in which these industries operate: present or coming changes in knowledge, technology, trade, demographics and industrial structure that have bearing on competitive strategy or socially-desired outcomes. Industry and government should then apply this understanding to the UK's current positioning and identify a small number of likely routes to competitive advantage. Finally, these strategies should lay out a plan for passive and active government support, primarily centred around the need for greater coordination of policy.

These strategies should be led jointly by DIUS and the Department for Business, Enterprise and Regulatory Reform (BERR) – working with HM Treasury, the Technology Strategy Board, devolved administrations and relevant agencies such as regulators and sector skills councils – and shaped by ongoing engagement with industry.

Collectively, these strategies should represent the UK's national mission for innovation.

Policy should be informed by new measurements for total innovation
The extent and importance of hidden innovation in research-intensive sectors demonstrates the inadequacy of focusing on research-focused indicators.

In firms, the increasing importance of total innovation makes formal R&D spend increasingly unhelpful as a guide to innovative performance and hence business growth. In policy, the focus on R&D as a proxy for national performance obscures a focus on business growth from innovation and the wider set of factors that shape innovation by firms.

This will require a new set of broader and more meaningful indicators to guide policy. These will be considered as part of NESTA's work on developing a new Innovation Index for the UK.

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The views expressed in this report represent those of NESTA only. References to other organisations, including those consulted in the course of the research, does not imply endorsement by those organisations.

Contents

Total Innovation
Why harnessing the hidden innovation in high-technology sectors is crucial to retaining the UK's innovation edge

Total Innovation

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1. The UK appears to perform poorly in innovation and the focus of policy has been on improving this performance

1.1 Innovation is vital to the future of the UK's economy and society

In an increasingly competitive global economy, innovation – the 'successful exploitation of new ideas' – is regarded as the major source of competitive advantage for mature economies like the UK.[1] As a result, HM Treasury has identified innovation as one of its five drivers of productivity.[2]

1.2 But the UK performs poorly compared to its competitors

Traditional innovation indicators, such as public and private investment in formal research and development (R&D) or the number of patents registered, suggest that the UK performs poorly.[3]

The UK's 'R&D intensity' (total expenditure on R&D as a percentage of national GDP) was 1.8 per cent in 2005, below Japan (3.31 per cent), Germany (2.54 per cent), France (2.2 per cent) and the United States (2.74 per cent).[4] UK businesses consistently spend less on R&D than their US, French and German counterparts, and below the OECD average.[5] Given the UK's comparatively low investment in R&D, it is no surprise that it also lags behind other leading countries on patenting.[6]

Further, the UK invests comparatively less than many other countries in higher education, at just 0.7 per cent of GDP, compared to 2.36 per cent in the US, 0.95 per cent in France, and the OECD average of 1.42 per cent.[7] However, this relatively low spending does at least appear to be highly productive; compared to the US, France and Germany, the UK consistently scores highly on numbers of scientific papers produced and citations per capita.[8]

Unsurprisingly, policy has focused on improving poor performance in R&D and increasing investment in science research (see 4.2).

2. The UK remains strong in some high-technology areas but is being challenged by the changing nature of innovation and rapidly increasing international competition

2.1 Focusing on aggregated data neglects how many UK high-technology sectors have moved to become high-value specialists

There is too much pessimism about high-technology sectors in the UK. Aggregated figures for national investment in R&D ignore the different patterns of specialisation in different countries, making investment in R&D potentially misleading as a way of capturing comparative performance in innovation.[9] The UK retains strengths in areas of the six sectors that represent the majority of R&D expenditure in the UK, from pharmaceuticals to electronics.

The UK has the second most significant pharmaceuticals sector in the world, with globally-renowned firms such as GlaxoSmithKline (GSK) and AstraZeneca, as well as major R&D centres for international firms such as Pfizer. It has the second largest aerospace industry in the world, with Rolls-Royce being one of only three major manufacturers of civil aeroengines, and with major development and production sites for one of the two major manufacturers of large civil aircraft in Airbus UK. Seven of the global top ten automotive manufacturers operate

1. As defined by the then Department of Trade and Industry (DTI), see Department of Trade and Industry (2003) 'Innovation Report, Competing in the Global Economy: The Innovation Challenge.' London: DTI.
2. HM Treasury (2000) 'Productivity in the UK: The Evidence and the Government's Approach.' London: HM Treasury.
3. According to the definition that is used for tax purposes in the UK, R&D is defined as any project to resolve scientific or technological uncertainty aimed at achieving an advance in science or technology, see Department of Trade and Industry (2004), 'Guidelines on the Meaning of Research and Development for Tax Purposes.' London: DTI. This definition is based on the OECD's Frascati Manual, see Organisation for Economic Co-operation and Development (2002), 'Frascati Manual 2002.' Paris: OECD.
4. Organisation for Economic Co-operation and Development (2007) 'OECD Science, Technology and Industry Scoreboard 2007.' Paris:OECD.
5. See Organisation for Economic Co-operation and Development (2005) 'OECD Science, Technology and Industry Scoreboard 2005, Briefing Note for the United Kingdom.' Paris: OECD.
6. The UK was granted 3 per cent of triadic patent families in 2005, far lower than the US (31 per cent) but also lower than Germany (11.9 per cent) and Japan (28.8 per cent). All data from Organisation for Economic Co-operation and Development (2007) 'OECD Science, Technology and Industry Scoreboard 2007.' Paris: OECD. A 'patent family' is a set of patents taken out in various countries for the purposes of protecting a single invention. Triadic patents are filed at the European Patent Office, the Japan Patent Office, and granted by the US Patent and Trademark Office.
7. Organisation for Economic Co-operation and Development (2007) 'OECD Science, Technology and Industry Scoreboard 2007.' Paris: OECD.
8. Ibid.
9. As argued in National Endowment for Science, Technology and the Arts (2006) 'The Innovation Gap.' London: NESTA.

in the UK, with its acknowledged expertise in engine development and manufacture, as well as the world's most successful motorsport industry.

Major UK telecommunications firms, such as BT and Vodafone, have pioneered new network infrastructures, products and services, placing the UK at the forefront of the trend of convergence between telecommunications and other media. There are highly innovative UK-based software and IT services firms, such as Sage, Misys and Autonomy in business applications. The UK also hosts some of the most technologically advanced and creative games software developers in firms such as Codemasters and NaturalMotion. Similarly, in electronics, the UK is home to world-leading firms such as ARM, CSR and Wolfson, as well as many major multinationals.

Collectively, these sectors generate £80.9 billion in gross value added (GVA) and employ 1.44 million people in the UK.[10] This is around 7 per cent of total UK GVA – more than half of total manufacturing GVA in the UK. Overall, this suggests that the UK's high-technology sectors are moving somewhat successfully to higher-value-added activities in the face of increasing global competition. In this sense, the UK is still competing in the 'race to the top'.[11]

What the UK does not have, compared to some other countries, are large home-grown mass market manufacturing firms in sectors such as electronics (especially consumer electronics), computing machinery, telecommunications, automotive and other transportation machinery, and chemicals. This lack of scale in some high- and medium-high technology sectors contributes to the UK's comparatively poor showing in aggregated R&D figures.

2.2 Innovation is becoming increasingly distributed between firms, including global suppliers

2.2.1 Innovation is becoming more complex and costly

But this should not be a cause for complacency. The nature of innovation in high-technology sectors is changing rapidly and may overtake UK industry and the policy designed to support it.

10. GVA measures the contribution to the economy of each individual producer or sector.
11. As The Sainsbury Review in 2007 argued, the UK needs to engage in a 'race to the top' by concentrating on the development of higher-value-added industries; see HM Treasury (2007) 'The Race to the Top, A Review of Government's Science and Innovation Policies.' London: HM Treasury.

Pharmaceuticals

The pharmaceutical sector makes a large contribution to the UK economy, with a gross value added (GVA) of £6.5 billion in 2004. As the fourth largest pharmaceutical sector in the world in terms of GVA, it directly employs 73,000 people, exports £13.8 billion worth of goods, and provides a trade surplus of £4.3 billion. The UK is second only to the US in global medicines brought to market; the same is true of biopharmaceuticals (drugs produced using biotechnology). The UK is also an important centre of bioprocessing (the manufacturing sub-sector).

Traditional innovation in pharmaceuticals requires very large upfront investments in R&D. Developing a new medicine takes on average 10-15 years and costs more than £550 million. Before it is licensed, a drug has to undergo a long and complex process of testing. Following this, for large-scale manufacturing, firms often need to build new facilities or reconstruct old ones.

Given the expenditures involved, the 'blockbuster model' has been used to describe the balance between risk and reward: the development costs for all products are supported by relatively few, very successful products. This is why pharmaceuticals represent the most research-intensive large-scale sector in the UK economy, with an R&D intensity of more than 15 per cent; they also account for 35.5 per cent of R&D in the UK. Only the US and Japan spend more in pharmaceuticals research.

The research-intensive nature of new pharmaceuticals has been reflected by the traditional industrial structure of the sector. Until the early 1980s, the sector was characterised by large, vertically integrated commercial firms responsible for the discovery of chemicals, clinical development, and marketing and distribution. Firms required and could afford large-scale industrial R&D labs, reflecting the magnitude of research opportunities and unmet needs.

See Appendix A for further detail.

Innovation has become more complex with new knowledge bases, alongside other cost pressures on investments in R&D.

- In pharmaceuticals the nature of drug discovery is being radically reshaped by the impact of new biological knowledge derived from advances in life sciences and genetics, but the resulting biopharmaceuticals are far more complex to develop and manufacture than traditional chemically-derived drugs (and even then may not be adopted by major purchasers).

- In aerospace, increasing demands for more efficient and reliable aircraft – with the use of composite materials in aerostructures, and increased use of electronic systems to replace hydraulic, mechanical and pneumatic systems – has made developing and integrating these elements more complex for major manufacturers.

- In automotive, despite a generally conservative approach to product design, modern vehicles are increasingly complex, for example, in the use of electronic components to control and monitor functions, making their integration increasingly challenging for major manufacturers.

- In software and IT services, large suppliers have become frustrated with the length, cost, and quality of the software product development process, not least because of the relatively short life cycle of some products and the ability of competitors quickly to launch similar products.

- In telecommunications, de-regulation and technological advances have driven a rapid convergence between what would have previously been separate sub-sectors (voice telephony, data and productivity applications, and video and television) opening up the sector to new entrants and new services. This has placed particular pressure on established providers, who have seen revenues from calls and lines decline from increased competition.

- In electronics, with advances in knowledge, devices are increasing in complexity with greater range in functionality, the packaging of components and devices, and the emergence of new materials (such as plastic electronics) for use in components. These innovations have the ability to improve applications in other products (such as mobile phones and digital cameras).

Aerospace

Aerospace is a comparatively small part of the UK economy, but one which adds considerable and growing value. Having increased its global market share from 9 per cent to 13 per cent since 1995, the UK aerospace industry is the second largest in the world (after the US). Worth £5.5 billion to GVA, it exports 63 per cent of its total sales, contributing a £1.54 billion surplus to the balance of trade in 2006. The UK sector directly employs over 124,000 people (a 25 per cent increase since 1995), and supports 276,000 jobs across the whole UK economy.

Traditional innovation in aerospace is a mix of applied research and continuous development. It is typically centred on high-cost and high-risk research-based product development programmes, with very long development cycles (often 15-20 years). Such innovation can lead to a change in the physical structure of an aircraft or its components. These cycles are often determined by the relatively rare opportunities offered by major new large civil aircraft development programmes such as the Airbus A380 and the Boeing 787.

Aerospace invests heavily in R&D, with expenditure (including defence) of £2.54 billion in 2006 (an R&D intensity of 12.7 per cent). The sector spends 11.4 per cent of all R&D in the UK, the second highest R&D intensity after pharmaceuticals.

Some of the most important recent and ongoing traditional innovation has been in the development of aeroengines capable of increased fuel efficiency and reduced emissions; the use of composite materials in aerostructures; and increased use of electronic systems to replace hydraulic, mechanical and pneumatic systems.

See Appendix B for further detail.

2.2.2 These pressures have led to innovation becoming increasingly distributed and collaborative

2.2.2.1 Firms are drawing on a wider range of actors

These pressures on traditional innovation have motivated many firms to seek the greatest possible efficiency from their R&D. This has led them to work more collaboratively with other firms and organisations to innovate.[12]

- In pharmaceuticals, new biological knowledge encouraged a major change in industry structure with the emergence of small, specialised biotechnology firms in the 1980s and 1990s. These biotechnology firms exploited their knowledge of new techniques. Subsequently, large pharmaceutical firms have attempted to capture their capabilities through licensing deals, strategic alliances, and other forms of open collaboration, as well as many mergers and acquisitions.

- In electronics, larger firms often now rely on capabilities that are no longer located in-house but are to be found in smaller, specialised firms. Innovation now increasingly takes place through cross-disciplinary collaborative partnerships and strategic alliances, where once it might have been largely performed by teams of scientists and engineers within large internal research laboratories. As in other sectors, it is now commonplace for innovative small and medium-sized firms to be acquired by larger firms following the successful demonstration of a new technology.

- In aerospace, major manufacturers such as Airbus and Boeing are increasingly designing new aircraft in collaboration with suppliers, rather than designing them in-house and passing blueprints for parts or sections to suppliers. For example, 6,000 engineers around the world are effectively jointly designing and engineering the new Boeing 787 aircraft. This has cut the typical four or five year time from concept to production by a year, and reduced development costs by 20 per cent.[13]

12. This also echoes the idea of open innovation, see: Chesbrough, H. (2003) 'Open Innovation: The New Imperative for Creating and Profiting from Technology.' Watertown, MA: Harvard Business School Press; also Chesbrough, H. (2006) 'Open Business Models: How to Thrive in the New Innovation Landscape.' Watertown, MA: Harvard Business School Press.
13. Bartholomew, D. (2007) The Promise and Peril of PLM PLM: Boeing's Dream, Airbus' Nightmare. 'Baseline.' 2nd May.

Telecommunications

Telecommunications is an important sector in its own right, but is vital to the UK's wider competitiveness as a knowledge-based economy. The sector includes fixed-line telephony, mobile and broadband services, as well as telecommunications equipment and network supplies.

Telecommunications contributed £21.3 billion in GVA in 2004, 2 per cent of the UK total. 8,500 firms employ 56,000 people directly or indirectly. The sector includes both large players who provide a wide range of products, applications and services, and small firms offering a single product or service. More than 50 per cent of the sector's revenues are generated by firms located in London, the South East and East of England. Cambridge is a particularly important research centre for a number of multinational firms.

Traditionally, network operators have invested significantly in the development of new technologies. BT is the most important investor in the fixed-line telecommunications sector. It invests the lion's share of the sector's annual £1.13 billion investment, much of it in software development. BT's R&D intensity of 5.1 per cent is much higher than that of the remaining fixed-line firms.

The sector's most visible technological innovation lies in the development of large-scale infrastructures. These long-term projects, some initiated a generation ago, enable more recent advances including the switch from analogue to digital networks, then to mobile and wireless technologies, broadband connectivity, and new internet-based next generation networks (for example BT's '21st Century Network' programme, in which it is investing £10 billion). Nevertheless, less high-profile incremental innovation accounts for a significant amount of activity – most firms spend up to 90 per cent of their development resources enhancing existing products. Operators such as BT also invest heavily in back office operational support systems to automate, integrate and simplify internal IT processes, improve customer services and reduce costs.

See Appendix C for further detail.

- In telecommunications, network operators such as BT work to package products and services developed with hardware and software suppliers. Such operators also have to compete directly with some of these suppliers who have entered the market (such as Cisco and Microsoft). In turn, operators have entered the IT services market, exploiting their expertise in developing software for their own infrastructures.

- Software has perhaps the most well-known example of distributed innovation in open source software and Web 2.0 technologies. Open source is built on the principle that the source code of a program should be readily accessible, so that users have the right to copy, modify, maintain and redistribute it, without paying royalties or fees. Web 2.0 is a general term for web technologies and design – including wiki, video-sharing, blogging and consumer feedback sites – which aim to facilitate information-sharing, collaboration and creativity among users. These highly user-driven and collaborative forms of product development, enabled by the internet, are challenging the traditional assumptions of where innovation comes from and who does it.

2.2.2.2. Large firms are delegating more responsibility for innovation to their suppliers

- In aerospace, the traditionally extensive and complex supplier networks between major manufacturers and first tier suppliers have been accelerating and deepening over recent years, with more responsibility being given to the suppliers.

First and second tier suppliers are being given increased responsibility for traditional innovation. They are often taking on R&D, engineering and design, tooling, testing, sub-system integration and pre-assembly (installing systems such as hydraulics, electronics and controls). 80 per cent of the parts in new Boeing aircraft are made outside the firm – including by Japanese manufacturers, who have for the first time succeeded in gaining extensive and advanced work on the technology-rich wing design. Airbus also intends to outsource around 50 per cent of

Software and IT services

Software and IT services are a vitally important sector for the UK, in enabling other sectors to thrive and in underpinning the modern knowledge economy. The sector includes the development of system or bespoke software, the design and implementation of large and complex business IT systems, project management, and retailing and support services.

The UK sector employs around 600,000 people (half in software and half in IT services) in 100,000 firms. It has a GVA of £23 billion with exports of £4.7 billion in 2004. The UK market for software products and services is the largest in Europe. There are a number of significant clusters: in England, many software and IT firms are based around Cambridge, the Thames Valley area, Manchester and the Midlands; in Scotland there are clusters around Silicon Glen and Dundee (which has a significant concentration of games software firms).

The sector comprises some very large, global players and a significant number of smaller, specialist firms. Almost all the world's major software firms have a substantial UK presence, whether for R&D, logistics distribution networks, or sales and marketing operations. The UK has particular strengths in accounting and finance (Sage), asset management (Misys) and knowledge management software (Autonomy).

Technological innovation in the sector is a mixture of radical and incremental innovation focused primarily on new products. The sector's £1.2 billion R&D in the UK is concentrated in larger firms, with over 40 per cent of spending in the top four UK firms. Large global suppliers with R&D facilities in the UK include IBM, Microsoft, Nortel, Northgate Information Systems, and Toshiba. These firms often engage with smaller firms by buying products or services, or contracting tasks to augment in-house skills and competencies. Software development is also closely linked to the computer hardware industry, as software must be designed specifically to the hardware on which it will be installed and operated.

See Appendix D for further detail.

future work, as part of a long-term trend towards globalised production. Sixty per cent of Rolls-Royce's R&D investment and 40 per cent of new product development spending over the past five years has been outside the UK.[14] This globalisation is not just driven by cost; often firms hope to gain greater access to foreign markets through distributing development and manufacturing activities.[15]

- Cost pressures in the pharmaceutical sector have led to increased outsourcing of the management of clinical trials and manufacturing.

New clinical research management organisations (CROs) now run many of the clinical trials required for regulatory approval. They account for more than 40 per cent of annual research spending by firms, compared to just 4 per cent in the early-1990s.[16] Many CROs are based in Eastern Europe, India and China. In recent years, their portfolio of services has widened to include more advanced technologies such as genomics and high-throughput (automated) screening, using proprietary techniques for which they often own the intellectual property rights. CROs can also offer post-commercialisation services such as sales and marketing.

- In automotive, manufacturers also now expect their top suppliers to undertake R&D and manage their own supply base. Suppliers now perform 15-30 per cent of 'design effort' (although this is concentrated in larger suppliers).[17]

In some cases, distributed innovation and collaboration reaches well beyond working with other firms.

- For example, in telecommunications, BT has been embracing open, user-led innovation.

14. Rolls-Royce (2006) 'Introduction, Rolls-Royce is a Global Company Providing Power for Use on Land, at Sea and in the Air.' Derby: Rolls-Royce.
15. For example, discussed in relation to aerospace in Newhouse, J. (2007) 'Boeing Versus Airbus.' New York: Knopf.
16. Business Insights (2006) 'Pharmaceutical Outsourcing Strategies, Market Expansion, Offshoring and Strategic Management in the CRO and CMO Marketplace.' London: Business Insights.
17. Automotive Innovation and Growth Team (2002) 'Design, Development and Manufacture Report.' London: AIGT.

Electronics and IT hardware

Electronic components are at the heart of most technological products, typically representing more than 20 per cent of the cost of the product. Moreover, electronics, photonics (signal processing devices using photons) and electric systems underpin activity in virtually all other industrial sectors.

The UK electronics sector generates £14.8 billion in GVA (1.3 per cent of total UK GVA), and accounts for 6 per cent of UK manufacturing. The sector employs around 216,000 people in over 10,000 firms. Where it was once dominated by large integrated 'national champions' such as ICL and GEC, increasing competition from emerging nations, fuelled by commoditisation and lower labour costs, has led to a decline in electronics manufacture in the UK. Nevertheless, electronics production in the UK ranked seventh in the world in 2004, and second in Europe behind Germany.

But the nature of the sector has changed. The dominance of large and medium-sized firms has been replaced by a growth in small firms, 90 per cent of which have fewer than 50 employees. These new firms are more specialist and high-value and work particularly with the aerospace and automotive sectors. Particular UK strengths now lie in semiconductor design, photonics, and the manufacture of specialist low-volume but high-value goods for international markets (such as mixing desks for the creative industries, control systems for mineral exploration and medical monitoring systems for health services). Some international original equipment manufacturers firms (OEMs) also locate parts of their design operations in the UK, including Fujitsu, Sharp and Philips. These firms are clustered in places like Silicon Gorge near Bristol, Silicon Fen around Cambridge and Scotland's Silicon Glen.

Electronics is a moderately high research-intensive sector; R&D expenditure in 2006 was £1.5 billion or 4 per cent of sales. It also accounts for 7 per cent of total business expenditure on R&D in the UK, third behind pharmaceuticals and aerospace. Many new advances have resulted from the commercialisation of research carried out in UK universities, for example Cambridge Silicon Radio (CSR) developed Bluetooth-based wireless systems. But firms also rely heavily on incremental innovations to remain competitive, especially in consumer electronics.

See Appendix E for further detail.

BT has opened up its entire network through open protocols and a software development kit (SDK) that is downloadable by users, entrepreneurs and firms. This appeals both to large established firms who want to integrate telecommunications services in their applications, and to users who are inventing new applications using the internet and traditional telecommunications services.

These trends have put much more pressure on the innovative capacity of suppliers. The pressure can be too much. Some manufacturers have overestimated suppliers' competencies and underestimated the required levels of expertise and investment required (for example, delays in the delivery of the Boeing 787 are said to be due to suppliers failing to cope with the extent of their new responsibilities).[18] As a result, some major manufacturers have decided to focus more on the larger, typically more capable suppliers.

Nonetheless, the trend towards outsourcing more of the responsibility for innovation is established. Major manufacturers, particularly in aerospace, automotive and pharmaceuticals, are becoming 'systems integrators', pulling together the components, skill and knowledge of suppliers, users and partners to deliver ever more complex products, services and systems.

2.2.2.3 Firms are also relying on universities to conduct research

Equally, as a result of this complexity and cost pressures on large firms, there have been increased links between firms and universities. University research is often playing a greater direct role in commercial innovation.

First, universities are increasingly serving as research centres for firms. In aerospace, research-intensive companies have traditionally conducted research in-house, but this is changing. Some firms have particularly good links. For example, Rolls-Royce, as part of an overall policy of 'capability acquisition', has outsourced much R&D to universities, establishing 'University Technology Centres' in the UK and across the world. These universities

18. See Bailey, J. and Clark, N. (2008) Parts Didn't Click Together for Boeing Jet. 'New York Times.' 17th January.

Automotive

Automotive remains a major manufacturing sector for the UK economy. Many foreign-owned manufacturers are located here, while home-grown strengths include engine development and motorsport. Automotive manufacturing contributes £9.8 billion in GVA (6.2 per cent of total manufacturing value-added); the retail and service/maintenance sectors generate a further £22 billion. Automotive is the UK's biggest manufacturing export sector, generating more than £20 billion annually. 1.65 million vehicles were manufactured in 2006 (making it almost a record year), with 73 per cent of them exported. The sector directly employs 221,000 people.

Traditional innovation in mass market automotive focuses on continuous incremental improvement to core product technologies. Suppliers are often responsible for important innovations, while manufacturers concentrate on process innovations. This innovation often has long lead times; the development of a car – from design to production logistics – takes up to five years (the development of engines and transmissions can be longer, between seven and ten years). Manufacturers and suppliers allocate production capacity well in advance, to accommodate production and renewal of their ranges. It is difficult and expensive to change designs and specifications once a model is in production.

Automotive R&D can be moderately high. The sector spends 5.2 per cent of all R&D in the UK, just over £1 billion each year, equivalent to an R&D intensity of 4.3 per cent. High performance engineering areas such as motorsport have much higher R&D intensities, often more than 30 per cent. Because of its scale, the automotive sector is the largest R&D investor in Europe, with around 20 per cent of total European manufacturing R&D.

By far the largest component of manufacturers' R&D expenditure is on new vehicle model development rather than more 'blue skies' innovation. Areas of focus include more efficient and cLeaner engines, electronic control systems for car functions including safety features, and so-called 'surprise and delight' features such as satellite navigation systems.

tend to be particularly involved in researching emerging technologies, such as radically different aeroengine designs or the use of new materials.

Second, university research and knowledge are increasingly being commercialised.[19] For example, the new biological knowledge in pharmaceuticals has often been advanced by universities and public laboratories, and later in spin-out and start-up firms. This process has been facilitated by changes in intellectual property rights and funded by the increased availability of venture capital and angel finance. Highly innovative firms have also emerged from universities in sectors such as electronics and software.

2.3 The increasing distribution of innovation is strengthening international competitors

By increasingly being given responsibility for higher-value-added activities (including innovation), firms in the supply chain in countries such as India and China are gaining the capabilities necessary to compete with Western firms. They can under-cut smaller Western supply chain firms by operating in lower-cost locations, but they also increasingly draw on a larger number of science and engineering graduates.

Such countries are using these advantages to develop as increasingly strong challengers in many high-technology sectors: China, India and some Eastern European countries in pharmaceuticals, automotive and electronics; Brazil, Japan and China in aerospace; and India in software and telecommunications.

The Indian software and business process outsourcing industry is expected to achieve $60 billion in exports of software and services by 2010; the UK is the second largest market for the Indian software sector after the US, at 18 per cent of total exports.[20] Similarly, India is predicted to take a $60 billion share of a total $1.1 trillion global spending on engineering services (including aerospace, automotive and telecommunications) by 2020.[21] While today only $10-15 billion of engineering services is off-shored, the market is expected to grow to $150-225 billion by 2020. In pharmaceuticals, India now represents 13 per cent of the global industry by value and its drug exports have been growing by 30 per cent a year.[22] The Indian government estimates that the sector has the potential to generate revenues of $22.4 billion in drug formulation by 2010.[23] In telecommunications, Indian equipment exports are estimated at $1 billion for 2008, but are predicted to grow to $2.5 billion by 2011.[24] India exported more than $155 billion in goods and services in 2008 (up from $63 billion in 2004).[25] The Indian government's target is $200 billion in exports by 2020, or 5 per cent of world trade; a four-fold increase in the next 12 years.

Similarly, China is now the world's top exporter. In 2006 it was responsible for 8.2 per cent of global exports (up from 5.9 per cent in 2003). China is the world's largest electronics manufacturer, with more than $300 billion in products in 2006.[26] It accounted for 18 per cent of global electronics output in 2005, compared to just 4 per cent in 1997. In telecommunications, China's exports increased by an average annual rate of 37 per cent between 2000 and 2006; in automotive products the equivalent figure was 45 per cent, and in computer and information services (including software development) it was 40 per cent.[27] Half of Chinese suppliers of electronic components, consumer electronics, and computer and telecommunications products expect more than 20 per cent growth in export sales during 2008; a quarter expect an increase of 10-20 per cent.[28] More than 80 per cent of suppliers anticipate increasing their production capacity by 20-50 per cent. The EU is the main destination for these exports.

Software illustrates how such competition can develop very rapidly. In the early 1990s, American and European IT and software firms faced the twin pressures of a need to reduce costs and a shortage of qualified software engineers in their own countries. So they began to locate some routine tasks and activities (such as IT help desks and call centres) in lower-cost locations, especially India. This helped develop the IT industry in India, and led to the rise of home-grown firms such as Infosys, Tata and Wipro. Such firms now offer a wide range of increasingly high-value services at significantly lower prices than their US or European counterparts. Other competitors are now emerging from Latin America, Eastern Europe and China, which is predicted to develop its own software industry even faster than India did.

Such rapid growth is not merely a matter of 'market forces'; it is also often due to concerted and coordinated efforts at building national champions in these emerging economies.

19. See Section 4, in HM Treasury (2007) 'The Race to the Top, A Review of Government's Science and Innovation Policies.' London: HM Treasury.
20. NASSCOM (2008) 'Strategic Review 2008.' New Delhi: NASSCOM.
21. Booz Allen Hamilton (2006) 'Globalization of Engineering Services - The Next Frontier for India.' McLean, Virginia: Booz Allen Hamilton.
22. KPMG (2006) 'The Indian Pharmaceutical Industry: Collaboration for Growth.' London: KPMG.
23. Department of Chemicals and Petrochemicals, Government of India (2005) 'Draft, National Pharmaceuticals Policy, 2006.' New Delhi: Department of Chemicals and Petrochemicals, Government of India.
24. Engineering Export Promotion Council (2008) 'Annual Supplement 2008 to Foreign Trade Policy 2004-09.' New Delhi: Engineering Export Promotion Council.
25. Ibid.
26. Reed Electronics Research (2006) 'Yearbook of World Electronics Data, Volume 3 - Emerging Countries 2006/2007.' Wantage: Reed Electronics Research.
27. World Trade Organization (2007) 'International Trade Statistics 2007.' Geneva: WTO.
28. Global Sources (2008) 'China Supplier Survey, 2nd Half 2007.' Singapore: Global Sources.

3. In the face of increasing international competition, UK firms need to harness 'hidden innovation'

3.1 We have neglected the 'hidden innovation' that is crucial to the UK's economy, including in manufacturing
Traditionally, innovation is determined by research and development, making R&D the fundamental source of value creation ('traditional innovation'). In this linear (or 'pipeline') model of innovation, R&D leads to new discoveries that are incorporated into a new product or process and then marketed to consumers. Because of its presumed importance, R&D has been used as a proxy for innovative performance between firms and between countries.

However, NESTA has argued that traditional indicators such as R&D are based on a model of innovation that is increasingly less relevant.[29] Such indicators reflect a view that innovation is synonymous with scientific and technological invention, neglecting the many other forms of 'hidden innovation' which are crucial to creating value in the economy.[30]

This is particularly important for the UK because of its lower reliance on manufacturing and greater reliance on services compared to some other countries. The innovation that matters most to services sectors is rarely science-based.[31] More broadly, the public and third sectors have very different forms of innovation from the science-based model.[32]

But hidden innovation is not just about innovation beyond manufacturing sectors; it is about recognising the neglected innovation across the UK's economy, including in manufacturing. Most sectors are likely to contain a varying combination of both traditional and hidden innovation.[33]

From this, seeking to recognise hidden innovation does not imply that the UK is 'doing fine' or that 'manufacturing doesn't matter anymore'. As The Sainsbury Review in 2007 argued, the UK's need to engage in a 'race to the top' by concentrating on the development of higher-value-added industries must include – but is not limited to – high-technology manufacturing sectors.[34] The UK requires both innovative services and high-technology manufacturing to remain competitive in the 21st century.

3.2 Hidden innovation is increasingly important in high-technology sectors

3.2.1 Leading high-technology firms are increasingly harnessing hidden innovation
NESTA has previously identified four main forms of hidden innovation:

- technological development that is not included under the official definition of R&D;

Boeing's use of composite materials

In aerospace, much traditional innovation is led by continuous, incremental (or 'iterative') development rather than by research; one estimate suggests that the 'R' represents only 10-15 per cent of R&D. Hence is it likely that much technological innovation is not captured in narrow measures of R&D.

The use of composite materials in the new Boeing 787 – comprising 50 per cent of the aircraft's weight – is based on years of basic scientific research. But Boeing and its major suppliers have also had to learn on the job how to manufacture and tool such materials for the specific requirements of aerospace. The benefits of composites have grown as Boeing's engineers have gained more experience in production processes using these materials.[35] For example, Boeing engineers discovered that composites are tougher than they initially imagined, and the firm has been able to guarantee customers that maintenance costs will be 30 per cent lower than for aluminium aircraft. This potentially represents a bigger saving for customers than the 20 per cent reduction in fuel costs the 787 can deliver compared with other aircraft – savings worth more than $3 billion over 20 years.[36] Such 'practical research' often lies outside formal R&D processes. But the development of efficient production processes for these materials is crucial to realising their potential benefits; in this case, unless composites can be manufactured properly, they will not produce the weight gains and fuel cost savings that airlines demand.

29. National Endowment for Science, Technology and the Arts (2006) 'The Innovation Gap.' London: NESTA.
30. National Endowment for Science, Technology and the Arts (2007) 'Hidden Innovation.' London: NESTA; National Endowment for Science, Technology and the Arts (2008) 'Creating Innovation, Do the Creative Industries Support Innovation in the Wider Economy?' London: NESTA.
31. National Endowment for Science, Technology and the Arts (2008) 'Taking Services Seriously.' London: NESTA.
32. National Endowment for Science, Technology and the Arts (2008) 'Transformers, How Local Areas Innovate to Address Changing Social Needs.' London: NESTA; National Endowment for Science, Technology and the Arts (2007) 'In and Out of Sync, The Challenge of Growing Social Innovations.' London: NESTA.
33. National Endowment for Science, Technology and the Arts (2007) 'Hidden Innovation.' London: NESTA. p.13.
34. HM Treasury (2007) 'The Race to the Top, A Review of Government's Science and Innovation Policies.' London: HM Treasury.
35. Smock, S. (2007) Boeing 787 Dreamliner Represents Composites Revolution. 'Design News.' 4th June.
36. BusinessWeek (2005) Boeing's Plastic Dream Machine. 'BusinessWeek.' 20th June.

- innovation in organisational forms and business models;
- innovation from combining existing technologies and processes in new ways; and
- 'micro-innovations' that aren't recorded in surveys of innovation.[37]

These four types can be seen across high-technology sectors.

3.2.1.1 Type I: Hidden innovation from technological development not included under the official definition of R&D

Type I hidden innovation comprises research and experimental development with a scientific and technological basis (the *Frascati Manual* definition of R&D), but is excluded from measurement for methodological reasons.

Iterative development can be significant even in highly research-intensive sectors. In pharmaceuticals, such innovation is often as important as breakthrough innovation. Later members of a drug product class are better, because practice has helped to improve effectiveness through improved formulations, a better understanding of how to use drugs and the patient groups that will benefit from them, and how they might be used to treat other diseases. One example is the developments in understanding of how to use existing drugs in cardiovascular medicine, such as aspirin, streptokinase, and ß-blockers. Such drugs may still be under-exploited; one study has estimated that 40,000 lives worldwide could be saved each year – 3,000 in the UK alone – from the greater use of aspirin.[38]

More moderate R&D intensities in some sectors, such as mass market automotive with its typical focus on incremental product development, also suggest a significant degree of technological innovation that is not captured in narrow measures of R&D. This is particularly likely with technologies developed first by competitors and then adopted by other manufacturers. Most core product technologies eventually become standard across all brands and models, from variable value timing for engines to satellite navigation. Much

37. National Endowment for Science, Technology and the Arts (2007) 'Hidden Innovation.' London: NESTA.
38. Antithrombotic Trialists' Collaboration (2002) Collaborative Meta-analysis of Randomised Trials of Antiplatelet Therapy for Prevention of Death, Myocardial Infarction, and Stroke in High Risk Patients. 'British Medical Journal.' 324, pp.71-86.
39. See GlaxoSmithKline (2008) 'Answering the Questions that Matter, Annual Report 2007.' Brentford: GSK; GlaxoSmithKline (2001) 'It's About You, Annual Report 2000.' Brentford: GSK.

GlaxoSmithKline's (GSK) Centres for Excellence in Drug Discovery (CEDDs)

Organisational and business model innovation has helped transform the pharmaceuticals industry. The contemporary growth in scientific understanding has created a major change in industry structure in the shape of small new biotechnology firms. These firms have often been less risk-averse in selecting and pursuing research projects. In response, large pharmaceutical firms have attempted to capture the capabilities held by small firms, through licensing deals, strategic alliances and other forms of collaboration, as well as mergers and acquisitions.

Some large firms have even adopted the organisational forms of small firms. In 2000, GlaxoSmithKline (GSK) created six new semi-autonomous business units called Centres for Excellence in Drug Discovery (CEDDs). Each CEDD focuses on a specific therapeutic area but has no more than 350 scientists each. This limitation is intended to support interaction and reduce bureaucracy, so that each unit acts with the flexibility and responsiveness of a smaller biotechnology firm. CEDDs in the UK include Neurology in Harlow, Respiratory, Inflammation and Respiratory Pathogens in Stevenage, and Biopharmaceuticals in Stevenage.

Given the very long lead times for drug development, the full impact of these organisational innovations is unlikely to be fully realised for many years. Nonetheless, following this innovation, GSK has more – and more radical – drugs in development: indeed it now has as many radical new products in development as it had total products in development just seven years earlier, with 53 per cent more radical new products.[39] The firm now leads other large firms in terms of mid- to late-stage development of products.

GSK has subsequently taken this model further with its Centre of Excellence for External Drug Discovery – a form of 'virtual' CEDD that works through a network of external alliances. Such approaches may represent the dominant model for the rest of the pharmaceutical sector in a few years' time.

innovation is therefore 'catch-up' – new to the firm but not necessarily new to the sector.

Similarly in telecommunications, incremental technological innovation is crucial for firms to remain competitive against other providers, but may not be considered sufficiently cutting-edge or novel, especially if such development has already been achieved by other firms. This is also prevalent in areas of electronics, especially fast-moving consumer electronics goods.

Furthermore, most small and medium-sized (SME) firms, such as suppliers, may not have formal (or significant) R&D programmes, yet they may be engaged in researching, developing and refining their products.

3.2.1.2 Type II: Hidden innovation in organisational forms and business models
Indicators that focus on research are blind to innovations in organisational forms or business models, despite the fact that these have become crucial for business performance in high-technology sectors.

Some forms of organisational and business model innovation, such as in GSK, are closely related to research: making R&D more efficient; drawing on and exploiting external knowledge and expertise; or focusing on R&D to the exclusion of other activities that traditionally firms would also have conducted.

Examples of the latter can be seen in the electronics sector. Following the loss of the large integrated firm in the UK as a result of increasing competition, some UK firms have adopted innovative new business models. Chip manufacture has moved offshore to lower labour cost regions, resulting in a focus on higher-value activities such as design and licensing of intellectual property (IP). This has spawned models such as 'chipless' firms that develop and market semiconductor IP such as ARM but do not manufacture themselves, and 'fabless' semiconductor firms such as Wolfson Microelectronics that use external third parties for their manufacturing operations. Such business models can be highly efficient at generating value. For example, ARM has a growth rate approximately twice that of the semiconductor industry as a whole.[40] The firm estimates that in 2006, 1.5 billion people – a quarter of the world's population – bought an ARM-powered product, generating more than £263 million in revenues, yet the firm employs fewer than 1,500 people.[41]

Other forms of organisational innovation are focused on improving the efficiency of other processes, such as 'Lean manufacturing' in automotive and aerospace. Lean focuses on the elimination or reduction of waste in various forms.[42] Output per worker is consistently significantly higher in Lean compared to non-Lean automotive manufacturers (double, in many cases). Toyota, its pioneer, has the highest consistent output of any major automotive manufacturer, equivalent to a lead in productivity of 5.17 labour hours per vehicle (or about $300 per vehicle) over the least productive major manufacturer in North America.[43] Similarly, Lean has been shown to lead to a 20-40 per cent improvement in productivity in aerospace SMEs.

Lean and 'Agile' development has also spread to the software and IT services sector. Agile development is an alternative to traditional product development (which emphasise initial major planning). Agile promotes development iterations throughout the life-cycle of the project via feedback through tests and releases of the evolving software (consumers and clients form part of this feedback). One survey of 1,700 firms across 71 countries found that using Agile processes led to increased productivity for 55 per cent of respondents; reduced software defects for 54 per cent; and reduced costs for 28 per cent.[44] Other benefits reported were better alignment between IT and business goals and reduced project risk.

Organisational innovation can also provide new services for customers. For example, in aerospace, firms such as Rolls-Royce are increasingly making the majority of their revenues from 'through-life management services', in part because competitive pressure on costs has left little or no profit from original equipment and supplies sales. Customers sign long-term maintenance and support contracts for reliability and predictable costs. In effect, the manufacturer is selling services, much of the value of which is based on brand qualities like reliability, permanence and expertise. For civil aircraft alone, Rolls-Royce now generates more than $2.6 billion in revenues from service agreements (63 per cent of its civil aerospace revenues), and more than £4.2 billion across the sectors the firm operates in.[45] Rolls-Royce's investment in developing and maintaining these services is equal to its investment in research and technology programmes.

Other firms have considered how to exploit their specialised design and technology expertise outside their own sectors; for

40. ARM (2007) 'ARM Holdings Plc Reports Results for the Fourth Quarter and Full Year 31 December 2007.' Cambridge: ARM.
41. ARM (2007) 'ARM Annual Report and Accounts 2006.' Cambridge: ARM.
42. Toyota developed the TPS in reaction to what it perceived as the wasteful overproduction of US automakers (particularly Ford), but was also inspired by a visit to an American supermarket chain (called Piggly Wiggly) which only reordered and restocked goods once they'd been bought by customers.
43. Harbour Consulting (2007) 'The Harbour Report™ North America 2007.' Troy, Michigan: Harbour Consulting.
44. VersionOne (2007) 'The State of Agile Development 2nd Annual Survey.' Alpharetta, GA: VersionOne.
45. Rolls-Royce (2008) 'Preliminary Results 2007.' Derby: Rolls-Royce.

example, McLaren Applied Technologies (formed in 2004) works with a diverse range of industries and develops commercial applications for technology developed for motorsport within the McLaren Group.

In telecommunications, new services and business models have become crucial to competitive survival for firms, especially in the context of deregulation and new market entrants. Established firms, especially those that in the past would have relied on revenues from their fixed-line networks, now need to think primarily in terms of innovative services for customers and how these might be supported by existing or emerging technologies. For example, BT's Global Services division focuses on networked IT and consultancy services for major corporations, organisations and government. Its revenues increased by 4 per cent to £9.1 billion in 2007, while traditional revenues declined.[46]

In software, the development of the 'Software as a Service' (SaaS) business model is reshaping the sector. In SaaS, software applications are supplied online and hosted by a provider rather than installed on the user's premises, and priced on a per usage basis. This is increasingly overturning the traditional 'licence + maintenance' business model; SaaS is predicted to capture more than a quarter of the $200 billion business software market by 2011.[47] The market leader, Salesforce.com (a US firm founded in 1999), serves more than 38,000 other firms and has one million paying users for its 'on-demand' Customer Relationship Management (CRM) software, with revenues around $700 million in 2007. Siebel Systems, Microsoft, Oracle and SAP have also entered the SaaS market. Tata Consultancy Services (TCS), India's largest service provider, is introducing a hybrid SaaS/services model that it calls 'IT-as-a-service', which is being aimed primarily at the local SME market and is predicted to be worth up to $9 billion a year.[48] However, smaller software firms – including in the UK – may struggle to meet customers' expectations in being able to deliver their products in this way. One survey found that around 70 per cent of its small UK firms are continuing with the traditional business model.[49] One notable exception is Huddle, a UK start-up established in November 2006, which combines online collaboration, project management and document sharing using social networking principles.

3.2.1.3 Type III: Hidden innovation from combining existing technologies and processes in new ways

Type III hidden innovation can be created from largely existing components when they are combined in new ways to deliver new products, services or processes.[50] Technology often plays a significant role in this type of innovation, but because this technology often isn't completely new it doesn't get counted in traditional indicators.

In software, the *Frascati Manual* only acknowledges development that represents a

BT's 'new wave' services

In telecommunications, investments in developing new technologies and infrastructure provide the basis for new services. Intense competition, regulation and technological advances such as mobile networks, have led to a decline in revenues from traditional fixed-line networks. Established operators have sought to develop innovative new services to drive or renew revenue growth.

BT Fusion is the world's first 'intelligent' mobile phone service. Customers are provided with a hub and up to six mobile handsets. When within range of the hub the call is routed through the hub and into the fixed broadband network. If the caller moves out of range then the call is seamlessly transferred to the mobile base station of BT's partner (Vodafone) as a mobile call. BT's new internet-based television service, Vision, connects to the same home hub and provides broadband video-on-demand via a Freeview digital terrestrial set-top box. BT is securing content deals with major film and television studios for this service.

These innovative products and services are part of what BT calls its 'new wave' activities (primarily networked IT services, broadband and mobile). In 2007, these activities generated revenues of £7.37 billion (36 per cent of total revenues), an increase of 17 per cent on the previous year (while traditional revenues fell 3 per cent).[51]

46. BT Group plc (2007) 'Annual Report & Form 20-F2007.' London: BT Group plc.
47. Desisto, R., Pring, B., Lheureux, B. and Karamouzis, F. (2006) 'SaaS Delivery Challenges On-Premise Software.' Stamford, CT: Gartner.
48. All, A. (2008) 'India's Tata Consultancy Services Introduces Hybrid SAAS Model.' [online] Available at: http://www.itbusinessedge.com/blogs/sts/?p=324
49. Intellect (2007) 'Software and IT Services Report – The Future.' London: Intellect.
50. Previous studies have emphasised the importance of this form of innovation, termed variously the 'recombination and re-use of known practices', 'recombinant innovation' and 'architectural innovation.' See respectively: David, P., and Foray, D. (1995) Accessing and Expanding the Science and Technology Knowledge Base. 'STI Review.' 16, pp.16-38; Hargadon, A. (2003) 'How Breakthroughs Happen: The Surprising Truth About How Companies Innovate.' Watertown, MA: Harvard Business School Press; and Henderson, R. M., and Clark, K. B. (1990) Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. 'Administrative Science Quarterly.' 35, pp.9-30.
51. BT Group plc (2007) 'Annual Report & Form 20-F2007.' London: BT Group plc.

'scientific and technological advance' as R&D and hence as innovation.[52] Yet much software development is characterised by 'cumulative technologies', involving the use and re-use of existing functions and routines which gradually evolve through incremental innovation.

For example, Service Oriented Architecture (SOA) represents a new approach to development, whereby program functions are separated into distinct units (services) which can be distributed over a network and can be combined and reused in more flexible and cost efficient ways to create business applications. One study estimates that SOA could reduce development costs by 25 per cent (about $53 billion) over five years across the 2,000 largest firms worldwide.[53] Some of this work may not be counted as innovation since it may not fundamentally alter underpinning technological standards or make significant advances in knowledge. The often continual and incremental nature of software development – and the virtual nature of the products – can add to the marginalisation of these forms of innovation.

Furthermore, the use of software and other supporting technologies has been valuable in improving quality and efficiency in production in aerospace and automotive. The use of software in areas such as 3D design and product development is making traditional innovation more efficient, but such software may have been developed first in other firms and often in other sectors.[54]

3.2.1.4 Type IV: Micro-innovations that aren't recorded in surveys of innovation

Type IV hidden innovation comprises the locally-developed, small-scale, incremental innovation that often goes unnoticed by traditional indicators.

Such micro-innovations are crucial to any 'engineering'-based sector (whether they focus on the design and development of physical products, or virtual products such as software, or both).

Finally, such micro-innovations are typically unsuitable for patenting (another of the traditional indicators). Even if they were, smaller firms do not have the expertise or resources to engage in patenting procedures, or to defend a patent against possible infringement, leaving many inventions invisible to such indicators.

3.2.2 In the face of increasing competition, there is a danger that established UK firms become 'locked-in' to their existing technologies and business models

3.2.2.1 Traditional innovation can become locked into existing 'platforms'

Much technological R&D can focus on incremental, augmentative innovation to existing 'platforms' instead of radical redesigns. Examples include the internal combustion engine and steel car body structures in automotive, the gas turbine engine in aerospace, and the mobile phone network infrastructure in telecommunications.

Toyota Production System

In many areas of engineering, there are small-scale problems and challenges that are dealt with outside of formal R&D programmes. These efforts may not be captured in traditional metrics. Toyota, a manufacturer with a strong reputation for new technology development, has a global R&D intensity of 'only' 3.7 per cent (lower, in fact, than the overall R&D intensity of the UK automotive sector at 4.3 per cent).[55] However, the Toyota Production System (TPS) represents a highly successful approach to generating and enshrining such 'micro-innovations'. TPS organises manufacturing and logistics to eliminate waste and inconsistency in products via an emphasis on continuous improvement, teamwork, just-in-time inventory, and becoming a 'learning organisation' through relentless reflection.

One study estimates that through its inclusive approach to improving production techniques, Toyota – which has two major production plants in the UK – implements one million new ideas each year (or 3,000 a day).[56] Most are small but effective solutions to real world problems, but their cumulative impact can be seen in large efficiency, quality and productivity gains. Toyota earns twice as much as any other carmaker, and in the first quarter of 2007 the firm overtook GM in global sales for the first time.[57]

52. See section 2.4 in Organisation for Economic Co-operation and Development (2002) 'Frascati Manual 2002, Proposed Standard Practice for Surveys on Research and Experimental Development.' Paris: OECD.
53. Aberdeen Group (2006) 'The SOA in IT Benchmark Report.' Boston: Aberdeen Group.
54. Somewhat paradoxically, the costs of such software might be eligible under the UK R&D tax credits scheme, but its use would not tend to be counted as being part of R&D under Frascati definitions.
55. Toyota (2007) 'Annual Report 2007, Building a Platform for Growth.' Toyota City: Toyota. UK data based on a study of the top 850 UK spenders on R&D, see Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
56. May, M. E. (2007) 'The Elegant Solution: Toyota's Formula for Mastering Innovation.' New York: Free Press.
57. Harbour Consulting (2007) 'The Harbour Report™ North America 2007.' Troy, Michigan: Harbour Consulting.

This innovation helps in increasing marginal performance or reducing costs, but doesn't amount to fundamental change. Yet many firms prefer to focus on it to maximise near-term productivity from investments in R&D, rather than engage in longer-term, more speculative and riskier 'blue skies' R&D.

In this way, firms can become 'locked-in' to their own technologies. This lock-in is often reinforced by a firm's organisational structures, business models and related investments around its existing platforms. For instance, the large-scale manufacture and distribution systems required by steel car body structures in automotive, the 'blockbuster' drug development business model in pharmaceuticals, and the revenue charging model for mobile calls and data in telecommunications.

Such lock-in can inhibit firms from exploiting new technological possibilities or new ways of serving their customers. For example, in aerospace and automotive, the emphasis on costs and reducing risk can lead to conservatism in product design and manufacture. This can be exacerbated by a traditional focus on product engineering rather than customer needs. Such sectors can be surprisingly slow to adopt new engineering techniques and methods, or more flexible designs.

The result can be a disconnect between manufacturers and customers. For example, airlines who are unhappy about aircraft performance and specifications, and customers who are not supplied with their desired car models. In the most extreme cases, established firms fail to respond quickly or radically enough to challenges from new firms.

To take one example: large automotive manufacturers have tended to resist alternative technologies to the internal combustion engine, such as rechargeable battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs). Yet these technologies have been around for over a century. Electric vehicles were once common, and the first hybrid motor was developed in 1901 by Ferdinand Porsche. Major US manufacturers have even been accused of deliberately sabotaging their own electric vehicle production efforts in order not to threaten their existing business model.[58]

Yet the dominant automotive technology and business model in automotive is neither financially nor environmentally sustainable. It is insufficiently profitable, lumbered with structural problems: over-capacity throughout the value chain; high fixed costs in manufacturing, product design and distribution; inflexible production systems; and inflexible product designs.[59] Reducing the number of vehicles held as unsold stock would bring an immediate financial benefit to the whole production and distribution chain, and would be far less environmentally wasteful. At some point, there is likely to be radical restructuring of the global automotive sector.

3.2.2.2 New firms – including in emerging economies – can develop radical innovations more suited to the major changes taking place in high-technology sectors

This lock-in explains why radical innovation often comes from new entrants. Such firms can be less risk-averse in selecting and pursuing projects, because they don't have the same investment in existing processes as established major firms. New competitors often do things in new ways, because they are organisationally and conceptually freer to do so.

For example, in pharmaceuticals, small new biotechnology firms were the first to attempt to capitalise on the growth in scientific understanding. The impact of the new knowledge is still being played out, but such technologies are likely to allow a small number of patients to be treated more effectively with personalised or specialised therapy. This will represent a major challenge to the blockbuster model of developing therapies that treat a large population, and so to the traditional business model in large pharmaceuticals.

In aerospace, a new paradigm for aircraft production may be emerging. Cheaper, more efficient approaches have been demonstrated by smaller innovative firms. For example, US firm Eclipse Aviation has launched its Eclipse 500 four-six seater 'air taxi'. Ex-automotive sector executives founded Eclipse with the express aim of producing a highly-reliable, low-weight aircraft for $1 million. The 500 is 50 per cent cheaper to operate than similar aircraft. Similarly, Toyota and Honda both have small aircraft at advanced stages of development.

In automotive, the alternatives to the internal combustion engine have remained marginalised technologies, but this may be about to change. Later in 2008, Tesla Motors, a Silicon Valley start-up firm, will deliver its Tesla Roadster, an electric performance sports car that can accelerate from 0 to 60 mph in less than four seconds (a similar performance

58. Paine, C. (2006) 'Who Killed the Electric Car?' Culver City: Papercut Films.
59. For example, of major US manufacturers, on each vehicle sold in North America in 2006, Chrysler Group lost $1,072, GM lost $1,436, and Ford lost $5,234; see Harbour Consulting (2007) 'The Harbour Report™ North America 2007.' Troy, Michigan: Harbour Consulting.

to a Lamborghini Murciélago). Another start-up firm, The Project Better Place initiative, is working to provide the infrastructure and scale necessary to make electric cars a viable alternative to fuel-based vehicles, starting in Israel. Another start-up, Zero Pollution Motors (ZPM), expects to produce the world's first air-powered car for the US in early 2010. Tata Motors – the producer of the ultra low-cost Nano 'people's car' – will be using the same technology in its Air Car for India in 2008. More generally, the automotive sector is open to challenge from radically new business models, for example, through innovations such as repeated leasing of vehicles through their life cycles, hyper-Lean production with high levels of outsourcing, and direct sales and distribution.

In telecommunications, many new services have been developed by new entrants. Start-up firms such as Skype have pioneered voice over IP (VoIP) based on using broadband connectivity to by-pass traditional charging models. As of the last quarter of 2007, Skype had 246 million customers, and has been acquired by the internet auction site eBay. Google also launched a similar service with Google Talk. Both firms had little experience of operating in the sector until they entered the market.

In electronics, entrants from China, India, Korea, Taiwan and Singapore are emerging as new sources of innovation and global standards. This includes innovations in process technology for electronic components (especially semiconductors and displays), where Korean and Taiwanese firms are among the industry leaders. This also includes system specification: Asian firms are now producing innovations in the design of complex systems in areas like digital consumer systems, wireless telecommunication systems, and business process software.[60]

3.3 Remaining competitive demands 'total innovation'

For established firms, then, the ability to develop new business models, organisational forms and processes becomes even more important, since this can help to free them to engage in new forms of technological development. This will allow them to enter new markets – or to remain competitive in existing ones.

In the face of intensifying competition and to ensure future growth, leading established firms in these sectors – from Rolls-Royce to BT, Toyota to GSK – are taking a broader approach to innovation. By seeking to integrate innovation in new technologies, products and processes (primarily traditional innovation) with innovation in business models, organisational forms and market positioning (hidden innovation), they create greater profits and protect their market position.

Internal strategic management and business processes become particularly important in harnessing the various different dimensions of innovation, by aligning the full range of the firm's resources behind them (including leadership, structure, strategy, processes, and culture). This combination of traditional and hidden innovation is 'total innovation'.

Perhaps appropriately, the concept has emerged from China.[61] 'Total Innovation Management' suggests that the successful technology innovation needs to include both technological and non-technological factors related to innovation. Traditional innovation is no longer sufficient.[62]

In particular, firms need to develop the innovative capabilities of their workforces through 'people-oriented' management. Based on case studies of major Chinese manufacturing firms such as Haier and Lenovo, the key to maximising innovative capacity is the philosophy and practice of regarding 'everyone as innovator'. This means that innovation is not only the responsibility of the R&D function, but should take place throughout the whole value chain – hence the importance of creating and sustaining an all-encompassing culture of innovation.

According to this school of thought, firms fail to maximise their innovative capacities when their culture lags behind their technology-focused innovation, when such technological innovation is not linked to operation strategy, and when they lack internal mechanisms to motivate innovation across the whole firm.[63]

Following this, it is no longer appropriate or accurate to understand innovation as the 'successful exploitation of new ideas'. This definition, while apparently broad, implicitly continues to privilege research ('new ideas') as the fundamental source and starting-point of innovation. In finally breaking from the linear model of innovation, we need to focus our understanding on the outputs and outcomes of innovation, and then trace back from these outputs to whatever activities contributed to them. We need to understand innovation as

60. Ernst, D. (2004) 'Late Innovation Strategies in Asian Electronics Industries: A Conceptual Framework and Illustrative Evidence.' East-West Centre Working Papers Economics Series. No. 66. Honolulu, Hawaii: East-West Centre.
61. Total Innovation Management (TIM) has been proposed as a new paradigm of innovation management by the Research Center for Innovation & Development (RCID) of Zhejiang University, China. See Xu, Q., Chen, J., Xie, Z., Liu, J., Zheng, G., Wang, Y. (2007) Total Innovation Management, A New Paradigm of Innovation Management in the 21st Century. 'The Journal of Technology Transfer.' 32 (1-2). April, pp.9-25.
62. This echoes the understanding that technological innovation is only one of the capabilities that a firm may possess for its competitive advantage - and is possibly the least distinctive capability, compared to its reputation, architecture, and strategic assets; see Kay, J. (1993) 'Foundations of Corporate Success: How Business Strategies Add Value.' Oxford: Oxford University Press.
63. Similarly, Henry Chesbrough has emphasised the importance of business models in creating value from technology: "The value comes from the party that has a business model to create and capture value from the patent, not from the invention of the patentable technology itself." Chesbrough, H. (2003) 'Open Innovation: The New Imperative for Creating and Profiting from Technology.' Watertown, MA: Harvard Business School Press. p.162.

any activities that seek to meet needs in new ways.

UK high-technology firms need to develop their capability for total innovation. Survey evidence suggests that larger UK manufacturing firms in particular are increasingly identifying design and development, and service provision, as their main competitive strengths as their advantages in production and assembly decline versus foreign competition.[64] (Only 2 per cent of firms see research as their main source of competitive advantage[65]).

Development of fuller innovation capabilities is particularly important for developed countries because of the increasing challenge from emerging economies in these high-technology sectors. Too many firms are unprepared for these changes: only by integrating all aspects of innovation can they cope with and exploit these changes, and so continue to create value for the UK.

4. UK policy for high-technology sectors remains narrowly focused on traditional innovation

4.1 Policy has begun to recognise hidden innovation

The former Department of Trade and Industry (DTI) commissioned research on innovation in services,[66] and NESTA and the Department for Business, Enterprise and Regulatory Reform (BERR) have been working together to investigate innovation in major service sectors in the UK economy through the Innovation in Services project.

Most recently, *Innovation Nation*, the White Paper published in March 2008 by the Department for Innovation, Universities and Skills (DIUS), gives a prominent place to hidden innovation and innovation in services. The White Paper presents a broad vision of innovation and its importance not only to manufacturing but also for services, the creative industries, the public sector and the third sector.[67] It explicitly recognises the importance of innovation beyond the invention of new technological products, by noting that the 'changing face of innovation' also includes services, business processes and models, marketing and enabling technologies.[68] In doing so, it takes a significant step beyond the traditional focus of innovation policy. It provides a valuable and challenging new direction for innovation policy in the UK, encompassing public procurement, regulation, access to finance, and intellectual property.

4.2 However, policy for high-technology sectors still focuses overwhelmingly on R&D and technology development

In response to the UK's perceived R&D under-performance, policymakers have introduced a wide range of initiatives focused on science, engineering and technology (SET) based sectors.[69] Mechanisms of support for technology-focused innovation have included the Technology Programme, which includes the Collaborative Research & Development (CR&D) grant, Knowledge Transfer Networks (KTNs), Knowledge Transfer Partnerships (KTPs), and R&D tax credits for activities that qualify.[70] Further research funding is available from the relevant research councils, such as The Engineering and Physical Sciences Research Council, Biotechnology and Biological Sciences Research Council, the Medical Research Council, and the Science and Technology Facilities Council.

Scotland, Wales and Northern Ireland have reflected a similar emphasis on SET, R&D in advanced technologies, and university-business collaborations, as have the initiatives of the English regions.[71] The English regions and the devolved administrations all provide local businesses with access to funding and support, from the Grant for an Innovative Idea (formerly SMART) to the Manufacturing Advisory Service and regional venture capital funds. In addition to the local delivery of national business support schemes, there are numerous one-off support schemes, from the collaborative innovation centres (CICs) in Yorkshire, the Emerging Technologies Scheme (ETS) in the South East to the Intermediary Technology Institutes (ITIs) in Scotland. These schemes have generally targeted several 'strategic' technologies and sectors.

Finally, some sectors have explicit, agreed programmes that encapsulate this support. For example, the National Aerospace Technology Strategy (NATS) is a partnership between industry, government and academia, to identify, research and validate 'key' and 'enabling' technologies.[72] Research and development partnerships have also been developed through Aerospace Innovation Networks (AINs) and Aerospace Technology Validation Programmes (ATVPs). Similarly, the defence sector benefits from the Defence Industrial Strategy launched in December 2005, and the subsequent Defence Technology

64. EEF (2007) 'High-value – How UK Manufacturing has Changed.' London: EEF.
65. Ibid.
66. Department of Trade and Industry (2007) 'Innovation in Services.' Occasional paper no. 9. London: DTI.
67. Department for Innovation, Universities and Skills (2008) 'Innovation Nation.' London: The Stationery Office.
68. Ibid. p.13.
69. For example, Department of Trade and Industry (2003) 'Innovation Report, Competing in the Global Economy: The Innovation Challenge.' London: DTI; Department of Trade and Industry/HM Treasury/Department for Education and Skills (2002) 'Investing in Innovation, A Strategy for Science, Engineering and Technology.' London: DTI/HM Treasury/DfES; and HM Treasury/Department of Trade and Industry/Department for Education and Skills (2004) 'Science & Innovation Investment Framework 2004-2014.' London: HM Treasury/DTI/DfES.
70. In July 2007, the Technology Strategy Board (TSB) became operational as an executive Non-Departmental Public Body sponsored by DIUS. The TSB promotes and supports research, development and the exploitation of science, technology and new ideas to benefit business. The TSB funds and coordinates Collaborative Research & Development, Knowledge Transfer Networks and Knowledge Transfer Partnerships.
71. See Appendix B, National Endowment for Science, Technology and the Arts (2006) 'The Innovation Gap.' London: NESTA.
72. Society of British Aerospace Companies /Department of Trade and Industry/Aerospace Innovation and Growth Team (2004) 'National Aerospace Technology Strategy.' London: SBAC/DTI/AeIGT.
73. Ministry of Defence (2005) 'Defence Industrial Strategy, Defence White Paper.' London: HM Stationery Office; Ministry of Defence (2006) 'Defence Technology Strategy.' London: Ministry of Defence.

Strategy.[73] These aim to improve how military equipment, supplies and services are procured and supported.

4.3 Policy neglects the hidden innovation in research-intensive sectors

Behind these initiatives lies a potentially dangerous assumption: that improving investments in formal R&D will be sufficient to ensure the survival of higher-value-added industries in the UK.

In the short- to medium-term, the UK must remain attractive and competitive as a place for major firms to locate their R&D, hence policymakers have been right to support R&D in these sectors and in the economy generally.

Yet while investments in formal R&D and linkages with the science research base will remain important, not enough is being done to stimulate or support total innovation to make the most of the opportunities that that research will present. In the near future, these high-technology sectors will need to respond not just to unexpected or 'disruptive' new technologies, but also to new business models, processes and services developed by competitors.

This reveals two major weaknesses in current innovation policy.

First, generic policies such as R&D tax credits are useful in subsidising existing incremental research-based innovation, but they do not in themselves steer firms to focus on longer-term, potentially disruptive research areas. Initiatives such as Knowledge Transfer Networks (which do focus on such areas) embrace far fewer firms than generic policies.

Second, initiatives focused on potentially disruptive technologies don't tend to include hidden innovation, such as the new business models and organisational forms that might be needed alongside these new technologies.

4.4 'Non-innovation policy' also shapes innovation in high-technology sectors

4.4.1 Regulation, including environmental and safety regulation, plays a major role in informing innovation activities in many sectors

There is a third weakness in current innovation policy. Typically, what is designated as 'innovation policy' does not encompass the wider set of policies that also influence innovation in these sectors – from taxation and regulation to public procurement, intellectual property rights to education and skills.

In pharmaceuticals, the speed and efficiency with which drugs pass through regulatory stages has a major impact on the returns to pharmaceutical firms' investments. Every day that a product is delayed reaching the market can cost $1-3 million in lost revenue.[74] But, understandably, regulators tend to focus on establishing the safety of new products rather than encouraging investment in new product development.

In telecommunications, 20 years of market liberalisation in the UK has nurtured competition to such an extent that firms from other sectors, often with no previous telecommunications experience, can now freely enter the market. The so-called 'super regulator', Ofcom, reflects the convergence in the sector.

In aerospace and automotive, tighter EU regulations require reduced carbon dioxide (CO2) and nitrogen oxide emissions. This promotes some forms of innovation: for example in aerospace, it has created strong demand for lighter aircraft, prompting the increased use of composites in airframes and components, and more efficient engines.

Similarly, in electronics, UK and European environmental regulation is increasingly informing product design and development, with more stringent requirements on packaging, recyclability, and the use of hazardous substances such as lead. These can act as both a barrier to and driver of innovation; it can limit the scope and parameters of a new product, but can equally stimulate innovation to find alternative oxides, alloys and nanocomposites. Furthermore, as in other sectors, energy use is emerging as a major issue and a likely area for greater regulation; the electronics sector will have increasingly to focus on minimising the consumption of electrical power by making devices and systems more efficient.

4.4.2 In some sectors, public procurement shapes innovation

In pharmaceuticals, government is often the major purchaser. This informs the kinds of drugs that are developed. The difficulty for governments is in determining the desired trade-off between efficient public procurement and promoting innovation and growth by pharmaceutical firms.

74. PhRMA (2007) 'Drug Discovery and Development, Understanding the R&D Process.' Washington DC: PhRMA.

Government is also a major customer of software and electronics hardware. Indeed, growth in the UK software sector is partly due to substantial investment over recent years in e-government initiatives such as new IT systems for the NHS (£30 billion over the last ten years), Transport for London's Congestion Charging and Oyster card projects, and 'Shared Services' (sharing back-office resources across councils and government departments).

4.4.3 Intellectual property rights have a major impact on innovation

In pharmaceuticals, the ability of firms to generate sufficient returns on their often large-scale and high-risk investments is directly shaped by IP regimes, especially the length of protection periods and the enforcement of these rights in different territories. At the same time, too much focus on IP can have a negative impact on innovation, where universities and other public research institutions focus on commercialising their knowledge and expertise rather than blue skies research; or where academics and universities have inflated expectations of IP, and deter innovation through excessive bureaucracy related to such expectations.

In software, a relative lack of IP enforcement has become a major issue, especially in some countries. It is estimated that 35 per cent of software on all computers globally has been obtained illegally, equating to £20 billion of lost revenues (in the UK, 27 per cent of software is obtained illegally, meaning lost revenues of £840 million[75]). The scale of IP infringement and lost revenues has a subsequent effect on the resources available for further innovation. (Similar issues affect the pharmaceuticals sector). Given the increasingly collaborative and open nature of innovation in software projects, there can be complex questions regarding ownership of the resulting products.

4.4.4 Skills are a crucial factor in innovation capability

As is widely-recognised, skills shortages and lack of 'work-ready' practical skills and knowledge inhibit innovation in many of these sectors. There are too few suitable graduates in areas such as: engineering and physical sciences, particularly physics and chemistry; computing and IT; and electronics.

However, in many sectors, the changing nature of traditional innovation and the importance of hidden innovation has emphasised the need for broader skills.

First, new scientific knowledge and technical skills are required. In pharmaceuticals, the new nature of drug discovery means that firms need skills in new fields such as biopharmaceutical formulation, bioprocessing, and computational analysis. Firms increasingly require interdisciplinary knowledge and skills. In pharmaceuticals, this means life science graduates with sufficiently strong skills in mathematics and physical sciences.

In telecommunications, rapid changes – including developing technologies such as VoIP, WiMax, 4G and next generation networks – as well as convergence demand new and continually up-graded skills.

In software, employers express concerns that university degrees do not keep pace with the rapidly-evolving sector, where current software languages did not exist a few years ago. Furthermore, rapid change means that IT professionals need to undertake almost continual professional development to update their skills, but as in many sectors with a high proportion of small firms, their employers often lack the resources to provide such training.

Second, firms need stronger non-technical skills, in management and leadership, business improvement techniques, change and project management.

In aerospace, identified skills gaps include systems thinking and engineering, project management, problem-solving techniques, and business understanding and strategy.

For major automotive manufacturers, the primary issue remains the quality and management practices at the first and second tier suppliers. The UK automotive supply chain has been regarded as poor in areas such as leadership, programme management and customer care. Thirty per cent of supply chain firms have no business plan, and fewer than 50 per cent have workforce training plans.[76]

In telecommunications, stronger strategic and management skills are needed to convert technical innovation into business innovation. Telecommunications workers need to obtain new business skills to manage technological development and to integrate this development with the design and delivery of new services, along with the skills to manage increasingly distributed and global relationships with suppliers.

75. Business Software Alliance/IDC (2007) 'Global Software Piracy Study.' Washington, DC/Framingham, MA: BSA/IDC.
76. Ricardo UK/Skills4Auto (2006) 'Vision for the UK Automotive Industry in 2020, Focusing on Supply Chain and Skills & Technology.' Shoreham-by-Sea/Birmingham: Ricardo UK/Skills4Auto. Similarly, see Automotive Innovation and Growth Team (2002) 'Design, Development and Manufacture Report.' London: AIGT.

Similarly, in software, development of complex products and projects requires not only in-depth and up-to-date technical skills but also a sophisticated set of business-oriented skills and understanding. Integrating technological knowledge with business skills enables firms to engage more effectively with clients, develop greater levels of innovation and so ensure sustainable competitive advantage.

In electronics, UK firms need to be more strategic in addressing skills to raise productivity and compete effectively. Improvements in management and leadership skills, technical and engineering skills, general business skills, procurement and supply chain management skills are needed. UK universities have a role to play in advancing supply chain management research, and, along with other organisations, training providers to teach best practice. Firms need continually to refresh their skills in this area and undertake training for this.[77]

5. Recommendations: The UK needs Total Innovation Strategies for high-value-added sectors to retain its competitive advantage

5.1 Innovation policy should be focused on business growth, embracing total innovation

The focus of innovation policy should shift from supporting research to stimulating wider innovative activities as they contribute to business growth.

It is much easier for firms to find support for more traditional research and technology projects than for innovative business models, novel services or risk-sharing partnerships. Increasingly, combining these with more traditional forms of innovation will prove integral to winning the 'race to the top', rather than being additional to it.

5.2 This will require an extension of sector-focused innovation policy

Total innovation reinforces the importance of sector-focused interventions. Technology roadmaps, support for specific emerging technologies and strategic alliances within industries can all help to stimulate and support longer-term innovation in disruptive areas.

Such intervention exists in aerospace and electronics, to some extent, but it rarely seeks to stimulate or support wider forms of innovation and change, such as in business models.

There are some exceptions that do embrace organisational change. For example, in automotive the Supply Chain Groups programme from 2003-2008 (jointly funded by the then Department of Trade and Industry, the English RDAs and the devolved regional assemblies) focused largely on process improvement through Lean manufacturing, and facilitated major productivity improvements of up to 40 per cent.[78]

At the same time, a sector-focused approach underlying innovation policy should be carefully constructed so as not to inhibit the potential cross-fertilisation of ideas and technologies between different parts of the economy. As NESTA has noted previously, sectors often draw on technologies and ideas from an 'innovation hinterland' of traditionally-unrelated areas.[79] In the case of high-technology sectors, this can be seen in the increasing importance of organisational and business model innovation – sometimes drawing on innovations developed in services sectors – and in the use of new materials originally developed in other high-technology areas.

5.3 The changing nature of traditional innovation and the demands of total innovation require stronger and broader skills

Of course, the performance of high-technology sectors in the UK will be undermined if there is an undersupply of people skilled in science, technology, engineering and mathematics (STEM). More students need to be inspired to study these subjects, and STEM careers must present an attractive alternative to employment in other sectors. This means developing more teachers who can teach these subjects creatively, increasing the use of 'enquiry-based learning' (discovery through experimentation), and continuing to improve how the value and importance of STEM careers is communicated to students.[80]

But narrow technical skills are not sufficient for total innovation. Education and training must develop the capabilities necessary for contemporary innovation, specifically more interdisciplinary skills and stronger strategic business skills.

As one of its projects, the new UK Commission for Employment and Skills (UKCES) should build on the work of the sector skills councils

77. Department of Trade and Industry (2004) 'Electronics 2015 – Making a Visible Difference.' Electronics Innovation and Growth Team Report. London: The Stationery Office.
78. This initiative supported 62 projects, involving 575 suppliers employing 160,000 people; see Department for Business, Enterprise and Regulatory Reform (2008) 'Report on the Business Environment for Japanese Automotive Supply Companies in the UK.' London: BERR.
79. See section 6.3, National Endowment for Science, Technology and the Arts (2007) 'Hidden Innovation.' London: NESTA.
80. See National Endowment for Science, Technology and the Arts (2005) 'Real Science, Encouraging Experimentation and Investigation in School Science Learning.' London: NESTA; and National Endowment for Science, Technology and the Arts (2007) 'Science: An Engine of Innovation.' London: NESTA.

to provide government with an analysis from the perspective of industry regarding the extent and quality of 'innovation-ready' skills in the UK, and advise on how the education, training and skills systems across the UK might be improved to ensure the better development of these skills.[81]

Further, universities and colleges should consider how they can provide students with greater opportunities to develop interdisciplinary skills and awareness, for example drawing on approaches such as NESTA's Crucible and Universities United initiatives.[82]

5.4 Innovation policy needs to prompt firms to anticipate – and benefit from – coming disruptions in high-technology sectors

As we have seen, many high-technology sectors are increasingly experiencing rapid changes, in scientific and technological knowledge and in their industrial structures.

Innovation policy needs to be better informed by these changes. This is why 'roadmapping' can be so valuable. For example, the Knowledge Transfer Network (KTN) in Digital Communications – established in December 2007 covering the telecommunications, IT and broadcasting sectors – aims to identify new and emerging technologies and the future capabilities needed within the sector to ensure that competitive advantages are realised for the UK.

Firms should be encouraged to explore new business models, organisational forms and ways of working, to prepare for and profit from these changes.

5.5 Policy needs to stimulate socially-desired innovations

Innovative approaches are needed to encourage socially desirable innovations that may not have a direct economic benefit. In pharmaceuticals, the under-supply of development in drugs for diseases that primarily afflict poorer countries could be met by 'advance commitments' by governments and international agencies. This would involve promises to purchase a given quantity of a treatment for diseases like malaria or tuberculosis that otherwise would attract very little investment.

Equally, innovation policy and regulation in aerospace, automotive and electronics hardware could be better used to meet environmental challenges. For example, in automotive, there should be more strategic funding in low-carbon technologies. The recent King Review of low-carbon cars recommended bringing existing low-emission technologies from 'the shelf to the showroom' as quickly as possible by: ensuring a market for low emission vehicles; moving the short-term focus back to automotive technology from biofuels; developing the UK as a location for high technology companies in the field, with good businesses support mechanisms encouraging inward investment and supporting key areas of underpinning science and engineering.[83] The Technology Strategy Board Low Carbon Vehicles Integrated Delivery Programme should provide greater coordination of activities from university research to future potential procurement opportunities, speeding up the time it takes to get low-carbon vehicle technologies into the marketplace.

5.6 These new demands on innovation policy require greater coordination

Given the breadth of policies that affect innovation, there is a need for their better coordination. For example, in pharmaceuticals, the better coordination of science funding with regulation and procurement would provide a more informed balance between short-term drug price containment and the social and economic benefits from radical new approaches to the development of drugs.

In automotive, as noted, regulation can play a role in stimulating innovation that reduces emissions, alongside direct support for increased research. Yet according to one study for government: "Uncertainty as to the likely strength of long-term policy for CO2 reduction in the transport sector means automotive and fuel companies are uncertain as to the priority to attach to carbon reduction/fuel efficiency goals relative to other objectives."[84]

5.7 Government and industry should develop Total Innovation Strategies for strategic industries

The UK needs to invest in its strategically important industries. These are the UK's current high-value-added industries and those that are identified as having the realistic potential to become high-value-added – our 'innovation edge'. 'Investment' in this context means economic and political commitment to their development.

The UK must develop comprehensive strategies for these industries. These strategies should be comprised of three main elements. They should chart likely changes in the environment

81. The UKCES is intended to play a critical part in securing a highly skilled, productive workforce and increasing employment levels, particularly for those from disadvantaged backgrounds. It will: advise government on strategy and policies relating to employment and skills; assess progress towards achieving national employment and skills ambitions for 2020; and have responsibility for the performance of Sector Skills Councils, advising government on re-licensing.

82. Crucible offers early-career researchers in science, technology, engineering and social sciences an opportunity to develop new collaborations across disciplines; Universities United is a pilot project to test an interdisciplinary approach to innovation with a particular focus in developing innovations for social benefit.

83. HM Treasury (2007) 'The King Review Part I: The Potential for CO2 Reduction.' London: The Stationery Office; HM Treasury (2008) 'The King Review of Low-Carbon Cars, Part II: Recommendations for Action.' London: The Stationery Office.

84. E4tech (2007) 'A Review of the UK Innovation System for Low Carbon Road Transport Technologies, A Report for the Department of Transport.' London: E4tech.

in which these industries operate: present or coming changes in knowledge, technology, trade, demographics and industrial structure that have bearing on competitive strategy or socially-desired outcomes.[85] Industry and government should then apply this understanding to the UK's current positioning and identify a small number of likely routes to competitive advantage. Finally, these strategies should lay out a plan for passive and active government support, primarily centred around the need for greater coordination of policy.

Two sectors have already benefited from coordinated strategies. As noted, the National Aerospace Technology Strategy (NATS) is identifying, researching and validating 'key' and 'enabling' technologies. But NATS, however important, is not a national aerospace strategy, in the sense of a broader vision beyond technology research and development.

More comprehensively, the Defence Industrial Strategy and the subsequent Defence Technology Strategy lay out a long-term, integrated strategy for the sector. The strategy encompasses research and technology development, government procurement, education, skills and training needs, improving innovation in supply chains, and through-life capability management. These strategies are based on a detailed analysis of the defence industry capabilities we need to retain in the UK, with changing needs and increased foreign competition.

DIUS, BERR, HM Treasury, the TSB, devolved administrations and relevant agencies such as regulators and sector skills councils, should work jointly with industry to develop Total Innovation Strategies for each strategic industry. These strategies should derive from the following activities:

- Charting: Deep analysis of the global threats and opportunities facing each industry, given the likely changes in the environment for these industries.

- Relating: Determining how the UK can respond to maximise its competitive advantages in these industries, given our current strengths and our ability to respond.

- Responding to ensure that the UK is best placed to maximise these advantages, by:

  – Aligning current policy mechanisms:

    - Reviewing how current funding, interventions and regulations at UK-wide, national and regional levels are related – including support for R&D, university research, business support, public procurement, skills development, and trade policy and development.

    - Establishing mechanisms for the better coordination of these elements where there are tensions or contradictions.

  – Extending current policy mechanisms:

    - Commissioning foresight exercises to stimulate thinking on the new business models and organisational forms that are likely to be required in these industries.

    - Integrating innovation in business models, organisational forms and processes into current mechanisms, such as the TSB's Innovation Platforms or regional initiatives that seek to strengthen supply chain firms.

    - Engaging public and private finance to invest in the development of UK strengths in these areas.

These strategies should be led jointly by DIUS and BERR, but will demand ongoing industry engagement.

Collectively, these strategies should represent the UK's national mission for innovation.

5.8 Policy should be informed by new measurements that capture total innovation
The extent and importance of hidden innovation in these research-intensive sectors demonstrates the inadequacy of relying on research-focused indicators alone.

In firms, the increasing importance of total innovation makes current indicators such as formal R&D spend increasingly unhelpful as a guide to innovative performance and hence business growth. This is because much investment in technological innovation is not recorded under the official definition of R&D – excluded activities include more developmental and applied forms of innovation, the innovative re-use of technologies, and 'micro' innovations. As we have seen, new organisational forms and business models are not registered as investments and the contributions of smaller innovative firms are also often excluded.

85. Foundations for this work already exist or are ongoing in some areas. Where appropriate, this work should build on the Innovation and Growth Teams (IGTs), established by the former DTI. Similarly, government has recently announced a new IGT for the UK automotive industry, in particular to explore how it should respond to low-cost competition and the move to low-carbon transport; see Department for Business, Enterprise and Regulatory Reform (2008) 'Business Minister Shriti Vadera Announces New Investigation into Automotive Industry.' Press release, 7th April. London: BERR.

In policy, the focus on R&D as a proxy for national performance obscures a focus on business growth from innovation and the wider set of factors that shapes innovation by firms. These include regulation, public procurement, and education and skills policy.

This will require a new set of indicators to guide policy. These will need to be broader and more meaningful than current indicators.

First, R&D and other indicators related to research will remain important, but only as part of a broader set of measures, and understood in terms of their relative significance for each sector, which of course varies greatly. Research-focused indicators could also be more specific; for example, such measures could track progress in selected, strategically important areas for innovation, against agreed 'technology roadmaps'.

Second, more indicators need to be developed for forms of hidden innovation such as services, new organisational forms and business models. Cross-sector surveys such as the Community Innovation Survey should record levels of investments in innovation in these activities, to provide a more accurate and comprehensive picture.

Third, policy requires more suitable and accurate indicators to assess the strength of business performance in higher-value-added sectors. Such wider 'health check' indicators could also provide benchmarks for national performance.

Unsurprisingly, many firms in these sectors have adopted broader indicators to track their own innovative performance. These can include the number of ideas generated, developed, refined and delivered, and the returns they generate; and revenues from new or innovative services. Industry-led surveys also illustrate useful indicators that could be included in these health checks, such as:

- the speed and success at which a firm is able to advance drugs through phases of development in pharmaceuticals;

- the adoption of and performance in Lean manufacturing techniques in aerospace and automotive;

- 'reduced cycle time' for product development projects in telecommunications;

- licensing of UK firms' IP in electronics and of the value added from strategic alliances, partnerships and collaborations; and

- innovations in software development processes, such as Agile and Lean approaches, or in how services are delivered such as Software as a service.

Fourth, there could be greater prominence given to measures of customer satisfaction and how these relate to new products or services. This is important in product-focused sectors such as aerospace and automotive, where the quality of the 'final' product delivered can be below customer expectations. But it may be even more critical for service-focused sectors or sub-sectors; one measure might be the degree to which new software and systems have contributed to customers' performance in software. (Indeed, there has been a trend in the software sector towards 'value-based pricing' whereby suppliers are rewarded with a percentage of client revenues generated as a result of new software and systems).

Finally, it would be useful to incorporate social and environmental performance outputs as measures of innovative performance. For example, in aerospace and automotive, these could include progress against reductions in emissions and fuel consumption.

Such measures will be considered as part of NESTA's work on a new Innovation Index for the UK.

Appendix A: Pharmaceuticals

Innovation through large-scale investments in research but undergoing radical changes that challenge the traditional 'pipeline' model

1. Pharmaceuticals are a major export earning sector for the UK

The pharmaceutical sector makes a large contribution to the UK economy, with a gross value added (GVA) of £6.5 billion in 2004, or 6.2 per cent of total UK GVA.[86] The UK sector was the world's fourth largest in 2002 in terms of GVA (the latest year for which internationally comparable data are available).[87] The UK pharmaceutical industry directly employed 73,000 people in 2004, 27,000 in 'R&D employment'.

Pharmaceutical exports in 2006 were £13.8 billion, with a trade surplus of £4.3 billion.[88] Of the major medicines sold in the UK, around half were developed in domestic laboratories. Furthermore, the UK is second only to the US in global medicines brought to market between 2000 and 2004.[89] UK firms were responsible for 17 (23 per cent) of the world's 75 top-selling drugs in 2003 and 19 per cent of the total value of global sales of those medicines, second only to the US in both cases.[90]

The two major UK firms are GlaxoSmithKline (GSK) and AstraZeneca. The US-headquartered Pfizer, the world's largest pharmaceutical firm, discovered four of its ten best-selling drugs at its European R&D headquarters in Sandwich, Kent (the only foreign site for R&D established by the firm). The North West and the South East are particular centres of drug research and development.

In biopharmaceuticals,[91] there are 46 UK companies and five non-UK companies developing products.[92] Again, the UK is second to the US (although Germany is catching-up quickly).

The UK is also an important centre of bioprocessing (the manufacturing sub-sector). Major processing sites in the UK include Merseyside (Lilly), Merseyside (Powderject, now part of Novartis), and Teesside (Avecia). Once again, the UK is second only to the US.[93] There are 22 biopharmaceutical contract manufacturing organisations (CMOs) in the UK, generating annual revenues of over $150 million.[94] This is equivalent to approximately 6 per cent of the global biopharmaceutical CMO market. The UK has major firms such as Avecia, Lonza and Cobra, alongside a host of smaller firms.

2. Innovation in pharmaceuticals is undergoing radical change in research and in new business models and organisation forms

2.1 Pharmaceutical is far less linear than is often supposed and the nature of research in the sector is changing rapidly

2.1.1 Innovation in pharmaceuticals still requires very large upfront investments in research and development

Developing a new medicine takes on average 10-15 years and costs more than £550 million (often more than £120 million for a specific drug and more than £400 million in capital costs and other failed drugs). Furthermore, before it is authorised for use, a drug has to undergo a long and complex process of testing (see 2.1.2).

Given the expenditures involved and the very low success rate in developing successful new drugs, innovation in the sector is very high-risk. The 'blockbuster model' describes

86. Office for National Statistics (2006) 'United Kingdom Input-Output Analyses, 2006 Edition.' London: Office for National Statistics.
87. Pharmaceutical Industry Competitiveness Task Force (2006) 'Competitiveness and Performance Indicators 2005.' London: PICTF.
88. The Association of British Pharmaceutical Industry (2006) 'Annual Review.' London: ABPI.
89. Pharmaceutical Industry Competitiveness Task Force (2005) 'Competitiveness and Performance Indicators 2005.' London: PICTF.
90. Paraxel Publishing (2006) 'Bio/Pharmaceutical R&D Statistical Sourcebook 2006/2007.' Waltham, MA: Paraxel Publishing.
91. Biopharmaceuticals are drugs produced using biotechnology, see 2.1.4.2
92. bioProcessUK (2007) 'bioProcessUK Annual Review 2007.' London: bioProcessUK.
93. Ibid.
94. Ibid. Revenue and market share data relates to 2006.

the balance between risk and reward: only a few, very successful products support the development costs for all products. So-called 'blockbuster' drugs are those with peak annual global sales of more than $1 billion. Even then, such drugs are likely to have no more than ten years in the market to recoup development costs and become profitable. Once their patent protection period ends, generic competitors can enter the market with resulting large price and market share falls for a drug's developer. To balance their exposure to risk, large firms typically maintain a portfolio of around 50-100 projects for which they continually assess the scientific, medical and commercial viability of their portfolios.

For these reasons, pharmaceuticals are the most research-intensive large-scale sector in the UK economy, with an R&D intensity of more than 15 per cent. They account for 35.5 per cent of R&D in the UK, three times as much as aerospace. UK pharmaceutical and biotechnology firms invested £7.4 billion globally in R&D in 2006, equivalent to £20 million a day (£9 million of it in the UK).[95] The biggest global spenders in terms of UK firms were GSK (£3.46 billion) and AstraZeneca (£1.99 billion); they dominate R&D by UK firms in the sector (representing 73 per cent of all spend).[96]

Only the US and Japan have higher R&D spending in pharmaceuticals; the UK represents around 9 per cent of world pharmaceutical R&D, more than double the 4 per cent of the global market for medicines represented by the UK.[97] The largest spender on R&D in the world is the American pharmaceutical firm Pfizer (£3.88 billion a year).[98]

2.1.2 New drugs progress through a staged process of discovery, development and testing

The model of pharmaceutical innovation has traditionally been divided into several stages of experimentation, information gathering and development (hence the assumption that it represents a linear model of innovation).[99]

In the 'pre-discovery' stage, researchers work to understand the mistakes in the complex molecular reactions (chemical pathways) which cause diseases. They try to identify and validate the drug 'target' (the step within the molecular pathway which when altered would make a drug effective in treating a condition). They then try to identify the right molecule (candidate drug) for this target.

'Lead' compounds go through a series of tests to provide an early assessment of pharmacological activity, in particular pharmacodynamics (the way the compound affects the body) and pharmacokinetics (the way it is processed by the body). The studies are performed in living cells, in animals and increasingly, using computational models.

In all, the discovery phase takes several years of intensive work. After starting with between 5,000-10,000 compounds, researchers are left with between one and five candidate drugs to be studied in clinical trials.

During development, drugs normally undergo substantial testing, including clinical trials, manufacturing experiments and outcomes research, before they can be authorised for use. The clinical trials activity typically represents the largest share of R&D costs (more than 40 per cent), while the discovery and pre-clinical phase represents only a quarter.[100]

Pre-clinical testing in animals follows the discovery phase. If a project is pursued beyond this point, costs increase markedly because testing in humans is riskier and far more expensive. Only about 20 per cent of drugs that enter the first phase of testing (there are three over several years) are eventually approved for sale.

Even if a drug makes it through these different phases (around a 4 per cent chance) there is no guarantee that it will be approved for sale. The information gathered through the entire process is compiled in a regulatory dossier that is submitted to authorities around the world. These bodies consider the evidence presented, listening to opinions and advice from independent experts, patient interest groups and other stakeholders before deciding whether the drug can be authorised for use.

During the final stages of development, firms begin the process of scaling-up manufacturing capacity to ensure that the new drug can be produced immediately following approval (by for example building new facilities or reconstructing old ones because the process differs from drug to drug). Given that a drug can still fail in late-stage development or not be approved for sale by regulators, this manufacturing development also carries a significant investment risk.

95. Based on a study of the top 850 UK spenders on R&D. Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
96. Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
97. Pharmaceutical Industry Competitiveness Task Force (2005) 'Competitiveness and Performance Indicators 2005.' London: PICTF.
98. Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
99. For more details about this process, see US Food and Drug Administration, Center for Drug Evaluation and Research (1999) 'From Test Tube to Patient: Improving Health Through Human Drugs.' Washington, DC: US Government Printing Office.
100. The Association of the British Pharmaceutical Industry (2007) 'Investing in the Future 2007.' London: ABPI.

2.1.3 The research-intensive nature of innovation in pharmaceuticals has been reflected by the traditional industrial structure in the sector
Until the early 1980s, the pharmaceutical sector was characterised in effect only by large, vertically-integrated commercial firms. These firms were responsible for the discovery of chemicals, clinical development, and drug marketing and distribution. Many firms had roots in the chemical industry and were located in countries with historic strengths in chemicals, notably Germany, Switzerland, the US, and the UK.

Firms required – and could afford – large-scale industrial R&D labs. This reflected the magnitude of both the research opportunities and of unmet needs, but also the need for scale to absorb the risks of drug development. There were many diseases for which no drugs had previously existed. Faced with a target-rich environment but with little detailed knowledge of the biological underpinnings of diseases, firms developed an approach now referred to as 'random screening', by which natural and chemically derived compounds were randomly screened in test tube experiments and laboratory animals for potential therapeutic responses. Strong patent protection in most major world markets, in addition to barriers to entry from regulations, enabled firms to earn favourable returns for their large R&D investments.

Meanwhile, non-profit institutions such as universities and public research laboratories produced basic research in chemistry and the life sciences. Broadly, these institutions engaged in 'open science', with their unpatented outputs published in scientific journals. Such researchers competed for grants but rarely had commercial interests. The commercial and publicly-funded sectors were largely distinct, the former focusing on applied research with commercial uses and the latter on basic, curiosity-driven research – although there were often significant relationships between the two.

2.1.4 However, 'traditional' innovation in pharmaceuticals is changing rapidly as a result of new knowledge, technologies and approaches

2.1.4.1 Despite its highly research-intensive nature, the linearity of pharmaceutical innovation has often been overstated
First, innovation in pharmaceuticals is cyclical and business-driven. Investment decisions are made at each stage based on business projections.

Second, the linear model fails to take adequate account of the final phase of the innovation process, that of achieving timely market diffusion and adoption to benefit patients.[101] Firms such as Wyeth and Novartis are moving to a 'learn and confirm' view of pharmaceutical research and development, recognising that the key requirement is to provide the evidence needed for regulators to feel confident in approving a new drug. This was also inherent in the blockbuster model; large firms were the only ones with the necessary competencies to manage large-scale clinical trials, gain regulatory approval, and market and distribute drugs.

Neglecting these factors helps to privilege 'breakthrough' over so-called 'me-too' drugs.[102] Yet incremental or 'continuous' innovation is as important as breakthrough innovation. Later members of a product class are often the best all-round product, because practice has helped to improve effectiveness through better formulations, a better understanding of how to use drugs and the patient groups that will benefit from them, and how they might be used to treat other diseases. Such innovations can emerge long after initial discovery through a more interactive innovation process between research scientists, clinicians and experts from other fields (who can better identify other uses).[103] One example is the developments in understanding of how to use existing drugs in cardiovascular medicine; aspirin, streptokinase, and ß-blockers were not considered for the diseases for which they are now associated for years or even decades following their initial introduction.[104] Such drugs may still be under-exploited; one study has estimated that 40,000 lives could be saved worldwide – 3,000 in the UK alone – from the greater use of aspirin.[105]

Similarly, in the biotechnology sector, a more accurate understanding of innovation would be as a slow and incremental process of technology diffusion rather than one of radical breakthroughs.[106] Such issues are not merely of academic interest; they can play a critical role in shaping the policies of large state purchasers who use such classifications to determine whether or not they will reimburse a new product and at what price.[107] (See 6.3).

2.1.4.2 Biological approaches represent a new paradigm for drug discovery
This new paradigm is the result of advances in life sciences and genetics. Most important are

101. Attridge, J. (2006) Innovation Models in the Biopharmaceuticals Sector. Discussion Paper 2. In Atun, R. (ed.) 'Innovation in Life Sciences: A Multidisciplinary Perspective.' London: Tanaka Business School, Imperial College London.
102. This is why it is misleading to focus on a simplistic 'breakthrough' versus 'me-too' distinction, as has been the case in some studies; for example, it has been suggested that only 27% of biopharmaceuticals provide 'some advance' and only 10% of all other drugs, see Arundel, A., and Mintzes, B. (2004) 'The Benefits of Biopharmaceuticals.' Innogen Working Paper 14. Version 2.0. Edinburgh: Innogen, University of Edinburgh.
103. Swan, J., Robertson, M., Bresnen, M., and Newell, S. (2006) 'The Evolution of Biomedical Knowledge: Interactive Innovation in the UK and US.' Swindon: Economic and Social Research Council.
104. Sheridan, D. (2006) Development and Innovation in Cardiovascular Medicine. Discussion Paper 3. In Atun, R. (ed.) 'Innovation in Life Sciences: A Multidisciplinary Perspective.' London: Tanaka Business School, Imperial College London.
105. Antithrombotic Trialists' Collaboration (2002) Collaborative Meta-analysis of Randomised Trials of Antiplatelet Therapy for Prevention of Death, Myocardial Infarction, and Stroke in High Risk Patients. 'British Medical Journal.' 324, pp.71-86.
106. Hopkins, M., Martin, P. A., Nightingale, P., Kraft, A., and Mahdi, S. (2007) The Myth of the Biotech Revolution: An Assessment of Technological, Clinical and Organisational Change. 'Research Policy.' 36 (4), pp.566-589.
107. Attridge, J. (2006) Innovation Models in the Biopharmaceuticals Sector. Discussion Paper 2. In Atun, R. (ed.) 'Innovation in Life Sciences: A Multidisciplinary Perspective.' London: Tanaka Business School, Imperial College London.

the development of techniques to analyse and manipulate genetic materials, and the impact of the revolution in molecular biology. This has led to an increasing convergence between traditional medicinal chemistry and the new biological knowledge.

Biopharmaceuticals are medical drugs produced using biotechnology (that is, technology that uses biological systems or living organisms to make or modify products or processes), as opposed to traditional chemically derived drugs. Biopharmaceuticals fall into a number of different product classes. These include recombinant human proteins (the largest group), recombinant human antibodies, vaccines, gene therapies, and cell and tissue therapies.

Biopharmaceuticals represent an increasingly significant proportion of drugs in development. They account for more than 10 per cent of current pharmaceutical sales worldwide but more than a third of drugs in development.[108] A number of biopharmaceuticals are now classed as 'blockbuster' drugs. In 2005, Epogen (recombinant human erythropoietin) was the biggest selling biopharmaceutical with sales over $3 billion, while Humira became the first UK discovered antibody product to achieve blockbuster status with sales of $1.4 billion (in 2007 sales had risen to $3.1 billion).

108. bioProcessUK (2007) 'bioProcessUK Annual Review 2007.' London: bioProcessUK.

Biopharmaceuticals are far more complex to develop and synthesise, as they require the integration of different disciplines, research areas and techniques. At the same time, this makes them attractive to pharmaceutical firms, as it is harder for generic competitors to copy the technologies.

2.1.4.3 There is increasing use of automation and other process innovations

The industry is as much concerned with establishing the methods by which new drugs can be industrialised as with the drugs themselves. Finding the optimal formulation continues to be a key part of every R&D project.

Increasing automation has already replaced laborious or time-consuming manual processes, reducing costs and greatly improving throughput. In the past, a chemist might have been able to produce between 50 and 100 new chemical compounds a year. Using new techniques and computer-controlled robots, he or she can produce nearly half a million a week.

'Rational drug design' (also known as 'structure-based drug design') rather than random screening has now become the dominant approach to research in the commercial sector. This approach targets a specific biological activity and identifies or creates a molecule involved in that activity. This requires greater understanding of biology and fundamental mechanisms. Firms build computer models of design targets and then analyse the shape and other characteristics that likely drug molecules should have in order to interact with the target.

2.1.4.4 Understanding human genetics is now a major part of drug discovery

We now know that many diseases can be linked to genetics. The information gathered through the successful mapping and sequencing of the human genome is playing a vital role in the discovery process, helping to identify areas for scientific exploration and potentially allowing medicines to be customised to groups of people or even individuals. Pharmacogenetics can help to identify whether an individual's genetic make-up could prevent them from benefiting from a drug. But this also adds complexity to existing development.

2.1.4.5 Manufacturing many drugs has become much more complex

Although bioprocessing (or biomanufacturing) was already applied to the manufacture of medicines like penicillin and other antibiotics derived from naturally occurring bacteria, the breakthrough necessary for its systematic application was the development of recombinant DNA. This makes it possible to insert DNA encoding for a particular protein into a bacterium or mammalian cell line and induce it to produce the desired product. The first product based on such genetic engineering, human insulin or Humulin, was launched in 1981.

Since then, genetic engineering of bacterial, viral, yeast and mammalian cells has given rise to a broad range of biopharmaceuticals. Manufacturing even the least sophisticated biopharmaceutical is fundamentally different and far more complex than manufacturing conventional (small molecule) drugs. Environmental factors such as temperature, pressure and growth medium must be tightly controlled and consistent to ensure the same product is produced each time. This is why one-fifth of the value of a biopharmaceutical drug derives from the wider supply chain (including raw materials, production and distribution).

2.1.4.6 University research and knowledge are increasingly being commercialised

These new approaches have often been led by universities, public laboratories, spin-out and start-up firms (see 2.2.1), facilitated by changes in intellectual property rights (3.5), funded by the increased availability of venture capital (3.6), and supported by firms in other areas such as information technology and advanced materials.[109] This has been mirrored by the creation of incentives for scientists in the non-profit sector to patent their work, and has changed the world of open science related to pharmaceutical research. The result is a much higher rate of collaboration and knowledge transfer between the non-profit and commercial sectors, and a greater similarity of research style.

2.1.5 Despite these developments, there have been increasing concerns about declining productivity

As more drugs are developed, the remaining diseases are those that are most difficult to understand and attack. They are also those for which it is more difficult to develop new drugs. At the turn of the millennium, despite the overall growth in the pharmaceutical market, many top-selling drugs were coming to the end of their patent periods and faced competition from generics.[110] (Between 2001 and 2005, branded drugs with total annual sales of $35 billion lost patent protection.) In addition, pharmaceutical firms have faced increased pressure on prices due to growing demands from governments, insurers and consumers to lower the costs of drugs.

Many of these concerns have been based on an output measure of new drug launches, but it has been suggested that much of the observed downturn in productivity is related to flaws in this measure.[111] Current performance is not particularly low by historical standards, factoring in a normal amount of volatility.[112] Productivity measures have declined mostly because of an increase in R&D spending that appears to be driven by escalating costs of drug development, particularly the need for large scale clinical trials. According to one study, from 1995-2005 there was a five-fold increase in the costs of clinical development and a 60 per cent increase in the real costs of preclinical development.[113] The 'crisis' therefore amounts to a failure to increase the number of new products whilst overall resources being invested globally have risen dramatically.

2.2 Organisational and business model innovation have become integral to innovation in pharmaceuticals

2.2.1 The growth in scientific understanding encouraged a major change in industry structure in the shape of small new firms

A new business model emerged in the 1980s and 1990s: the specialised biotechnology firm. As in many other sectors, innovation was first pursued not by large incumbents but by much smaller, new companies.[114] These firms were less risk-averse in selecting and pursuing research projects.[115]

Most were university spin-offs, usually formed through collaborations between scientists and professional managers, and backed by venture capital. Their specific skills resided in knowledge of the new techniques and in the research capabilities in their specific areas.

Choosing the most appropriate business model has been crucial for biotechnology firms.[116] Although many firms were founded with the long-term aim of becoming large integrated pharmaceutical producers (the vertical model), they often experienced organisational and financial constraints (for example, a lack of experience and capacity to manage clinical testing or marketing), and many have subsequently become specialised suppliers of specific techniques and research projects. This has created a kind of 'feeder' system of new knowledge and techniques for the sector.

2.2.2 Large pharmaceutical firms now approach small, specialised suppliers as a further source of development opportunities

The industry has seen a large number of mergers and acquisitions in the last 20 years, with little increased productivity. Whilst these still occur, there has been a significant increase in licensing deals, strategic alliances, and other forms of collaboration between firms of various sizes in the commercial sector as an alternative to outright acquisition. Similarly, firms have sought to work more closely with the non-profit sector (see 3.4).

However, absorbing new knowledge and approaches has sometimes proved difficult for existing large pharmaceutical firms. It could only be fully exploited through the development of in-house capabilities, which made it possible to absorb and complement the knowledge supplied by small firms and universities. This has required radical changes in research procedures, a redefinition of the

109. Coombs, R., and Metcalfe, J. S. (2002) Innovation in Pharmaceuticals: Perspectives on the Coordination, Combination and Creation of Capabilities. 'Technology Analysis & Strategic Management.' 14 (3), pp.261-271.
110. Pharmaceutical patent systems in OECD countries offer twenty years protection from imitators. However, patents must be secured at the time of invention, and hence the intervening years needed for the development of innovations normally reduce the effective period of protection to 10-12 years.
111. Cockburn, I. (2006) Is the Pharmaceutical Industry in a Productivity Crisis? In Jaffe, A., Lerner, J., and Stern, S. (eds.) 'Innovation Policy and the Economy.' 7, pp. 1-32.
112. Cockburn, I. (2006) Is the Pharmaceutical Industry in a Productivity Crisis? In Jaffe, A., Lerner, J., and Stern, S. (eds.) 'Innovation Policy and the Economy.' 7, pp. 1-32; also Charles River Associates (2004) 'Innovation in the Pharmaceutical Sector.' London: Charles River Associates; Messinis, G. (2004) 'R&D Price Inflation, Real BERD and Innovation: Pharmaceuticals, OECD 1980-2000.' Working Paper 18. Melbourne: Centre for Strategic Economic Studies, Victoria University of Technology.
113. Charles River Associates (2004) 'Innovation in the Pharmaceutical Sector.' London: Charles River Associates.
114. The first new biotechnology start-up, Genentech, was founded in 1976 by Herbert Boyer, one of the scientists who developed the recombinant DNA technique, and Robert Swanson, a venture capitalist. Genentech constituted the model for most of the new firms.
115. Guedj, I., and Scharfstein, D. (2004) 'Organizational Scope and Investment: Evidence from the Drug Development Strategies and Performance of Biopharmaceutical Firms.' NBER Working Paper 10933. Cambridge, MA: National Bureau of Economic Research; also Styhre, A. (2006) Science-based Innovation as Systematic Risk-taking, The Case of New Drug Development. 'European Journal of Innovation Management.' 9 (3), pp. 300-311.
116. Lim, L. (2003) Bio-Business Models. 'Cambridge Manufacturing Review.' Winter, pp.7.

disciplinary boundaries within large firm laboratories and some changes in divisional structures.[117] For example, Pfizer has recently announced the creation of a new biological unit that will operate outside of its main R&D organisation, although partnering with it.

Large European firms have been slower to adopt molecular biology compared to US firms, and have remained more closely linked for longer to the cognitive and organisational procedures that governed research when chemistry constituted the main knowledge base.[118] This may have produced a vicious circle, since new biotechnology firms have sometimes lacked an essential source of survival and growth through collaborative agreements with larger firms.

GlaxoSmithKline Centres for Excellence in Drug Discovery

GlaxoSmithKline (GSK) created six Centres for Excellence in Drug Discovery (CEDDs) in 2000, each focusing on a specific therapeutic area. GSK divided its then 1,900 scientists between these units.

The aim was to improve productivity, especially given the 'decline' of the blockbuster model of development. Specifically, to maximise the advantages of scale at the beginning of development (the search for validated targets) and at the end (the management of large-scale trials and regulatory approval), while organising the middle of the process (converting promising compounds into viable products) with the flexibility and responsiveness of a smaller biotechnology firm.[119]

Major pharmaceutical firms have typically relied on centralised decision-making about whether to progress projects, though this can be highly bureaucratic. The merger of Glaxo Wellcome and SmithKline Beecham presented an opportunity to restructure processes for the new combined firm.

Each CEDD is led by a senior vice-president and contains no more than 350 scientists (mostly biologists and chemists but with some physicians and clinical researchers). The size limitation is intended to support interaction and reduce bureaucracy. The centres are structured around biological therapeutic areas, focused on small sets of diseases or related disease mechanisms, including: neurology; respiratory, inflammation and respiratory pathogens; and cardiovascular, cancer and urogenital.

The CEDDs have relative autonomy; they can suggest attractive targets to two centralised research groups to identify drug targets and lead compounds (potential medicines), but these groups are not required to accept these compounds and can deal with external firms to license other promising lead compounds. The CEDDs assume responsibility for projects once they reach the lead optimisation stage. They can also work together, for example where a candidate compound appears to be effective against multiple targets. The first point at which the process is centralised is in development.

This model also incentivises research scientists. Previously, scientists were recognised (but often not rewarded) for finding targets. CEDDs bring scientists more into the drug development process; they are rewarded for being part of the development of successful drugs (echoing the equity-based incentive structures of small biotechnology firms).

Given the very long lead times for drug development, the full impact of these organisational innovations is unlikely to be fully realised for many years. Nonetheless, following these innovations, GSK has more – and more radical – drugs in development. In 2007, GSK had 157 projects in clinical development, of which 118 were new chemical entities or vaccines; this included 34 'key assets' in late stage development.[120] This compares to 2000, when the firm had 118 projects in clinical development, of which only 77 were new chemical entities or vaccines.[121] In other words, GSK now has the same number of radical new products in development as it had total products in development just seven years earlier, with a more than 53 per cent increase in radical new products. The firm now leads other large firms in terms of mid- to late-stage development of products.

117. Coombs, R., and Metcalfe, J. S. (2002) Innovation in Pharmaceuticals: Perspectives on the Coordination, Combination and Creation of Capabilities. 'Technology Analysis & Strategic Management.' 14 (3), pp.261-271.
118. McKelvey, M., and Orsenigo, L. (2001) 'Pharmaceuticals as a Sectoral Innovation System.' Göteborg/Brescia/Milan: Chalmers University/University of Brescia/Bocconi University.
119. Huckman, R. S., and Strick, E. P. (2005) GlaxoSmithKline: Reorganizing Drug Discovery. 'Harvard Business Review.' May, pp.1-21.
120. GlaxoSmithKline (2008) 'Answering the Questions that Matter, Annual Report 2007.' Brentford: GSK.
121. GlaxoSmithKline (2001) 'It's About You, Annual Report 2000.' Brentford: GSK.

2.2.3 Some large firms have adopted the organisational forms of small firms
GSK has subsequently taken this model further. Its Centre of Excellence for External Drug Discovery (CEEDD), created in 2005, is a small executive team accountable for delivering proof of concept molecules into late-stage development through a network of external alliances. CEEDD in effect 'virtualises' a portion of the drug discovery pipeline by acting as an 'external' CEDD. It is also responsible for accessing innovative approaches to drug discovery, that is, for developing process and organisational innovation, not just new products.

This approach may represent the dominant model for the rest of the sector in a few years' time. By 2015, large pharmaceutical firms are likely to focus more on core competencies such as sales and marketing, supported by a network of R&D organisations including long-term relationships with biotechnology firms.[122] An alternative vision is that firms diversify into selling not just products but 'healthcare packages' including diagnostic tests, drugs and monitoring devices, offering personalised 'targeted treatment solutions' for patients (a reflection of the new biological foundations for drug discovery and development).[123]

2.2.4 Cost pressures in the sector have led to increased outsourcing of research and manufacturing
Few firms still have large teams of in-house clinical researchers. Most rely on clinical research management organisations (CROs) to run the clinical trials required for regulatory approval.[124] CROs now account for more than 40 per cent of annual research spending by firms, compared to just 4 per cent in the early-1990s.[125] Many of the leading CROs have their European headquarters in the UK and the UK has a number of world-class CROs of its own, but Eastern Europe also has a well-developed infrastructure for outsourcing, and India and China are expected to account for a significantly greater proportion of such work over the next five years.

The role of CROs has grown rapidly as a result of the increasing pressure on pharmaceutical firms to bring drugs to market more quickly and the increased complexity of clinical trials and regulatory submissions. The ability of CROs to cut clinical trial times by as much as 30 per cent has become critical to large firms, especially given their concerns over R&D productivity and generic competition. CROs are more able than most firms to conduct studies on a multinational and multi-centre basis.

In recent years, the portfolio of services offered by CROs has widened to include R&D enabling technologies such as genomics, high throughput screening, and combinatorial chemistry, using proprietary techniques for which they often own the intellectual property rights. CROs can also offer post-commercialisation services such as sales and marketing.

2.2.5 Open innovation is changing the concept of a firm's innovation capacity
Finally, the internet has enabled new means of sourcing innovation. Firms like Innocentive and Nine Sigma offer innovation brokering services, giving pharmaceutical firms access to tens of thousands of creative minds in the search for solutions to the challenges of drug discovery. Similarly, Imaginatik (a UK firm) is a leading provider of innovation and collaborative problem-solving software and processes; Pfizer has recently invested in the further expansion of the firm.

The impact of this change is evident in the approach taken by Procter & Gamble, who sold off the research arm of their pharmaceutical business with the intention of sourcing development opportunities externally. Chorus, a firm set up by Eli Lilly to run high-speed proof of concept programmes on parts of Lilly's portfolio, manages its projects through a large network of external suppliers. The ability to coordinate the various contributions across this network and provide strong knowledge leadership is central to success in this new model.

3. Pharmaceutical innovation is determined by many inter-related government policies that interact with the innovation capacities of firms

3.1 Regulation and public procurement play a major role in shaping the conditions for innovation
Access to quality, affordable healthcare is increasing regarded as a human right. Medical knowledge is therefore seen as a 'public good'. At the same time, pharmaceuticals are a private, for-profit sector. As a consequence, government is heavily involved in shaping the environment for innovation in pharmaceuticals, through regulation and procurement, but also research funding and infrastructure (3.4)

122. Business Insights (2005) 'The Pharmaceutical Market Outlook to 2015, Implementing Innovative, Long-term Strategies for Sustainable Future Growth.' London: Business Insights.
123. IBM (2002) 'Pharma 2010: The Threshold of Innovation.' Somers, New York: IBM.
124. Milne, C.-P., and Paquette, C. (2004) 'Meeting the Challenge of the Evolving R&D Paradigm: What Role for CROs?' Boston: Tuft Center for the Study of Drug Development.
125. Business Insights (2006) 'Pharmaceutical Outsourcing Strategies, Market Expansion, Offshoring and Strategic Management in the CRO and CMO Marketplace.' London: Business Insights.

and intellectual property rights (3.5). The challenge of providing an attractive investment opportunity in a managed 'public service' market is one that is of increasing concern to pharmaceutical firms.

The speed and efficiency with which drugs pass through regulatory stages has a major impact on the returns to pharmaceutical firms' investments. Every day that a product is delayed reaching the market can result in $1-3 million in lost revenue.[126]

Government is not only a regulator; it is also the major purchaser in many countries, including the UK through the National Health Service (NHS). Both regulation and procurement are major factors in shaping the incentives for further investment in drug development.

In the UK, under the terms of the current Pharmaceutical Price Regulation Scheme (PPRS), pharmaceutical firms have the freedom to set launch prices of new drugs within an overall cap on the rate of return they can earn from all of their branded sales to the NHS.[127] This makes the UK a more attractive market than countries where launch prices have to be agreed in advance. However, UK expenditure on new drugs remains comparatively low.[128] In 2004, 17 per cent of UK drug expenditure went on products launched during the previous five years, a lower share than in all other comparator countries except Japan (16 per cent), and well below the 27 per cent in the US.

Governments must achieve a trade-off between efficiency in public procurement and promoting innovation and growth by pharmaceutical firms. The benefits from new drugs are often very difficult to quantify and can accrue over a long period, despite the public pressure that can build up to provide certain new drugs. Regulators also tend to focus on establishing the safety and efficacy (relative to the cost of purchase) of new products rather than encouraging investment in new product development, despite a general acceptance by many health agencies (including the UK National Institute for Health and Clinical Excellence, NICE) that innovation should be rewarded with higher prices.

In addition, in most countries at least two different public agencies are charged with the separate tasks of providing healthcare to a country's population, approving new products, and promoting innovation. Such agencies can have different and often conflicting goals.

The voice of the patient is also becoming a more significant factor in the provision of drugs, as evidenced by the public debate over the availability of Herceptin in 2006. An apparently inconsistent policy of providing the drug led to major protests, even though it had not at that point been fully approved for use.

3.2 Firms invest in R&D in areas with the greatest expected profits

Firms' decisions are informed by market potential, which is in turn affected by regulation and public procurement, the prevalence of a particular disease, the quality of existing treatments, and expectations about competing treatments and pricing. A 10 per cent increase in demand for care in a particular therapeutic area is associated with a 5-8 per cent increase in R&D spending.[129] Firms also take into account technical feasibility, according to their investments in related areas, their skills and knowledge, as well as the knowledge and skills of organisations they can work with. Private R&D investment can also follow non-profit investment, that is, the supply of knowledge from basic science research.

The imperative of showing a profit for investors means that, whilst firms do develop 'orphan drugs' (treatments for rare diseases) some drugs may not be developed due to limited potential returns. This has sometimes translated to a lack of focus on diseases that primarily affect people in poorer countries,[130] a difficult issue for an industry that is charged with both shareholder return and public good.

3.3 Skills gaps may inhibit innovation

In the UK, there are skills gaps amongst graduates in a range of technical respects: adequate grounding in higher level mathematics amongst science graduates; inadequate practical experience, particularly in chemistry, in vivo disciplines, pathology, toxicology and engineering; chemistry and the specialisations which build upon it; and computational analysis skills.[131] Skills shortages and gaps are particularly high in the bioscience area: the number of universities offering bioscience-related subjects is declining; the number of first degrees gained in bioscience-related subjects has declined over the last six years, by 27 per cent in Biological Sciences and 23 per cent in Chemistry; and only a small minority of the graduates in these subjects enter the bioscience industry or go onto

126. PhRMA (2007) 'Drug Discovery and Development, Understanding the R&D Process.' Washington DC: PhRMA.
127. The PPRS was created by negotiation between the government and the pharmaceutical industry in 1957. It is normally renegotiated every five years; the current scheme dates from 2005. However, the UK government recently announced that it is renegotiating the PPRS early.
128. Pharmaceutical Industry Competitiveness Task Force (2005) 'Competitiveness and Performance Indicators 2005.' London: PICTF.
129. Ward, M., and Dranove, D. (1995) The Vertical Chain of Research and Development in the Pharmaceutical Industry. 'Economic Inquiry.' 33 (1), pp.70-87.
130. This is particularly pertinent given the increase in clinical trials taking place in poorer countries for drugs that are aimed primarily at Western markets, see Shah, S. (2006) 'Body Hunters, How the Drug Industry Tests Its Products on the World's Poorest Patients.' New York: The New Press.
131. The Association of British Pharmaceutical Industry (2005) 'Sustaining the Skills Pipeline in the Pharmaceutical and Biopharmaceutical Industries.' London: ABPI.
132. SEMTA (2007) 'Bioscience Sector Skills Agreement Stage 3: Gap Analysis – UK.' Watford: SEMTA.

higher degrees in the subject.[132] There are also related skills shortages in specific areas such as bioprocessing and biopharmaceutical formulation.[133]

In addition, the UK sector has skills shortages in non-technical respects: innovation and business improvement techniques; change and project management; health and safety; and management and leadership.[134] Leaders and managers need to be able to adopt a complete value chain perspective of biopharmaceutical commercialisation, and be committed to continuous improvement in bio-processing.[135]

Furthermore, given the rapidly changing nature of innovation in the sector, there is a lack of strong interdisciplinary skills, for example, life science graduates with sufficiently strong skills in mathematics and physical sciences.

3.4 Universities, the research base and research clusters are increasingly supporting innovation

As collaborations have grown, innovation in the commercial sector has increasingly depended on the research strengths of academic institutions, especially following advances in molecular biology.

Despite the global nature of the industry, geography remains important. For example, commercial research labs located near universities tend to be more productive, suggesting that these labs benefit from knowledge spillovers from their academic neighbours.[136] Some large European firms have chosen to locate research facilities in areas close to major academic institutions, such as GSK in Research Triangle Park, North Carolina, near three major research universities, and Novartis in Cambridge, Massachusetts, near Harvard and MIT. Similarly, commercial biotechnology has grown fastest in the Bay Area of California, where Stanford and two major University of California campuses are located, and Boston/Cambridge.

The development of biotechnology firms in the US has been aided by two other advantages: legislation that facilitated the transfer of technology out of universities to commercial enterprises (the 1980 Bayh-Dole Act)[137] and a particularly well-developed venture capital industry (see 3.6).

However, collaborations between industry and universities can be undermined by factors such as: an asymmetry of knowledge and skills between partners; insufficient funding by industry; inflated expectations of the value of intellectual property rights (IPR) by academics or universities;[138] a lack of administrative support for academics; and excessive university bureaucracy.[139]

3.5 Retaining intellectual property rights is crucial to ensuring returns on investment for pharmaceutical firms

Two related issues that have been the subject of considerable debate are intellectual property rights (IPR) in developing countries, and the impact of expanding IPR on open science.

First, several developing countries have decided to ignore IPR on major products. For example, in 2007 Brazil moved to compulsory licensing of Efavirenz, an AIDS drug produced by Merck, after negotiations to lower the price failed.

Second, the expansion of patent protection to include areas such as the genome, research tools, and other forms of scientific knowledge has facilitated 'markets for technology' and thus made possible small firms that specialise in one aspect of the drug development process. However, there are concerns that science is becoming increasingly commercialised and that this may inhibit further research.[140] Although some of these concerns might be overdone, the potential exists for exclusionary behaviour to become more prevalent as the potential commercial returns to scientists increase.

3.6 Venture capital has helped to create many new firms but with mixed success

As we have seen, venture capital has been an increasingly important driver of R&D in the sector since the 1980s, particularly in the US but also in the UK. However, attrition rates – through bankruptcy or merger and acquisition – have often been high. The relatively short-term view in the standard venture capital markets means that biotechnology firms which focus on new products now tend to rely on large pharmaceutical firms to take drugs into clinical development. However, firms that have 'platform technologies' rely on a broader range of relationships which can be less secure; they have often sold their technologies to major pharmaceutical firms at an early-stage of development.

133. bioProcessUK (2006) 'bioProcessUK Annual Review 2006.' London: bioProcessUK.
134. Cogent (2007) 'A Sector Skills Agreement for the Cogent Sector UK.' Warrington: Cogent. Cogent is the Sector Skills Council for the chemicals, pharmaceuticals, oil and gas, nuclear, petroleum and polymer sectors; these skills gaps run across these sectors.
135. See bioProcessUK (2005) 'Developing Bioprocess Leaders Workshop.' London: bioProcessUK.
136. Furman, J., Kyle, M., Cockburn, I., and Henderson, R. (2006) 'Public & Private Spillovers, Location and the Productivity of Pharmaceutical Research Knowledge.' NBER Working Paper 12509. Cambridge, MA: National Bureau of Economic Research.
137. Zucker, L. G., and Darby, M. R. (1996) Star Scientists and Institutional Transformation: Patterns of Invention and Innovation in the Formation of the Biotechnology Industry. 'Proceedings of the National Academy of Sciences.' 93, pp.12709-12716.
138. Jensen, R. A., Thursby, J. G., and Thursby, M. C. (2003) Disclosure and Licensing of University Inventions: 'The Best We Can Do with the S**t We Get to Work With.' 'International Journal of Industrial Organization.' 21 (9), pp.1271-1300; Thursby, J. G, and Thursby, M. C. (2003) Industry/University Licensing: Characteristics, Concerns and Issues from the Perspective of the Buyer. 'The Journal of Technology Transfer.' 28 (3-4), pp.207-13.
139. Kleyn, D., Atun, R., and Kitney, R. (2006) Partnerships and Innovation in the Life Sciences. Discussion Paper 8. In Atun, R. (ed.) 'Innovation in Life Sciences: A Multidisciplinary Perspective.' London: Tanaka Business School, Imperial College London.
140. Andrews, L., Paradise, J., Holbrook, T., and Bochneak, D. (2006), When Patents Threaten Science. 'Science.' 314, pp.1395-1396.

4. Innovation is hidden because R&D and patents do not capture broader investments in innovation, especially in a rapidly changing industry

4.1 Raw R&D counts do not translate directly to firm productivity or success

In general, there is a positive relationship between the number of patents owned by a pharmaceutical firm and the number of drugs it ultimately launches. However, firms vary in their efficacy at drug development; for instance, a firm may generate numerous patents (because it provides incentives for researchers to patent as much as possible, or because they are located in countries that tend to grant high levels of patents), but may not launch many new drugs as a result of poor management of clinical trials. (Productivity is also challenging to measure in a sector where regulatory bodies have significant influence on which products reach the market and the price that can be charged for them.)

Investments in stronger capabilities in these areas are an example of a Type I hidden innovation – a complementary investment in technological innovation. It is why narrow measures such as levels of R&D investment, or equally the number of patents generated, are often insufficient in capturing a firm's capacity for innovation.

Given that the innovation process in pharmaceuticals is actually far less linear than is often supposed, it is unwise to focus on one year's count of R&D investment compared to another to compare innovative capacity. Knowledge and assets investments from the past – or developed through strategic alliances and other collaborations – may assist a firm in developing new products and bringing them successfully to the market. This can also be seen to represent a Type III hidden innovation – the exploitation of largely existing technologies to support other forms of innovation.

4.2 The changing industry structure confuses traditional metrics

Innovations in organisational forms and business models represent a Type II hidden innovation. As suggested, these have been important for large firms in particular in adjusting to the changing nature of innovation in the pharmaceutical sector.

Changes in industry structure have also made it more difficult to rely on inputs and outputs such as R&D and patents, given the complex and overlapping network of collaborations and alliances. There can at once be both double-counting and under-counting of inputs and outputs. At present, there is little research on how the new industry structure compares to the old model of vertical integration in terms of total productivity.[141]

Furthermore, traditional R&D and patenting surveys can overlook the innovation taking place in smaller and newer biotechnology firms, especially if they do not conduct much R&D.[142]

4.3 R&D indicators do not include therapeutic and social benefit

An additional problem with raw counts of R&D and patents is that they do not incorporate measures of therapeutic and social benefit. As a result, they are problematic if used by policymakers to evaluate existing policy. The difficulty is in identifying the marginal impact of policy on the quality and social usefulness of the outputs of drug development, and not just on levels of R&D investment.

As the payers (the NHS in the UK) have looked for more evidence of a drug's social benefit, so the discipline of Health Economics has become more important to the sector. Assessing the impact that a new drug can have on society as a whole has become as important as its clinical efficacy in securing reimbursement.

5. Innovation could be better measured by more detailed surveys

5.1 A broader range of indicators can be used to evaluate sector-wide performance

The Pharmaceutical Industry Competitiveness Task Force (PICTF) developed a set of indicators for sector-wide competitiveness and performance.[143] These cover a diverse range of areas, from 'supply conditions' (such as the number of graduates with relevant science degrees, total hourly labour costs versus comparator countries, and of course R&D spend), through 'demand and regulatory conditions' (including pharmaceutical sales as a proportion of GDP, time for regulatory approval and from approval to launch), to 'industry outputs' (patents, UK firms' share in major markets, the trade balance and employment levels).

Similarly, a framework has been developed for comparing the performance of national

141. However, firms that are active in a broader range of diseases appear to have higher productivity than focused firms, see Cockburn, I., and Henderson, R. (2001) Scale and Scope in Drug Development: Unpacking the Advantages of Size in Pharmaceutical Research. 'Journal of Health Economics.' 20 (6), pp.1033-1057; Larger and more experienced firms seem best positioned to advance their projects particularly in phase 3 clinical trials.

142. Lhuillery, S., Raffo, J., and Carpentier, C. (2006) 'Investigating Data Sources for Biotech Firms Identification.' OECD Workshop on Biotechnology Outputs and Impacts. Paris 11th December. Lausanne/Paris/Paris: EPFL, CEMI/CEPN, Université Paris Nord/INPI, Paris.

143. PICTF was a joint government and industry task force established in 2000 to look at ways of ensuring that the UK remained an attractive location for the pharmaceutical industry. See Pharmaceutical Industry Competitiveness Task Force (2006) 'Competitiveness and Performance Indicators 2005.' London: PICTF. Similarly, for the biopharmaceutical sub-sector, see bioProcessUK (2006) 'bioProcessUK Annual Review 2006.' London: bioProcessUK.

'biomedical innovation systems', covering a range of indicators in 'knowledge generation' (such as patents), 'knowledge diffusion' (including the number of biomedical technology alliances), and 'knowledge use', from early-stage (the market value of listed biomedical firms), to pre-product and post-product development (the number of drugs approved).[144] Such a scorecard of measures helps to produce a more rounded picture of national sector performance.

5.2 Individual firm performance in drug development can also be tracked

For many years, performance in drug development at firm level has been assessed primarily by tracking the speed and success at which a firm is able to advance drug candidates through each phase of development. The key indicators have been the numbers of drugs entering and exiting each phase, with a focus on ensuring that there is a large enough supply to ensure some success based on standard industry attrition rates. More recently, this has been joined by estimations of the potential value of a firm's portfolio.

In assessing inputs, finer measures of resources committed to R&D may be preferable to the R&D number reported by firms for accounting purposes, such as the number of PhD scientists on staff or hours spent on research activity.

In measuring outputs, simply counting new drug launches neglects the clinical performance or commercial success of different drugs. Despite the best efforts of many researchers, it has been difficult to find agreed measures of drug quality.[145] Furthermore, new drug counts ignore the incremental innovation to existing developed drugs, such as simplified dosing, improved delivery methods, or the discovery of new uses. This is an area requiring more work: these measurements can directly shape health policy (not least decisions about the purchase of a new drug).

6. Innovation could be improved by going beyond research funding to ensure a coordinated innovation policy for pharmaceuticals

6.1 New competitors are emerging

European pharmaceutical firms face an increasing challenge both from lower R&D costs in developing countries and a more competitive US.[146]

Developing countries are increasingly being used for R&D activities, especially through the use of contract research organisations (CROs), particularly in Eastern Europe. These CROs benefit from more than low-cost patient reimbursement. For example, patients in the region tend to be less medicated, reducing the risk of patients using competing medications and compromising the integrity of data.

Some rapidly developing countries are emerging as major centres of R&D. The Indian pharmaceuticals sector is developing strongly, through greater involvement by multinationals as well as the growth of indigenous firms. India now represents 13 per cent of the global industry by value and its drug exports have been growing by 30 per cent a year.[147] The Indian government estimates that the sector has the potential to generate revenues of $22.4 billion in drug formulation by 2010.[148] Some countries have a highly focused approach to developing strengths, for example, the biomedical sciences sector in Singapore.

6.2 Policy has focused on supporting research in new fields

Clearly, then, public support for research is important. However, in the UK, specific support has been relatively narrowly focused.

A national strategy for the bioscience sector was published at the end of 2003 based on the work of the Bioscience Innovation and Growth Team (BIGT).[149] One of its main recommendations was to develop a public and regulatory environment supportive of innovation, as well as attract and retain a high quality scientific and managerial talent base, through two new programmes to support the interdisciplinary education essential to the bioscience sector. The BIGT also recommended the creation of a National Clinical Trials Agency (NCTA) to support excellence in clinical trials and clinical research within the NHS, and establishing a network of bioprocessing centres of excellence. Subsequently – though not as a result of the BIGT recommendations – two world-class Bio-processing Centres of Excellence have been established in Liverpool and Edinburgh. The BIGT report also led to the establishment of bioProcessUK, a Knowledge Transfer Network.

Furthermore, the Bio-processing Research Industry Club (BRIC), established as a public-private collaboration between the Biotechnology and Biological Sciences Research Council, the Engineering and Physical

144. Rasmussen, B. (2005) 'Developing the Biomedical Industries in Canada and Australia: An Innovation Systems Approach.' Working Paper 24. Melbourne: Centre for Strategic Economic Studies, Victoria University of Technology.
145. For example, Dranove, D., and Meltzer, D. (1994) Do Important Drugs Reach the Market Sooner? 'RAND Journal of Economics.' 25, pp.402-422.
146. Charles River Associates (2004) 'Innovation in the Pharmaceutical Sector.' London: Charles River Associates.
147. KPMG (2006) 'The Indian Pharmaceutical Industry: Collaboration for Growth.' London: KPMG.
148. Department of Chemicals and Petrochemicals, Government of India (2005) 'Draft, National Pharmaceuticals Policy, 2006.' New Delhi: Department of Chemicals and Petrochemicals, Government of India.

Sciences Research Council, and the UK biopharmaceutical industry, awarded £5 million to nine projects in 2006 and £3.5 million to eight projects at seven universities in 2007, to support faster and more efficient development and manufacturing techniques.

There has also been strong support at the regional level from local authorities, Regional Development Agencies (RDAs) in England and the Scottish Executive and Welsh Assembly Government. The Welsh Development Agency encourages technology transfer through the Wales Innovation Relay Centre, which runs a Bioscience Brokerage Event that brings together academic institutions with commercial partners. Similarly, the RDAs have supported the growth of bioscience, and specific bodies such as the Eastern Region Biotechnology Initiative and the London Biotechnology Network, which support bioscience clusters.

Finally, the Cooksey report in 2006 recommended that the Medical Research Council should continue to support fundamental science, but that new government funding should go mainly to translational research aimed at developing treatments and creating wealth.[150] This was based on the view that there had been insufficient emphasis on turning achievements into new therapies and making these commercially successful.

6.3 Supporting incremental and continuous as well as radical innovation should be part of a more holistic policy for innovation in pharmaceuticals

However, the continued success of the UK pharmaceutical sector requires more than support for research. Given that incremental and continuous innovation is as important as breakthrough innovation, policy should try to ensure that it encourages and facilitates this broader innovation.[151] In particular, there needs to be a greater recognition of the importance of diffusion and adoption, which ultimately generate the returns to fund further investments in innovation.[152]

This suggests the need to shift away from a narrow emphasis on inputs such as the science base and outputs such as breakthrough products, toward a more balanced support for incremental innovation, adoption and diffusion.[153] Another way of putting this is that the focus of policy should shift from R&D inputs towards R&D productivity and returns to R&D, or from science funding towards business performance.[154]

This requires the better coordination of science funding with regulation and procurement. For example, healthcare policymakers understandably focus on short-term cost containment, but in doing so they risk undermining the widespread social and economic benefits that have long been predicted from the radical changes in scientific understanding. In particular, new technologies are likely to allow a small number of patients to be treated more effectively with personalised or specialised therapy, a very different approach from the blockbuster model of developing therapies that treat a large population – and from existing regulatory models of assessing the 'value' and safety of drugs.

The industry is concerned that Health Technology Assessment (HTA) methodologies might fail adequately to recognise the value of incremental advances, for example, so-called 'me-too' drugs. In the UK, NICE commissions HTA reports that evaluate 'technologies' (not only drugs but medical devices, procedures, screening and settings for care) through the synthesis or systematic review of scientific evidence. It is important that HTA is based on appropriate methods to establish a drug's broader value, so that further incentives for innovation are not undermined.[155] This is particularly important in the context of the debate over the reform of the Pharmaceutical Price Regulation Scheme (PPRS), which the UK government has announced it is renegotiating earlier than its previously scheduled date for renewal in 2010.[156]

6.4 The UK also needs to do more to develop interdisciplinary skills

Given how the sector is changing, stronger and more widespread interdisciplinary skills and knowledge are crucial. Pharmaceutical workers need an understanding across the manufacturing chain, 'from the gene to the product'. They must also understand the relationship between a range of scientific disciplines and the business implications of the interplay between those disciplines. In addition, the ability of physicians to work across a wide range of scientific fields at 'the bench and bedside' is critical to continuous innovation.[157]

For example, it would be pointless to develop a therapy that was not amenable to large-scale manufacturing or where the manufacturing or formulation costs were prohibitive. And yet, the formulation of biopharmaceuticals is not usually covered specifically in mainstream education (university pharmacy departments still tend to focus on small molecule

149. The Bioscience Innovation and Growth Team (BIGT) was established in 2003 by the then Department of Trade and Industry (DTI), the Department of Health and the BIA. The BIGT consisted of leading figures from the bioscience industry, financial institutions, universities, research bodies and government. See Bioscience Innovation and Growth Team (2003) 'BioScience 2015 – Improving National Health, Increasing National Wealth.' London: BioIndustry Association/ Department of Trade and Industry/Department of Health.
150. The review led by Sir David Cooksey was established in March 2006 to examine the best institutional arrangements for the new single fund for health research announced in the Budget. Cooksey, D. (2006) 'A Review of UK Health Research Funding.' London: HM Treasury.
151. Sheridan, D. (2006) Development and Innovation in Cardiovascular Medicine. Discussion Paper 3. In Atun, R. (ed.) 'Innovation in Life Sciences: A Multidisciplinary Perspective.' London: Tanaka Business School, Imperial College London.
152. Attridge, J. (2006) Innovation Models in the Biopharmaceuticals Sector. Discussion Paper 2. In Atun, R. (ed.) 'Innovation in Life Sciences: A Multidisciplinary Perspective.' London: Tanaka Business School, Imperial College London.
153. Attridge, J. (2006) Innovation Models in the Biopharmaceuticals Sector. Discussion Paper 2. In Atun, R. (ed.) 'Innovation in Life Sciences: A Multidisciplinary Perspective.' London: Tanaka Business School, Imperial College London.
154. As argued by Messinis, G. (2004) 'R&D Price Inflation, Real BERD and Innovation: Pharmaceuticals, OECD 1980-2000.' Working Paper 18. Melbourne: Centre for Strategic Economic Studies, Victoria University of Technology.
155. Von der Schulenburg, J.-M. G. (2006) The Regulatory Environment for Pharmaceutical Innovation in Europe. Discussion Paper 6. In Atun, R. (ed.) 'Innovation in Life Sciences: A Multidisciplinary Perspective.' London: Tanaka Business School, Imperial College London.

pharmaceuticals). There is also very limited postgraduate research activity using industrially relevant models; as a consequence, it is rare to find anyone with specific qualifications or skills in the formulation of biopharmaceuticals at any level of a firm.[158]

New and emerging fields are very likely to increase the demand for a cross-disciplinary approach. For example, 'Systems Biology' should have a profound effect on drug development.[159] This groundbreaking scientific approach seeks to understand how all the individual components of a biological system interact in time and space to determine the system's functioning. It allows insight into the large amount of data from molecular biology and genomic research, integrated with an understanding of physiology, to model the complex function of cells, organs and whole organisms, bringing with it the potential to improve our knowledge of health and disease. Yet in general, universities have been slow to respond to such changes in the traditional boundaries of subjects.[160]

It might also be that universities should include officially accredited courses on Pharmaceutical R&D project management and alliance management as part of a healthcare curriculum. This might also be achieved through an internationally recognised additional module to a PRINCE2 or similar project management qualification.

6.5 Internationally, there should be innovative policy for neglected diseases

The under-supply of development in drugs for diseases that primarily afflict poorer countries has led to a novel and high profile policy proposal by Michael Kremer of Harvard University. Kremer proposes 'advance commitments', or promises to purchase a given quantity of a treatment for diseases like malaria or tuberculosis that otherwise attract very little investment.[161] This policy is an example of a 'pull' approach to innovation, which contrasts with the 'push' of sponsoring or subsidising R&D costs in targeted areas. 'Pull' refers to the expected payoff from an innovation; 'push' affects the cost of research. Expected returns to R&D depend on both the payoffs and the costs. The advance commitments, which would be made by governments of relatively wealthy countries or philanthropic organisations, would guarantee profits to firms that successfully innovate.

156. In February 2007, the Office of Fair Trading (OFT) recommended that the PPRS be replaced with a 'patient-focused value-based' pricing scheme, in which the prices paid for drugs reflects the therapeutic benefits for patients. See Office of Fair Trading (2007) 'The Pharmaceutical Price Regulation Scheme.' London: OFT.
157. Sheridan, D. (2006) Development and Innovation in Cardiovascular Medicine. Discussion Paper 3. In Atun, R. (ed.) 'Innovation in Life Sciences: A Multidisciplinary Perspective.' London: Tanaka Business School, Imperial College London.
158. BioIndustry Association/bioProcessUK (2005) 'The Challenges of Improving the Formulation and Delivery of Biopharmaceuticals.' London: BIA/bioProcessUK.
159. Academy of Medical Sciences/Royal Academy of Engineering (2007) 'Systems Biology: A Vision for Engineering and Medicine.' London: Academy of Medical Sciences/Royal Academy of Engineering.
160. The Engineering and Physical Sciences Research Council's Life Sciences Interface programme has established 12 Doctoral Training Centres that offer an interdisciplinary approach to postgraduate training. Given that as noted modern medicine and biology present challenges that require input from mathematicians, physicists, chemists and engineers, these Centres, based at universities, seek to supply appropriately trained people who can work at the interface between engineering and the physical sciences and the life sciences. However, each Centre has been funded to support only up to five annual cohorts of up to ten students.
161. Kremer, M., Glennerster, R., and Williams, H. (2006) Creating Markets for Vaccines. 'Innovations.' 1 (1), pp.67-79.

Appendix B: Aerospace

Innovation through technological development and partnerships with an increasing role for hidden innovation in business processes and services

1. Aerospace is a comparatively small but very high-value-added part of the UK economy

The aerospace industry involves the manufacture of aircraft and their components as well as their maintenance, repair and overhaul (MRO).

The UK has the second largest aerospace industry in the world in terms of value added.[162] Turnover was £19.81 billion in 2006.[163] The sector accounts for 0.6 per cent of UK gross value added (GVA) or £5.5 billion – around 4 per cent of the value added of the UK's manufacturing industry as a whole.[164] The indirect contribution made through the sector's wider supply chains raises its overall contribution to 1.2 per cent of GVA.[165]

The UK sector has increased its global market share from 9 per cent to 13 per cent since 1995.[166] The industry is one of the UK's largest exporters; it exports 63 per cent of its total sales, with over £12.43 billion of export sales in 2006, contributing £1.54 billion surplus to the balance of trade.[167] There has been a consistently positive aerospace trade balance in the past two decades.

The UK sector comprises over 700 companies including 400 MRO sites. It directly employs over 124,000 people (an increase of more than a quarter since 1995), and supports a total of 276,000 jobs across the UK economy.[168] Over half of all establishments employ fewer than five people, but over two-thirds of total employment is found on sites with more than 500 people. It is estimated that there may be up to 2,500 aerospace SMEs in the UK.[169]

In some regions, aerospace forms the centre of high-technology clusters of design and manufacture, with a large number of SMEs clustered around major manufacturer-assemblers (called 'primes') and larger suppliers. Examples include the aerospace industry based around Airbus UK (North Wales), BAE Systems and Rolls-Royce in the North West of England, which accounts for 54 per cent of the high-technology jobs in the region.[170] The Midlands has a significant aerospace cluster which directly generates more than 45,000 jobs, including Rolls-Royce in Derby, Smiths in Wolverhampton and Goodrich in Birmingham and Wolverhampton.[171] There is also a significant aerospace cluster in the South West with Rolls-Royce and Airbus UK in Bristol, and AgustaWestlands in Yeovil; the South West Regional Development Agency is also the lead region for aerospace.

There are currently two prime manufacturers of large civil aircraft (LCAs): Boeing (which is American) and Airbus (which is European). Airbus UK has sites in Filton, near Bristol, and Broughton, North Wales.[172]

Worldwide, there are three prime manufacturers of civil aeroengines: General Electric (GE), Pratt & Whitney (both American) and Rolls-Royce (British), all of which manufacture engines for both civil and military aircraft. Rolls-Royce is the world's second largest commercial aeroengine manufacturer, with its main plants in the UK in Derby, Bristol, Barnoldswick in Lancashire, and Ansty in Leicestershire.

There are also a number of manufacturers of airframes and engines for smaller regional aircraft. The Canadian company Bombardier has a plant in Belfast (formerly Short Brothers). Bombardier Aerospace, Belfast products include

162. Although the two main European aerospace industries in the UK and France are of roughly similar size in terms of turnover; see House of Commons Trade and Industry Committee (2005) 'The UK Aerospace Industry, Fifteenth Report of Session 2004–05.' London: The Stationery Office.
163. Society of British Aerospace Companies (2007) 'UK Aerospace Industry Survey 2007.' London: SBAC.
164. House of Commons Trade and Industry Committee (2005) 'The UK Aerospace Industry, Fifteenth Report of Session 2004–05.' London: The Stationery Office.
165. According to SBAC, recorded in House of Commons Trade and Industry Committee (2005) 'The UK Aerospace Industry, Fifteenth Report of Session 2004–05.' London: The Stationery Office.
166. Department of Trade and Industry (2004) 'National Aerospace Technology Strategy, Implementation Report.' London: DTI.
167. Society of British Aerospace Companies (2007) 'UK Aerospace Industry Survey 2007.' London: SBAC.
168. House of Commons Trade and Industry Committee (2005) 'The UK Aerospace Industry, Fifteenth Report of Session 2004–05.' London: The Stationery Office.
169. Society of British Aerospace Companies (2007) 'UK Aerospace Industry Survey 2007.' London: SBAC.
170. House of Commons Trade and Industry Committee (2005) 'The UK Aerospace Industry, Fifteenth Report of Session 2004–05.' London: The Stationery Office.
171. Midlands Aerospace Alliance/East Midlands Development Agency/Advantage West Midlands (2003) 'Midlands Aerospace Cluster Strategy.' Melton Mowbray/Nottingham/Birmingham: Midlands Aerospace Alliance/East Midlands Development Agency/Advantage West Midlands.
172. GKN has been selected by Airbus as the preferred partner for the acquisition of the Filton site.

aircraft components and engine nacelles for its parent company and for Boeing, Rolls-Royce Deutschland, GE and Pratt & Whitney

Major suppliers include Smiths and GKN. Smiths Group is a world leader in electronic systems for civil and military aircraft. It employs 5,500 people in 18 sites around the UK. Smiths Aerospace was acquired by GE Aviation in 2007 and is now named GE Aviation Systems. GKN is a large global first tier supplier, including in aerospace, with technology leadership in advanced aerostructures including composite structures.[173] GKN Aerospace has design centres with over 600 design engineers in Weston-Super-Mare and Cowes in the UK, and Nashville, Tennessee, and Melbourne, Australia.

2. Innovation in aerospace is increasingly distributed via complex risk-sharing partnerships but is also embracing new business models and processes

2.1 Traditional innovation – mainly iterative development – remains crucial but is becoming increasingly distributed

2.1.1 Traditional innovation is a mix of applied research and iterative development

Traditional innovation in aerospace is typically centred on high-cost and high-risk research-based product development programmes, with long development and payback cycles.[174] This innovation results in a change in the physical structure of an aircraft or the components within it. These cycles are often determined by the relatively rare opportunities offered by major new large civil aircraft development programmes, such as the Airbus A380 and the Boeing 787.

Aerospace invests heavily in R&D. Business expenditure on R&D (including defence) was £2.54 billion in 2006 (an R&D intensity of 12.7 per cent), the second largest after pharmaceuticals.[175] R&D in aerospace has more than doubled in real terms since 1997, compared with a rise of 12 per cent in manufacturing as a whole. The sector spends 11.4 per cent of all R&D in the UK.[176] Rolls-Royce's R&D intensity in 2006 was 5.7 per cent, Smiths 5.1 per cent, and GKN 2.1 per cent.[177]

Even so, the innovation process is not linear. Rather, it is cyclical and interactive, and involves a series of more modest gains made primarily through incremental improvements dictated by the manufacturing cycle, not the 'big breakthrough' of science-push models.[178] In combination, however, incremental

Rolls-Royce Trent 1000 engine

The Rolls-Royce Trent 1000 is the launch engine for all three versions of the new Boeing 787 aircraft. It represents the latest in a comparatively low-risk policy of continuously building on proven advanced technology, in this case the Trent turbofan 'family' of engines.[179]

The Trent family are all derived from the RB211 engine, originally developed for the Lockheed L-1011 (TriStar), which entered service in 1972. In the late-1980s, Rolls-Royce decided that to succeed in the large engine market of the future, it would have to offer engines for every large civil aircraft. In view of the enormous development costs required to bring a new engine to market, the only way to do this would be to have a family of engines based on a common core.

The three-shaft design of the RB211 was an ideal basis for the new family, as it provided flexibility. The three-shaft system means that the large diameter fan is isolated on its own shaft. This allows the rest of the engine to be scaled in a variety of proportions to give different bypass and pressure ratios to suit the specific aircraft on which the engine is installed.

The first Trent in service was the Trent 700, which began commercial flights on the Airbus A330 in 1995. Trent 1000 innovations include power extraction from the intermediate pressure system to produce the required electricity via a gearbox-mounted generator. This solution, unique to three-shaft engines, will result in lower fuel burn. The Trent 1000 also features the latest 'intelligent engine controls' – including new-generation predictive maintenance tools (see section 2.2.1.3).

173. Composites are combined materials which can ensure lower-weight but higher strength and stiffness structures compared to traditional materials (in the case of aerospace in particular, carbon fibre reinforced plastics in place of aluminium and titanium).
174. For example, Jackson, I. (2004) The Future of the Defence Firm: The Case of the UK Aerospace Industry. 'Defence and Peace Economics.' 15 (6). pp.519-534.
175. Society of British Aerospace Companies (2007) 'UK Aerospace Industry Survey 2007.' London: SBAC.
176. Based on a study of the top 850 UK spenders on R&D, Department for Innovation, Universities and Skills/Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
177. Ibid.
178. Royal Aeronautical Society (2007) 'Trade and Industry Committee, Creating a Higher-value-Added Economy, A Submission from the Royal Aeronautical Society 24th October 2007.' London: RAS.
179. Rolls-Royce (2006) 'Rolls-Royce Runs First Trent 1000 on Schedule.' Derby: Rolls-Royce.

innovation has resulted in significant changes in the industry and its products.

The timescale for the research and implementation of new products can be twenty years. For example, Rolls-Royce's R&D 'Vision' programme has three broad time bands: up to five years (technologies available 'off-the-shelf'); around ten years (technologies currently at the validation stage); and up to twenty years and beyond (technologies emerging or as yet unproven, the focus for the firm's research base). Similarly, Airbus began talks with major international carriers about requirements for a 'super-jumbo' passenger aircraft in 1991, but the first A380 plane entered service only at the end of 2007.

Some of the most important recent and ongoing traditional innovation has been in areas such as the development of aeroengines capable of increased fuel efficiency and reduced emissions, the use of composite materials in aerostructures, and increased use of electronic systems to replace hydraulic, mechanical and pneumatic systems.

2.1.2 Traditional innovation is becoming increasingly distributed between firms, suppliers and universities

2.1.2.1 Suppliers are being given an increasing role in innovation

Every prime manufacturer obtains components from across the world; all have collaborative arrangements with firms in other countries. Aerospace has extensive and complex supplier networks, especially between airframe manufacturers and first-tier suppliers who often share the risk of innovation.

While these supplier networks are not new, these processes have been accelerating and deepening over recent years. Boeing now outsources 80 per cent of work.[180] Airbus's intention is to outsource around 50 per cent of the aerostructure work for the new A350 XWB, up from its current rate of 25 per cent.[181]

This is part of a long-term trend towards globalised production. A major driver of this trend is gaining access to markets, particularly in Asia.[183] In addition, aircraft are traded in US dollars, a major advantage for US manufacturers. European firms have been moving to globalised production to reduce their

180. House of Commons Trade and Industry Committee (2007) 'Recent Developments with Airbus, Ninth Report of Session 2006–07, Volume I.' London: The Stationery Office.

181. Ibid.

182. Ibid.

Airbus wings

Wing design is crucial in improving the performance of aircraft. Throughout the lifetime of Airbus, the UK has had overall responsibility for the wings for all Airbus aircraft. The UK content of Airbus wing production is about 70 per cent. This covers a range of activities, including design and development. The UK has been named 'Airbus Centre of Excellence for Wing and Pylon' (pylons are the mountings which affix the engine to the wing). This means that Airbus in the UK has supervisory responsibility for any part of the wing built anywhere in the world.

Broughton in north Wales is responsible for large component manufacture (such as wing skins and spars) and sub-assembly, wing final assembly and equipping. It is widely acknowledged to be the world's leading manufacturer of large civil aircraft wings.[182] Filton near Bristol is in charge of engineering research, technology and wing design including landing gear and fuel systems, as well as some component manufacture.

The UK has led the development of new approaches for the A380 wing. These include new aerodynamic testing methods (such as combined analysis of components), structural optimisation techniques (for example, using carbon fibre reinforced plastic to attach the trailing edge flaps to the main wing structure), and materials (such as composite primary structures in the wingbox, which carries the airloads into the fuselage). In addition, patented load reduction techniques were developed to enable the fuel system to control the loads actively on the wing in all phases of flight, thereby reducing stresses on the wing and saving weight, continuing a tradition started in the UK with Concorde. Securing a risk-sharing partner for the Filton plant will be crucial to the further transition from metallic to carbon fibre composite design and manufacturing technology.

disadvantage (a process called 'dollarisation'). For example, for the first time, Rolls-Royce is to assemble some of its engines for wide-body passenger aircraft outside of the UK, by building test and assembly plants in Singapore and in the US.

This globalisation is also reflected in the location of R&D. In 2006 R&D spent overseas by UK aerospace firms grew by 5.5 per cent and accounted for 16 per cent of total UK aerospace R&D.[184] There has been an increase in overseas R&D from £140 million in 1996 to £470 million in 2006.[185] Sixty per cent of Rolls-Royce's R&D investment and 40 per cent of new product development spending over the past five years has been outside the UK.[186] But these headline figures do not provide the whole picture of how innovation is increasingly distributed.

For a start, innovation is increasingly being pushed down supply chains. First and second tier suppliers are being given increasing responsibility for traditional innovation, in areas such as R&D, engineering and design, tooling, testing, sub-system integration and pre-assembly (installing systems such as hydraulics, electronics and controls).

This is most prominent in the case of the Boeing 787. In the past, Boeing has designed aircraft in-house, then passed blueprints for parts or whole sections to manufacturing partners. For its new aircraft, Boeing is turning this process on its head, designing the 787 in collaboration with partners. In effect, 6,000 engineers around the world are jointly designing and engineering the aircraft.[187]

This trend puts more pressure on the innovative capacity of suppliers, and has encouraged a rationalisation of supply chains and a movement towards larger suppliers, with primes focusing on procuring from far fewer, more capable 'talented suppliers'.[188] Even then, some suppliers are said to be struggling with the new demands of the more delegated innovation process. Delays in the delivery of the Boeing 787 are said to be due to suppliers failing to cope with the extent of their new responsibilities.[189] In one case, Boeing has had to buy out a major 787 structures partner, Vought, in the US because of the impacts that Vought's underperformance was having on the 787 programme overall.

Second, there are complex and overlapping collaborations between firms. For example, International Aeroengines is a multinational company jointly owned by Pratt & Whitney, Rolls-Royce, Japanese Aeroengines Corporation, and MTU Aeroengines (from Germany). Each partner contributes an individual module to the V2500 engine, an arrangement that enables each partner's engineers to focus their attention on continuously refining that module.

Such extended innovation has been facilitated by using Product Lifecycle Management (PLM) software and 'Innovation Technology' (IvT). PLM software manages every aspect of a product's life cycle, from concept and design, to manufacturing, maintenance once the product is sold, and through to its eventual retirement. IvT includes eScience (computer-intensive science that is conducted through highly distributed networks), virtual reality, simulation and modelling techniques, and rapid prototyping.[190]

For the 787, Boeing is using PLM software to reduce the four-five year time frame from concept to production by one year, or about 20-25 per cent, and reduce development costs by 20 per cent, or from $12 billion to $10 billion.[191] Its distributed approach to innovation relies on a 16 terabyte data master data repository for all design and engineering information located in Bellevue, Washington state.

However, a greater reliance on PLM and virtual models and tests (as opposed to costly real-world mock-ups or trials) can cause problems. The delay to the production of the Airbus A380 has been attributed to incompatibilities in the design software being used by teams in different countries. This has cost the company an estimated $6 billion.[192]

2.1.2.2 Universities are increasingly serving as research centres for firms

Traditionally, research-intensive companies have conducted research in-house, using their own facilities and regularly recruiting graduates and PhDs. University-industry collaboration is not new in aerospace, but some companies have been particularly active in establishing links. For example, Rolls-Royce, as part of an overall policy of 'capability acquisition', has outsourced much R&D to universities, in particular by establishing (currently 29) University Technology Centres (UTCs) in the UK and across the world.

Similarly, the Advanced Manufacturing Research Centre (AMRC) at the University of Sheffield is a £45 million partnership with

183. In terms of aircraft delivery value (as opposed to numbers of aircraft), Asia/Pacific is forecast to become comfortably the largest market, with a value of nearly $1 trillion, due to the large quantity of twin-aisle airliners expected to be delivered into the region compared to the North American and European markets. See Rolls-Royce (2006) 'Market Outlook 2006-2025.' Derby: Rolls-Royce.
184. Society of British Aerospace Companies (2007) 'UK Aerospace Industry Survey 2007.' London: SBAC.
185. Ibid.
186. Rolls-Royce (2006) 'Introduction, Rolls-Royce is a Global Company Providing Power for Use on Land, at Sea and in the Air.' Derby: Rolls-Royce.
187. Partners include Alenia Aeronautica of Italy (main fuselage), Japan's Mitsubishi Heavy Industries (wings), Fuji Heavy Industries (centre wingbox) and Kawasaki Heavy Industries (part of the fuselage as well as the wings and landing gear), and Goodrich Aerostructures of Chula Vista, California (nacelles and thrust reversers).
188. Smith, D. J. and Tranfield, D. (2005) Talented Suppliers? Strategic Change and Innovation in the UK Aerospace Industry. 'R&D Management.' 35 (1), pp.37-49.
189. See Bailey, J., and Clark, N. (2008) Parts Didn't Click Together for Boeing Jet. 'New York Times.' 17th January.
190. Gann, D. and Dodgson, M. (2007) 'Innovation Technology: How New Technologies are Changing the Way We Innovate.' London: NESTA.
191. Bartholomew, D. (2007) The Promise and Peril of PLM PLM: Boeing's Dream, Airbus' Nightmare. 'Baseline.' 2nd May.
192. Ibid.

Boeing that builds on the research within the University's faculty of engineering. The Centre received initial government funding of nearly £6 million from the then DTI and additional support from Yorkshire Forward RDA and the European Union regional development fund.

Universities tend to be particularly involved in emerging technologies. For example, the Environmentally Friendly Engine (EFE) is a collaborative programme for a new generation of gas turbine engines, to contribute to the performance targets set by the Advisory Council for Aeronautics Research in Europe (ACARE).[193] The programme involves 11 partners, five from industry and six from academia (and is one of the Aerospace Technology Validation Programmes under the National Aerospace Technology Strategy, see 3.5).[194]

2.1.2.3 Aerospace also benefits from technology transfer from other sectors

Given the complexity of aircraft systems, there are significant technology flows to and from other sectors, including defence, marine, energy, ICT and software, and materials sciences. In particular, there are many examples of technology transfer between civil and defence aerospace. For example, Boeing has benefited from research into composite wings by NASA, and advances in composite fuselages are derived from Boeing's military programmes including the B2 stealth bomber and the V22 Osprey joint service tiltrotor aircraft.

2.2 'New' forms of organisational and business process innovation are becoming more important in aerospace

2.2.1 Major firms are moving to become systems integrators

Hidden innovation in aerospace focuses on changes in organisation or service delivery (Type II hidden innovation).

One prominent example is systems integration. This refers to integrating components, skill and knowledge from other firms, including suppliers, to deliver ever more complex products, services and systems.

Boeing and Airbus have become systems integrators as they have outsourced more work. Their strategy is to retain their position at the highest value-generating point in the supply chain, with close relationships with their customers. But this strategy carries some risk: the technical skills and intelligence necessary for integrating systems effectively is lost through the very outsourcing that puts a greater emphasis on systems integration in the first place.[195]

2.2.2 Lean manufacturing

More generally, Lean manufacturing is probably the most important organisational innovation for aerospace firm competitiveness. Efficiency and competitiveness in production processes have become as crucial to aerospace firms' survival as technology and product performance. The importance of Lean is strongly related to an increasing pressure on costs (see 3.1).

Lean was first introduced in the automotive industry (see Appendix F) and subsequently extended to aerospace as well as other manufacturing sectors. It focuses on the elimination or reduction of waste in various forms, and involves, inter alia, through-life management, inventory, cycle and lead time reductions, and quality management.[196]

Lean can lead to a 20-40 per cent improvement in productivity in aerospace SMEs, but UK firms have lagged behind their US rivals in implementing Lean processes.[197] To address these performance challenges, a UK Lean Aerospace Initiative (UK-LAI) was initiated in 1998, jointly funded by the EPSRC and SBAC, and involves Warwick, Nottingham, Bath and Cranfield Universities.[198] In addition, the sector has developed SC21, the Supply Chains of the 21st Century programme.

2.2.3 Through-life management services

Pressure on costs in both the civil and military markets has left little or no profit from original equipment and parts sales (see 3.1).[199] This has led to new business models focussing on aftermarket and long-term service contracts.

3. Aerospace innovation is determined by pressures on costs and environmental impact

3.1 Costs and efficiency are the main drivers of innovation

The aerospace and air travel industries can be highly cyclical, depending on the global economy. Before 2001, the civil aerospace sector was operating at full capacity with record production levels. Since 2001, a number of events had caused a slowdown in passenger air travel: the impact of the global economic slowdown; the terrorist attacks on the US on 11th September 2001; continued uncertainty

193. These are to achieve by 2020: a 50 per cent cut in CO_2 emissions per passenger-km, associated with a 50 per cent reduction in fuel consumption; an 80 per cent reduction in NO_x (nitrogen oxide) emissions; a reduction in perceived noise levels to half their current average value; and a reduction in engine weight.

194. Partners in the research consortium are: Rolls-Royce; Goodrich Corporation; Bombardier Aerospace (Belfast); HS Marston Aerospace (Wolverhampton); Unison Engine Components (Burnley); and the following universities: Birmingham; Cambridge; Loughborough; Oxford; Sheffield; and Queen's Belfast.

195. A point made in Newhouse, J. (2007) 'Boeing Versus Airbus.' New York: Knopf.

196. Lean has been summarised in five principles: precise valuation of specific products; identification of the value stream for each product; ensuring that value flows without interruptions; ensuring that that value is pulled from the producer; and that perfection is pursued. See Womack, J. P., and Jones, D. T. (1996) 'Lean Thinking, Banish Waste and Create Wealth in Your Corporation.' London: Simon and Schuster.

197. Aerospace Innovation and Growth Team (2003) 'An Independent Report on the Future of the UK Aerospace Industry.' London: Department of Trade and Industry.

198. A US precursor was launched in 1993 as a partnership between the US Air Force, Massachusetts Institute of Technology, labour unions, and aerospace businesses.

199. Ward, Y. and Graves, A. (2005) 'Through-Life Management: The Provision of Integrated Customer Solutions by Aerospace manufacturers.' University of Bath School of Management Working Paper Series, 2005.15.

in the Middle East, including the conflicts in Afghanistan and Iraq; and the SARS crisis in Asia.

These cycles exacerbated the already often brutal economics of the air travel industry. Several major airlines have aging fleets and have lost over $10 billion each year for the past five years, making it difficult to invest in new aircraft. This has driven the growth of leasing; now more than 35 per cent of aircraft are leased rather than owned by operators, making leasing companies very important customers for aircraft.

These conditions can drive innovation. Incentives to reduce costs are particularly strong. For airlines, this means more efficient (cheaper to run) aircraft. For manufacturers, it means Lean manufacturing, increased outsourcing, risk-sharing partnerships, supply chain management, and new business models such as extended services.

3.2 Innovation is often inhibited by risk reduction and conservatism

At the same time, the emphasis on costs and reducing risk can lead to an understandable conservatism in product design and manufacture. This is a sector already quite conservative in its dominance by product engineering rather than customer needs. For example, it can be slow to adopt new engineering techniques, easily replicable designs or more flexible aircraft for customers. Low-cost airlines in particular require simplicity, lower costs and lower environmental impact.

This disconnect between manufacturers and customers can also occur at a macro-level. Over the last two decades, Airbus and Boeing have persisted in building larger, longer-range, more technically advanced aircraft, as opposed to developing a smaller more flexible aircraft for higher volume single aisle markets. Yet neither Airbus nor Boeing has designed a new 200 seat single aisle aircraft for over twenty five years, despite the fact that this type of aircraft accounts for nearly 50 per cent of all civil aircraft sold. This may present an opening for new competition from Asia.

3.3 Reducing environmental impact has become increasingly important

With the upward trend in fuel prices and environmental concerns, there is strong demand for lighter aircraft, prompting the increased use of composites in airframes and components, and more efficient engines. The industry states that it has delivered a 50 per cent improvement in fuel efficiency in the last 30 years, and a 75 per cent reduction in noise

200. Rolls-Royce (2008) 'Preliminary Results 2007.' Derby: Rolls-Royce.

Rolls-Royce TotalCare

TotalCare comprises a suite of aero-engine aftermarket (or after-sale) services. Such services have expanded rapidly in the last five years, such that they now contribute 63 per cent of Rolls-Royce's civil aerospace revenues (55 per cent of total Group revenue, up from 30 per cent in 1991).[200] More than 55 per cent of Rolls-Royce's modern engine fleet is covered by TotalCare or similar service agreements, generating revenues of more than $2.6 billion (more than £4.2 billion across the sectors the firm operates in). Rolls-Royce's investment in developing and maintaining these services is equal to its investment in research and technology programmes.

Rolls-Royce provides maintenance and support for airline customers over the lifetime of the engine, typically more than 20 years. The company charges a fixed price per flying-hour that the engine is in use, thereby accepting much of the financial risk of malfunction or breakdown; this gives the firm a greater vested interest in the long-term reliability of its products.

The service innovation of TotalCare is also dependent on technical advances, for example engine health monitoring (EHM). This provides the basis for predictive maintenance and fleet planning that forms an integral part of the package. 24/7 Operations Rooms, located in Derby, Bristol and Dahlewitz in Germany, support a fleet of over 3,000 engines that are continuously monitored, collating technical data streamed direct from the aircraft in flight via live satellite feeds.

As part of its 20-year global industry outlook, Rolls-Royce forecasts estimate a total market opportunity worth $500 billion for the provision of product-related aftermarket services (compared to $600 billion in engine sales).[201]

nuisance.[202] But the issue of the environmental impact of air travel is receiving increased public and media attention.

Tighter EU regulations and the proposal to include aviation CO2 emissions in the European Emissions Trading Scheme (ETS) mean that there is an ongoing need to reduce CO2 and NOx emissions. Research on lower-emission aeroengine design is progressing in several directions, but continued reliance on fossil fuels seems inevitable for the foreseeable future (alternative potential sources are ruled out on energy intensity grounds). Greater environmental sustainability will also demand more 'technology insertion', reducing the environmental impact of older but still operating aircraft.

However, the current evolution of existing technologies is reaching its limit, and more radical designs of aeroengines will be needed to achieve environmental goals. There is research underway exploring how to reduce aircraft noise, from aircraft design (shielding engines within the structure) to new operations. A transatlantic collaboration between Cambridge University and MIT is working on a silent aircraft project, which has already suggested significant improvements.[203]

3.4 Safety and reliability have always been key concerns

A relatively unusual aspect of aerospace innovation is the huge costs at the later stages of development for validation and safety testing. The long-term operation of engines adds to the importance of this development stage; maintenance firms continue to service engines that were originally designed and manufactured decades ago.

3.5 Publicly-supported strategic research initiatives are important for long-term technological innovation

Strategic aerospace R&D and innovation in the UK has been strongly influenced by the Aerospace Innovation and Growth Team (AeIGT), established in 2002 by the then DTI. The team comprised representatives from industry, government, academia and trade unions, with an overall remit of determining how to retain and improve the global competitiveness of the industry. Its subsequent report recommended a re-focusing of R&D on technologies in which the UK can lead the world, and strengthening project management and business processes in the sector.[204]

AeIGT also recommended the establishment of a National Aerospace Technology Strategy (NATS) as a partnership between industry, government and academia, to identify, research and validate 'key' and 'enabling' technologies.[205] More partnerships have been developed through Aerospace Innovation Networks (AINs) and Aerospace Technology Validation Programmes (ATVPs). AINs comprise networked research institutes and firms covering core research themes. ATVPs for the civil sector include powered wing, the environmentally friendly engine, and more electric aircraft.

3.6 Workforce skills are crucial

Aerospace is a particularly skill-intensive industry. However, there are identified skills gaps in both technical areas and in wider skills. The latter include systems thinking and engineering skills, project management, process excellence, teamwork, problem-solving techniques, Lean thinking and application, risk management, knowledge management, and business understanding and strategy.[206] Such skills would better support the implementation of process excellence throughout the value chain, and faster and Leaner product development processes.

4. Innovation is hidden because iterative development is not part of formal R&D and because organisational forms of innovation are not well captured in traditional indicators

4.1 Much traditional innovation in aerospace is iterative development rather than research

Much traditional innovation in aerospace is iterative development rather than research; one estimate suggests that the 'R' represents only 10-15 per cent on R&D.[207] Hence is it likely that much technological innovation is not captured in narrow measures of R&D (Type I hidden innovation).

For example, the use of composite materials in the Boeing 787 – comprising 50 per cent of the aircraft's weight – is based on years of basic scientific research into such materials.[208] But Boeing and its major suppliers have also had to learn on the job how to manufacture and tool such materials. The benefits of composites have grown as Boeing's engineers have gained more experience in production processes using these materials, sometimes in unexpected directions, even opening up new design possibilities. For

201. Rolls-Royce (2006) 'Market Outlook 2006-2025.' Derby: Rolls-Royce.
202. Society of British Aerospace Companies (2007) 'UK Aerospace Industry Survey 2007.' London: SBAC.
203. See http://silentaircraft.org
204. Aerospace Innovation and Growth Team (2003) 'An Independent Report on the Future of the UK Aerospace Industry.' London: Department of Trade and Industry.
205. Society of British Aerospace Companies / Department of Trade and Industry/Aerospace Innovation and Growth Team (2004) 'National Aerospace Technology Strategy.' London: SBAC/DTI/AeIGT.
206. As identified in the Sector Skills Agreement for the Aerospace, Automotive and Electronics sectors, completed in January 2006; see Sector Skills Council for Science, Engineering and Manufacturing Technologies (2006) 'SEMTA Sector Skills Agreement, Electronics, Automotive and Aerospace Industries.' London: SEMTA.
207. Royal Aeronautical Society (2007) 'Trade and Industry Committee, Creating a Higher-value-Added Economy, A Submission from the Royal Aeronautical Society 24th October 2007.' London: RAS.
208. Smock, S. (2007) 'Boeing 787 Dreamliner Represents Composites Revolution.' Design News. 4th June.

example, Boeing engineers discovered that composites are tougher than they initially imagined, and the firm has been able to guarantee customers that maintenance costs will be 30 per cent lower than for aluminium aircraft. This is a potentially bigger saving for customers than the 20 per cent reduction in fuel costs the 787 can deliver compared with other aircraft. The savings could be worth more than $3 billion over 20 years.[209]

Such 'practical research' often lies outside of formal R&D processes. But the development of efficient production processes for these materials is crucial to realising their potential benefits; in this case, unless composites can be manufactured properly, they will not produce the weight gains and so savings in fuel costs that airlines demand.

4.2 Organisational and business model forms of innovation are not currently captured well in traditional metrics

Innovation and learning is a whole organisation capacity, which even highly technologically advanced firms can struggle with.[210] Firms need to design effective organisational forms that ensure the rapid and widespread circulation of information (Type II hidden innovation).

Furthermore, levels of investment to develop service innovations such as Rolls-Royce's TotalCare and similar services are not recorded in surveys such as the Community Innovation Survey, or often in R&D metrics.

4.3 Aerospace also demonstrates the exploitation of largely existing technologies to support other forms of innovation

This can be seen in the way that advances in monitoring technologies have enabled real-time monitoring services such as that provided by Rolls-Royce's TotalCare, or the exploitation of PLM software to enable new, extended forms of collaboration. These are forms of Type III hidden innovation.

4.4 Small-scale and localised innovation is also important

As in other areas of engineering, there are small-scale problems in aerospace that are dealt with outside of formal R&D programmes; these efforts may not be captured in traditional metrics (Type IV hidden innovation). These could include day-to-day creative improvements in practice, use and adaptation of materials and tools or collaborative working arrangements.

5. Innovation could be better measured by investigating its contribution to productivity and to environmental performance

5.1 New measures should investigate the relationship between innovation and productivity, including hidden innovation

Some measures combine the effects of traditional and hidden innovations. Productivity measures, such as GVA per worker or total factor productivity are probably the most useful.

Labour productivity (GVA per worker) in the aerospace industry in the UK was estimated to be ahead of Japan and Spain in 2001, but behind its major competitors (US, Canada, France, Italy and Germany).[211] However, the UK may be catching up.[212]

Interestingly, UK R&D has increased, but not as fast as productivity. One explanation for the rapid growth in productivity in the late 1990s is that it was prompted by hidden innovations. This was indeed the period when organisational changes were becoming more common , including widespread merger and acquisition activity, greater supply-chain efficiency (including reductions in numbers of suppliers and increasing roles for those remaining), and increased use of outsourcing. This requires further investigation.

5.2 Other business performance outputs could also be used to track the impact of forms of hidden innovation

The UK Lean Aerospace Initiative (UK-LAI) has proposed the following metrics for improved competitiveness in aerospace:

- Customer acceptance/rejection rate (quality)
- Achievement of delivery schedules (customer satisfaction)
- Increased value added through waste elimination
- Employee training and development
- Stock turnover rate (inventory reduction)
- Floor space utilisation (smoother flows)[213]

These measures have yet to be applied.

209. BusinessWeek (2005) Boeing's Plastic Dream Machine. 'BusinessWeek.' 20th June.
210. Wang, C. I., and Ahmed, P. K. (2003), 'Innovation, Knowledge Management and Learning: A Case Study of GKN.' Working Paper Series. Telford: University of Wolverhampton.
211. House of Commons Trade and Industry Committee (2005) 'The UK Aerospace Industry, Fifteenth Report of Session 2004–05.' London: The Stationery Office.
212. Braddon, D. and Hartley, K. 'The Competitiveness of the UK Aerospace Industry', Applied Economics, Vol. 39, Issue 6, April 2007.
213. Society of British Aerospace Companies (undated) 'Aerospace Metrics Measures for Improved Competitiveness.' London: SBAC.

5.3 Topic-specific research programme outputs could also be tracked

In addition to measuring inputs to innovation, it would be useful to capture progress in selected, strategically important areas for innovation, perhaps against agreed 'technology roadmaps'.

For example, the National Advisory Committee for Aerospace Manufacturing (NACAM) identified six priority research topics in its 2006 report.[214] These were: surface engineering and coatings; net shape titanium; affordable composites; ultra low-cost tooling; digital manufacture; and assembly integration. NACAM suggested through its road mapping exercise that the UK was falling behind the rest of the world in the development of advanced manufacturing technology for aerospace applications.

5.4 Social and environmental performance outputs should also be taken as a measure of innovative performance

For traditional innovations, a list of measures reflecting current objectives and concerns would include: emissions; noise; fuel consumption; engine efficiency; aircraft weight. These indications are regularly monitored, and EU targets have been set for some of them.

6. Innovation could be improved by developing support programmes that embrace hidden innovation, to respond to the long-term challenge posed by new competitors

6.1 The UK will increasingly need to compete with new entrants as the global balance of power begins to shift

The UK must retain high level systems integration capability. This is where the greatest value is created.[215] The assumption that this 'total capability' can be maintained in leading countries while distributing ever more capabilities to other countries needs to be examined more critically.

As in so many other areas of manufacturing, increased competition from low-cost economies has increased pressure at the lower value-added end of the UK aerospace supply chain. Small, lower-technology firms often lack the capacity to make the kinds of organisational and process changes required to stay competitive.[216]

But the longer-term issue is with higher-value-added activities. The cumulative stock of knowledge of leading aerospace firms represents a major barrier to entry for potential competitors, as do the huge investments that are required for significant developments in aircraft hardware.

Yet competition from emerging economies is growing.[217] Some countries, such as Taiwan, Indonesia and Brazil, have established their own aerospace industries. Regional aircraft producers such as Bombardier of Canada and Embraer of Brazil could move into producing larger aircraft. India and China are leveraging market access in return for investment and collaboration. China and Russia are making efforts to develop regional jet programmes, with support from Western manufacturers anxious to get better market access. Both could eventually become significant players in partnership with Western firms, especially with well-funded, highly motivated state-led investment strategies.

The extent of Japan's involvement in the development and production of the Boeing 787 could also represent a major opportunity for the Japanese sector to advance. Thirty-five per cent of the 787 will be manufactured in Japan. The country's aerospace sector has succeeded in gaining extensive and advanced work on the technology-rich wing design (and not just its manufacture).[218] Boeing has never before handed this kind of work to a subcontractor.[219] Japan has now developed expertise in most aspects of aerospace manufacture and has a declared intent to increase its share of the civil aerospace market to 15 per cent by 2025.[220] Mitsubishi and Kawasaki have announced plans for short-range and regional aircraft.

In addition, a new paradigm for aerospace production may be emerging. Cheaper, more efficient approaches to production have been demonstrated by smaller innovative firms. For example, US firm Eclipse Aviation has launched its Eclipse 500 four-six seat 'air taxi'. Ex-automotive sector executives founded Eclipse with the expressed aim of producing a highly-reliable, low-weight aircraft selling for $1 million. The 500 is 50 per cent cheaper to operate than similar aircraft.[221]

Toyota and Honda both have small aircraft at advanced stages of development. The announcements from Honda and Toyota on their prototype small executive aircraft suggested that, taking account of their history, the emergence of a new paradigm is highly

214. Gindy, N., Hodgson, A., and Johnston, S. (2006) 'Research Opportunities in Aerospace Manufacture.' National Advisory Committee for Aerospace Manufacturing. NACAM was sponsored by the then DTI through the National Advisory Committees Knowledge Transfer Network, reporting to the Aerospace Technology Steering Group (ATSG) and the National Defence Industries Council (NDIC) R&T committees. Its purpose is to advise the UK on the future direction of aerospace manufacturing research and technology. It consists of representatives from UK industry, academia, DTI, EPSRC, and MoD.
215. Royal Aeronautical Society (2007) 'Trade and Industry Committee, Creating a Higher-value-Added Economy, A Submission from the Royal Aeronautical Society 24th October 2007.' London: RAS.
216. Rose-Anderssen, C., Baldwin, J.S., Ridgway, K., Strathern, M., Varga, L., and Allen, P.M. (2007) 'Learning and Development in Commercial Aerospace Supply Chains.' Irish Academy of Management conference, 3rd–5th September.
217. House of Commons Trade and Industry Committee (2005) 'The UK Aerospace Industry, Fifteenth Report of Session 2004–05.' London: The Stationery Office.
218. McGuire, S. (2006) 'The United States, Japan and the Aerospace Industry: Technological Change in the Shaping of a Political Relationship.' Working Paper. Bath: University of Bath.
219. One analysis also emphasises that Boeing gains access to cheaper finance through this approach, since the first tier suppliers help to finance the programme; see Newhouse, J. (2007) 'Boeing Versus Airbus.' New York: Knopf.
220. As noted in Gindy, N., Hodgson, A., and Johnston, S. (2006) 'Research Opportunities in Aerospace Manufacture.' National Advisory Committee for Aerospace Manufacturing.
221. For example, the Warwick Innovative Manufacturing Research Centre at the University of Warwick has begun to investigate opportunities for simplifying aircraft design through manufacturing excellence.

possible. The longer-term critical question is then whether UK aerospace firms can remain competitive against the emerging threat from such new entrants.

6.2 Programmes of support should embrace hidden innovation as well as anticipate disruptive technologies

6.2.1 Existing policy interventions focus on new products, as opposed to business or commercial innovations

In the short- to medium-term, the UK has to remain attractive to major firms as a place to locate their innovation activities including R&D. Such competitive pressures demonstrate the importance of government R&D support in aerospace.

The aerospace sector can apply for support for R&D under the Technology Programme, which includes the Collaborative Research & Development (CR&D) grant and Knowledge Transfer Networks (KTNs), and of course R&D tax credits for activities that qualify.[222] Aerospace was granted around £153 million through the Technology Programme between April 2004 and April 2007 (£110 million from central funds – more than a quarter of total Technology Programme funding – and £43 million from the regions), an estimated £60-£80 million each year through R&D tax credits, Selective Finance for Investment/Regional Selective Assistance of more than £33 million in 2006, as well as support for overseas sales campaigns.

Repayable launch investment (RLI) – commonly referred to as 'launch aid' – is also available. This is justified on the basis that aerospace projects are characterised by high costs and long payback periods. RLI payments are made for eligible development costs to firms in the early years of a project. Repayments to government are usually based on a per-aircraft or per-engine basis, with a target rate of interest and specified time period. The provision of RLI is entirely discretionary; there is no formal scheme, promotion or budget.[223] Around £1 billion of RLI has been provided since 1997.

In total, the former DTI estimated that annual funding for the sector has risen to £45 million a year (now around £50 million) – more than twice the level of public support provided under the previous funding system, but not yet at the level of the 'required' £70 million per annum set out in NATS.[224]

What is most crucial is that such support includes a focus on disruptive technology. For example, Rolls-Royce's core technology and capability is centred on the gas turbine, across all of the sectors in which it operates (civil and defence aerospace, marine and energy). The relatively rapid emergence of a disruptive new technology could seriously challenge its – and many other firms' – existing knowledge, expertise, and business models.

6.2.2 Strategic support programmes should be widened to include hidden innovation, possibly as part of a national policy for aerospace

In the longer-term, the UK aerospace sector will need to respond not just to new technologies, but to new business models, processes and services developed by competitors.

First, the developing challenge from emerging competitors needs to be formally assessed, including a review of their national strategies for aerospace.[225]

Second, NATS, however important, is not a national aerospace strategy, in the sense of a broader vision beyond technology research and development. Government should consider the need for such a national strategy in response to the analysis of emerging global competitors.

Third, such a strategy (or failing that, a revised NATS) should encompass forms of innovation beyond scientific and technological research. For the UK industry to remain competitive, the AeIGT considered that it must exceed US, French and German productivity levels by 2022.[226]

This will require increased performance in all forms of innovation. AeIGT argued in 2003: "Key to driving a step change in UK performance is recognition that Process Excellence Implementation is equally as important as Technology Demonstration."[227]

This is why initiatives that focus on developing expertise within supply chains are important. For example, in 2006, the North West Aerospace Alliance launched its Aerospace Supply Chain Excellence Programme in partnership with Airbus, BAE Systems and Rolls-Royce and with support from the Northwest Regional Development Agency. This aims to equip firms with the knowledge and skills to manage innovation, at the operational and strategic levels. Specifically, it aims to integrate the management of market, technological and organisational factors to

222. For example, the Materials KTN supports activities such as the WINGNet network, aimed at identifying the critical materials science required to improve the UK's performance in the sustainable use of materials in the aerospace sector. Similarly, the National Composites Network is a KTN that embraces the entire UK composites industry and its supply chain. It is establishing Regional Centres of Excellence where firms can obtain hands-on support and expert advice, such as the Airbus Composite Structures Development Centre at Filton, and the GKN Aerospace Composites Research Centre at Cowes on the Isle of Wight.

223. Subsidies such as RLI have been a long-running matter of dispute between the US and Europe on behalf of Boeing and Airbus. The EU has claimed that US subsidies for Boeing have cost Airbus $27 billion in losses, while the US Government has argued that Airbus has wrongly enjoyed subsidies of up to $205 billion over the past decades; BBC News online (2007) 'Boeing's US Aid 'Hurting Airbus.' 26th September.

224. Paragraph 37, House of Commons Trade and Industry Committee (2007) 'Recent Developments with Airbus, Ninth Report of Session 2006–07, Volume I.' London: The Stationery Office.

225. The House of Commons Trade and Industry Committee recommended in 2005 that government should conduct an official study into the threat from emerging competitors.

226. Aerospace Innovation and Growth Team (2003) 'An Independent Report on the Future of the UK Aerospace Industry.' London: Department of Trade and Industry.

227. Aerospace Innovation and Growth Team (2003) 'An Independent Report on the Future of the UK Aerospace Industry.' London: Department of Trade and Industry: p.91.

improve the competitiveness of the North West's aerospace firms.

Similarly, the Society of British Aerospace Companies (SBAC) is currently rolling-out its supply chain initiative, SC21, across the UK. SC21 is a broad industrial change programme, developed by the industry, designed to improve the competitiveness of the sector by raising the performance of its supply chain. It includes Lean production and quality accreditation, and customer and supplier relationships.

Beyond this, a new set of initiatives is needed to anticipate a coming paradigm shift in aircraft manufacturing, from design for manufacture, new business models and processes, to e-commerce.

Appendix C: Telecommunications

Innovation through technological disruption and communication convergence leading to a role for hidden innovation via new service provision

1. Telecommunications is an important economic sector in its own right, vital to the UK's competitiveness as a knowledge-based economy

The telecommunications sector involves: (i) telecommunication services (fixed-line telephony services, mobile services and broadband) and (ii) telecommunications equipment and network supplies.[228]

These two main groupings of activities have a number of important sub-segments, which comprise the supply chain:

- Network operators (such as BT, Cable & Wireless, Vodafone, O2, Thus, Orange – who are fixed line and/or mobile operators);
- Systems and networking software (providers of technology such as Convergys, LogicaCMG);
- Data and networking equipment (suppliers of equipment such as Alcatel-Lucent, Siemens-Nokia, Motorola, Avaya, Oracle, Ericsson, Cisco Systems); and
- End-user communications equipment (for example, D-Link, Siemens, Telsey).

Total industry revenue was estimated at £56.7 billion in 2006.[229] The UK sector continues to make a significant contribution to the UK economy, with £21.3 billion in GVA in 2004, equating to 2 per cent of total gross value added for the UK.[230]

There are around 8,500 firms in the UK sector and 56,000 people are employed either directly or indirectly in the sector[231] (28,000 professionals are employed directly in the sector, with the remaining 28,000 people employed in other industries).[232]

The sector includes large players who provide a wide range of infrastructure, products, applications, and services through to small firms that have a single product or service offering. In the UK, BT continues to be the largest fixed-line provider, with an estimated overall UK turnover of £17.2 billion and accounting for 37 per cent of total telecommunications turnover.[233] Other smaller fixed-line providers in the UK are Vanco, Eircom, and Kingston Communications (KCOM). These firms have varied business portfolios: Vanco is a virtual operator focusing on communications services for enterprise clients, IT outsourcers and carriers. Eircom is mainly a fixed line operator, but also has a mobile business. Kingston Communications (known as KCOM) sells integrated IT and communications services to businesses, and internet and telecommunications services to selected consumer markets within the UK (see Section 2.1.1 for further detail.)

There are five mobile network operators in the UK (Vodafone, O2, T-Mobile, Orange and 3), and together with independent service providers and mobile virtual network operators (MVNOs) – such as Virgin Mobile and Tesco Mobile – contribute around 35 per cent of total UK telecommunications turnover.[234]

The telecommunications equipment sector has a small number of large global players.[235] Equipment manufacturers aim to develop products for the next generation of telecommunications networks. A number of firms have expanded their R&D activities in key telecoms technologies: Motorola, Nortel Networks, Ericsson and Alcatel-Lucent

228. This includes: terminal equipment (fixed line phones, PBXs and mobile handsets); cables and infrastructure (broadcast, fixed, and radio/mobile); switching components and associated installation services (infrastructure technologies, offered as hardware or software modules and associated with delivering peer2peer, push2talk, ad-hoc and mesh networks, and SMS-to-voice conversion, as well as radio frequency technologies such as Bluetooth, Sensor Area Networks (Zigbee), VoiP and Ultra Wide Band). See UK Trade and Investment (2007) 'ICT Marketing Strategies: Evidence Base' [CD-Rom] London: UK Trade and Investment.

229. Ofcom estimates the sector to have a turnover of around £47 billion. The discrepancies in the figures are because ONS estimates include revenues from services such as network hardware provision and maintenance (which Ofcom do not regulate). Office of Communications (Ofcom) (2007) 'The Communications Market 2007'. London: Ofcom, Chapter 4: pp.271-272.

230. The Office for National Statistics (2006) 'Input Output Analyses 2006 Edition.' London: ONS.

231. Inter Departmental Business Register (2004-2007) 'Analysis of UK Local Units in VAT based Enterprises' [online] Available from http://www.statistics.gov.uk/idbr/idbr.asp

232. e-skills UK (2008) 'Technology Counts - IT & Telecoms Insights 2008.' London: e-skills UK.

233. However, internationally, BT's revenues are lower than those of comparable European firms, partly because it doesn't own a mobile network business. In 2006 BT's global turnover was £20.1 billion while Deutsche Telekom and France Telecom reported revenues of £42 billion and £36 billion respectively. Office of Communications (Ofcom) (2007) 'The Communications Market 2007'. London: Ofcom. Chapter 4: p.272.

234. These new entrants to the sector are discussed in Section 2.2.1. Office of Communications (Ofcom) (2007) 'The Communications Market 2007'. London: Ofcom. Chapter 4: pp.271-272.

235. Telecommunications is a scale economy business, and so operators looked to buy technology from firms who could supply industry-wide solutions. This led to the emergence of national champions within the network equipment provider community – GEC and Plessey in the UK, Alcatel in France, Siemens in Germany, Ericsson in Sweden, and Lucent in the US. These firms became the primary source of new technology and innovation used by operators.

236. UK Trade and Investment (2007) 'ICT Marketing Strategies: Evidence Base.' [CD-Rom] London: UK Trade and Investment.

237. Department for Business Enterprise and Regulatory Reform (2001) 'Competitiveness in the UK Electronics Sector.' London: BERR. Chapter 2.

238. UK Trade and Investment (2007) 'ICT Marketing Strategies: Evidence Base' [CD-Rom] London: UK Trade and Investment.

239. Ibid.

240. The first technical innovation in the sector - the telegraph (messaging using Morse code down wires) - was patented in 1836. Voice communications followed in the late 19th century – (Alexander Graham Bell invented the telephone in 1876) and this quickly became established as the main form of communicating.

241. Fairbairn, C. (2006) Serving the Public Good in the Digital Age: Implications for UK Media Regulation. In Richards, E., Foster, R. and Kiedrowski, T. (2006) 'Communications - The Next Decade: A collection of essays prepared for the UK Office of Communications.' London: The Stationery Office. Chapter 2.

242. Ten years ago, BT spent £307 million on R&D. Many of BT's peers did the same: in 1999, France Telecom invested €593 million in R&D and Deutsche Telekom spent €700 million on R&D.

243. Harrison, P. F. (1997) Customer Service Systems – Past, Present and Future. 'BT Technology Journal' 15 (1), pp.29-45.

244. Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard – Fixed-Line Telecommunications Sector Summary.' London: DIUS/BERR.

Technologies have established Centres of Excellence in advanced technologies and have significant R&D facilities in the UK. For example, Lucent and Motorola have their world headquarters for UMTS (Universal Mobile Telecommunications System) in the UK because of the UK's strengths in wireless technologies. In addition, Alcatel has its key manufacturing operation for the submarine cable sector in the UK and Nokia and Siemens have significant research centres for third-generation (3G) mobile in the UK.[236]

Over 50 per cent of the sectors' revenues are generated by firms located in London, the South East and East of England and this total exceeds 75 per cent when the North West, Yorkshire & Humberside and the West Midlands are included.[237] Regional clusters can be found near Cambridge, around Bristol and Edinburgh. Cambridge hosts research centres for a number of communications multinationals (such as ARM, AT&T, Broadcom, Cambridge Silicon Radio, Nokia, Nortel, Qualcomm, Symbian, and Toshiba) building on a long academic and industry tradition in wireless technology. Virtual groupings such as the Institute of Advanced Telecommunications have also developed, concentrated around key universities and the international research centres of many of the largest global firms.[238] A number of international firms have established their European headquarters in the UK (for example, the Japanese NTT DoCoMo and, more recently, all the Chinese operators).

The UK is a centre of excellence in niches of the sector, particularly in the development of advanced 3G mobile products and services, as well as short-range wireless technologies, such as Bluetooth. The UK also has a strong communications R&D skills base; in particular in RF and mixed signal design (analogue and digital).[239]

2. Innovation in telecommunications has delivered profound technological changes in recent years, which in turn, is enabling new forms of service innovation and business models

2.1 Traditional innovation is technologically focused, and is a mix of radical and incremental development

2.1.1 Innovations in technological connectivity, provided by the telecommunications sector, have been a key enabler and transformer in the information, communication and technological revolution

More technological innovation took place in the telecommunications sector in the last two decades of the 20th century than in the preceding 150 years.[240]

The sector has recently experienced a hugely innovative phase, with technologies emerging that have considerably impacted the evolution of modern communications, from distribution technologies (for example, digital, broadband and mobile) to consumer devices (for example, MP3 players, Blackberries and the iPhone).[241]

Traditionally, network operators have invested significantly in the research and development of new technology. BT regularly reported annual investments of around £300 million in R&D.[242] This resulted in the filing of patents (for example, BT developed early fibre optics, and registered World Wide Web hyperlink patents) and the deployment of proprietary systems – BT's proprietary Customer Services System (CSS) is a good example. Introduced in 1986, CSS provided BT with all the information to support its core customer activities, from billing and order taking to sales support and fault recording. By 1999 it was the biggest civilian computer system in Europe.[243] Today, BT's R&D agenda focuses on wireless data services, software development to facilitate telecommunications networks and upgrading parts of the copper wire networks to higher capacity optical fibre networks.[244]

Total expenditure on R&D in the fixed-line sector in 2006 was £1.127 billion. BT accounted for virtually all of this: a total of £1.119 billion with an R&D intensity of 5.1 per cent.[245] Excluding BT, R&D intensity is relatively low for the remaining fixed-line telecommunications: with Vanco at 2.8 per cent, Eirco at 0.1 per cent and KCOM at 0.1 per cent. Sales in the fixed-line sector grew by only 4 per cent during 2006 but BT, in particular, chose significantly to increase R&D investment (by 54 per cent). The fixed-line telcommunications' ratio of R&D investment to sales has risen sharply over the last five years – and is unique in doing so; this matches the sector's growth in R&D investment (up 54 per cent in 2006 and 94 per cent over the average R&D in the four prior years). This is because the sector has had to invest heavily into Internet Protocol (IP) networks (see Section 2.1.1.3). IP networks are expected to significantly lower future operating costs and deliver returns on current investments.[246]

The types of technological innovation created by the sector – some created a generation ago but which have enabled more recent advances – include:

2.1.1.1 The switch from analogue to digital
By the end of the 1960s, the technology for switching from analogue (sound waves) to digital had been tried and proven. The Post Office (the national monopoly operator at that time) was ready to transform Britain's telephone network from analogue into digital based on electronics and binary data transmission. This would make Britain's network one of the most advanced in the world.

System X was conceived by the Advisory Group on System Definitions, an alliance involving the Post Office and industry groups, and set up in 1968 to define the shape of the future telephone network and how it could be achieved. Collaborative development between the Post Office and its three principal equipment suppliers – GEC, Plessey and STC – culminated in the first of the British-designed digital switching systems called 'System X'.

The development of System X exchanges was the cornerstone of modernisation of the existing network, by replacing analogue exchanges with digital switching centres interconnected with digital transmission links. It enabled an increased variety of facilities and services to be made available to the telecommunications user, resulting in ISDN (Integrated Services Digital Network) and ISDN 2. The System X family of digital exchanges marked a leap forward into the era of microprocessors.

The change from the old-style technology to modern digital switching was a lengthy process, involving collaboration, research, development and testing.[247]

But the switchover changed the underlying communications technology and enabled far more fundamental change a generation later. Digital network technology increased the bandwidths available and increased data transference rates dramatically to speed up data communications, making the innovative offering of broadband possible.

2.1.1.2 The development of broadband
During the late 1990s and early 2000s, broadband became the successor to narrowband (public switched telephony service) connectivity in the home and workplace. For most of the 20th century the voice Public Switched Telephony Network (PSTN) and telex (messaging) were the primary means of communication between two fixed points. Significant migration of domestic internet connectivity from dial-up to broadband started in 2000 and has continued annually.[248] With PSTN only voice calls, faxing or making dial-up internet calls were possible. Broadband offers a far faster and richer 'triple-play' experience (with voice, fast internet access and video all available simultaneously), but also the potential for the communications operator to offer far more services than it has in the past (see Section 2.2.2).

2.1.1.3 Internet protocol and next generation networks
Most networks have been designed to deal with narrowband (PSTN) communications traffic, with most data traffic handled in overlay networks of various types. With the advent of Internet Protocol (IP),[249] voice (both fixed and mobile), data, and video traffic can be transported in the same way (as packets of data) and on the same network. There have been a number of next generation network (NGN) programmes in the sector designed to collapse the overlay networks into one.[250] This move to all-IP networks is only possible because of the move from analogue to digital a decade earlier. Moving to all-IP networks also enables operators to extend their network reach beyond the network termination point (NTP, that is, the socket on the wall) into the home and office and to offer new services (see Section 2.2.2).

Next generation networks are a significant focus of R&D investment for the sector and for the UK; IP networks are expected to significantly lower operating costs and provide a more flexible platform for new services (for example, consumers will be able to access voice and data from any device). Whilst the fixed-line sector has had disappointing growth and profitability over the last few years, such new investments are expected to deliver high returns in the future. The most prominent NGN is BT's 21st Century Network programme (21CN), with BT investing £10 billion and Cable & Wireless and Colt are also investing heavily in NGNs.

2.1.1.4 Mobile and wireless technologies
The technologies used for communication are changing. Fixed phones and desktops are connected to the fixed network infrastructure using either narrowband (PSTN) or broadband (usually asynchronous digital subscriber line – ADSL – technology). Mobile connectivity to

245. Consisting of £741 million of capitalised software development – a re-focusing of its business mix towards IT services - and £378 million of R&D operating costs. See Department for Innovation, Universities and Skills/Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
246. Department for Innovation, Universities and Skills/Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
247. In 1975, a new R&D centre opened at Martlesham Heath in Suffolk. Today it is one of the most advanced centres for telecommunications research in Europe. It has supported many 'leading edge' developments, including BT's pioneering work on optical fibre technology and submarine cable transmission systems. Now called Adastral Park, it is host to a science park and is one of BT's five satellite earth stations.
248. Fairbairn, C. (2006) Serving the Public Good in the Digital Age: Implications for UK Media Regulation. In Richards, E., Foster, R., and Kiedrowski, T. (2006) 'Communications - The Next Decade: A Collection of Essays Prepared for the UK Office of Communications.' London: The Stationery Office. Chapter 2.
249. First developed in the US in the 1970s, Vint Cerf was co-designer (along with Bob Kahn) of the mechanisms known as transmission control protocol (TCP) and the internet protocol (IP). The protocol freed up the amount of traffic the internet could carry and the new bandwidth opened the doors to all the content available today and enabled the internet's capability to be used by everybody.

wireless networks uses different technologies, most typically UMTS (universal mobile telephony service, or third generation mobile – 3G), GSM (global service mobile, or second generation mobile – 2G), or WiFi, as used with laptops.

The pace of change in mobile technologies is unrelenting.[251] Just as GSM succeeded analogue, UMTS/3G mobile technology is replacing GSM. The promise of 3G is to deliver broadband-like speeds to mobile devices, opening the internet to mobile-users. UMTS is in turn being superseded by HSDPA (high speed digital packet access) with the development of 4G predicted as the next new wave of mobile technology.

Wireless technologies have also emerged: WiFi is the most prevalent (offering broadband connectivity within enabled buildings and public hotspots) for laptops, and WiMax (which offers broadband wireless access for laptops to towns and districts). Bluetooth technology is now widely used for hands-free connectivity and technologies such as NFC (Near-Field Communications) which is used on applications such as the Oyster cards on London transport.

2.1.2 Incremental innovation

In addition to the more radical innovation that has taken place within the sector over recent years, incremental innovation also counts for a significant amount of activity, and remains an important part of the innovation process, ensuring firms remain competitive with their service or product offering and retain market share. Indeed, it has been estimated that up to 90 per cent of firms' development resources are being used to support the introduction of service line extensions and feature enhancements on products.[252] For example, whilst the underlying technology (2G or 3G) remains the same, handsets have continuously improved in terms of functionality (voice, SMS, MMS, MP3, photos), specification (battery life, photo resolution, storage capacity), and design (from tablet to clam shell, and the current slider-phones). The effect of this incremental innovation is that it has transformed the mobile from being a communications-only device (voice plus text) into one that also caters for entertainment (music and TV) and photography.

2.1.3 Process innovation

European operators such as BT, France Telecom and Deutsche Telekom are all investing heavily in 'internal IT processing factories'. These back office operational support systems are intended to automate, integrate and simplify internal IT processes, radically improving customer service and reducing costs. This type of innovation is central to the long-term viability of the traditional communications service providers. Operators will need to become efficient at data processing, where the lowest cost will ensure competitive advantage.[255]

Vodafone

Vodafone started life in Racal (a military electronics company). Along with its US partner Millicom (and the other licensee BT's Cellnet), it was the first to get a licence for public mobile telephone services in 1982 (beating companies such as Ferranti, Plessey and GEC). Racal's system for voice and data would be called Vodafone. Over a two year period, a small team of Racal engineers designed and planned a detailed and innovative approach to a cellular network.[253] Radio planning was to be Vodafone's technical core competency with which it would compete with its rivals.

Accepted by early adopters, there were 19,000 people signed to Vodafone mobile services by 1985 and Vodafone had achieved the licence requirement of 90 per cent coverage of the UK population by 1987 (two and a half years early). Vodafone and Cellnet competed, but also co-operated, in areas such as advertising and price, in order to sell the idea of mobile communications and to protect revenue, to the benefit of both. As Vodafone became an increasingly large contributor to Racal's income, a decision was taken in 1988 to turn Vodafone into a company in its own right. In 1989, the Department of Trade and Industry issued new licences to develop new networks and increase competition enabling Orange and One2One to enter the mobile market. Vodafone has developed into a global player, with a turnover of £1.209 billion, and 8.8 million customers in 25 countries in Europe, the Middle East, Asia Pacific and the US.[254]

250. Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
251. Although, the time it takes to develop and deploy technology is far longer than may be realised. For example, the deployment of third generation (3G) wireless technology was four years behind initial expectations.
252. Innovaro (2005) 'Innovation Briefing: Teleco Innovation.' London: Innovaro Ltd.
253. Put simply, a process of understanding how radio waves travelled across geographical environments and where mast antennas should be located to receive mobile signals.
254. Spufford, F. (2003) 'Backroom Boys. The Secret Return of the British Boffin.' London: Faber and Faber.

2.2 Technological innovations in telecommunications are enabling a range of new service innovations, provided by 'traditional' operators but also new suppliers, and new ways of collaborating

2.2.1 Innovation within the supply chain is changing, as new suppliers enter the sector

Market liberalisation has nurtured competition to such an extent that firms from other sectors, often with no previous sector experience, can now freely enter the market. Technological convergence is also driving this trend (see Section 3.3).

Traditionally, network operators (such as BT) provided services to customers based on the technology and equipment purchased from equipment suppliers (for example, Oracle, Cisco and Ericsson), who in turn purchased components from sub-contractors: a 'bottom-up' supply chain. Now, operators no longer have a monopoly on providing innovative products and services to customers. New entrants, from outside the sector, have entered the market. Suppliers (such as Cisco and Microsoft) also deal directly with the customer. Consumers are also feeding into the process (see Section 2.2.3). The supply chain is no longer purely linear and one-way.

Started in 2003, Skype, for example, launched voice over IP (VoIP) based on using broadband connectivity to by-pass PSTN interconnection tolls and access the 'free' internet[256] and was so successful that it was acquired by the internet auction site eBay. Google also launched a similar service with Google Talk. Both firms had little experience of operating in the sector until they entered the market.

By collaborating with network operators (through wholesale services) and the traditional technology suppliers, firms such as Tesco, Sainsbury's, the Post Office, Carphone Warehouse, the UK's four major mobile companies (Vodafone, T-Mobile, Orange, and O2), and Sky[257] have been able to provide services to customers (such as broadband services at a retail level) stimulating greater competition and innovation.

2.2.2 New service innovations and business models

New technology enables new services; this has been evident since the foundation of the telecommunications industry.[258] With technological advances, traditional revenues from calls and lines have declined. For example, mobile telecommunications services revenues are expected to plateau across Europe. Mobile penetration in most developed countries now exceeds 100 per cent, and revenues are expected to continue to grow slowly as operators offer more services over 3G networks. Fixed voice telecommunications services revenues are declining rapidly but fixed line data services (broadband) continue to grow, and the UK has the second highest total of broadband connections in Europe after Germany.[259]

Consequently, operators have sought to use innovative new services to drive or renew revenue growth.[260] Examples of mobile phone services include voice and messaging (SMS) and MMS (multi-media messaging using photos and video clips) with recent developments including TV services being picked up on mobiles – a service developed in Korea but being trialled in the UK by O2 and Vodafone.[261] However, take up of this has been somewhat poor. Mobile broadcasting is the least developed of the digital platforms: it does not yet exist in a number of countries. However, it is estimated that by 2010, most developed countries will have at least one mobile broadcast network enabling 'live' television channels to be broadcast to mobile phones and other portable devices (complementing other mobile services, and distributed over 3G networks).

Femtocells

A recent innovation in mobile phone technology has been the development of 'femtocells' – small devices that improve indoor mobile phone coverage, and have the potential to move telephone 'traffic' off congested cellular networks and onto their fixed line counterparts (which have more capacity and are usually faster). Femtocells are about the size of a Wi-Fi base station and link a mobile wirelessly to a fixed line broadband internet connection. Although the technology may not be available until early 2009, UK firms, such as ip.access and Ubiquisys are central to developing this emerging innovation.[262]

255. Ofcom (2005) 'Final Statements on the Strategic Review of Telecommunications.' London: Ofcom.
256. During the last quarter of 2007, Skype had 246 million customers.
257. Financial institutions (for example, Fidelity at Colt) and also private equity (for example, the Carlyle group) are also entering the market; see Ovum (2007) 'Private Equity and Telecoms: Why Now and What Next.' London: Ovum Plc.
258. However, Edquist argues that service innovations and technological innovations in the telecommunications sector are converging and becoming critically interdependent, see Edquist, C. (2003) 'The Internet and Mobile Telecommunications System of Innovation.' London: Edward Elgar Publishing.
259. UK Trade and Investment (2007) 'ICT Marketing Strategies: Evidence Base' [CD-Rom] London: UK Trade and Investment.
260. Fairbairn, C. (2006) Serving the Public Good in the Digital Age: Implications for UK Media Regulation. In Richards, E., Foster, R., and Kiedrowski, T. (2006) 'Communications - The Next Decade: A Collection of Essays Prepared for the UK Office of Communications.' London: The Stationery Office. Chapter 2; Cleevely, M. (2006) 'The Role of Ofcom in Encouraging Innovation'. London: Ofcom.
261. Op cit.
262. Graham-Rowe, D. (2008) Why Every Home Should Have One. 'New Scientist' 8 March 2008, pp.24-25.

Broadband has been able to offer consumers a far faster and richer 'triple-play' experience, (with voice, fast internet access and video all available simultaneously). 'Quadruple-play' (fixed-line, mobile, internet and TV) are also now being offered to consumers. BT's current focus is on its 'new wave' services: predominantly broadband, mobility and IT services. BT Fusion (FMC) and BT Vision (IPTV) are examples of this.

As a consequence of the provision of new services, new business models are emerging. For example, some services are sold as bundles (for example, broadband line plus IT support) or a service may be delivered in a different (technologically-enabled) format, such as, over a line rather than physically (for example, digital photo vaults from BT), or advertising services delivered by a provider via the internet to a mobile phone. Service innovation and resultant new business models are set to proliferate. One survey found that 69 per cent of providers worldwide expect business model transformation to be the primary source of value over the next five years; 72 per cent expect collaboration with external partners will be critical as new business models are structured and implemented.[263]

The next generation of innovation in mobile service provision will be in connection with 'concept of presence' (or location-based services). The vision many operators and their suppliers envisage is that of 'unified communications' (UC). Unified communication is about being able to communicate from any device, to any device, using whichever technology as appropriate. UC solutions are now being offered (or at least promised) by operators, and also by suppliers. This means that UC technology will detect where an individual is, and then deliver relevant content (for example, rail or bus timetables, nearest bookshops) depending on where the individual is located. Presence information[264] can also inform others where the recipient is located (for example, a train journey delay, or a parent looking for a child). Presence information is an important component of UC – delivering communications in the right format depending upon the receiver's situation.

2.2.3 Open innovation and collaboration as a business model

BT has been embracing open, user-led innovation and has opened up its entire telecommunications network through open protocols and a software development

263. IBM Institute for Business Value (2007) 'Telecoms Switches Emphasis. Preliminary Analysis of the 2007 Telecoms Industry Survey.' New York: IBM Global Business Services.
264. These solutions use a mix of GPS (to identify where the individual is located), 3G (to link to relevant websites) and intelligent systems to provide information of relevance to the individual situated in a location.
265. BT Group plc (2007) 'Annual Report & Form 20-F2007.' London: BT Group plc.

BT's 'new wave' services

BT Fusion is a fixed-mobile convergence (FMC) phone service. Fusion was a world first when launched by BT in 2005. When ordering the service from BT, the customer is provided with a hub and up to six mobile handsets. To make a call with the mobile, the customer dials the number in the usual way. When within range of the hub the call is routed through the hub and into the fixed broadband network for delivery. If the caller moves out of range of the hub then the call is seamlessly transferred to the mobile base station of BT's partner (Vodafone) for routing as a normal mobile call. When outside of the home, the Fusion mobile acts just as any normal mobile phone. When within range of a BT WiFi hotspot Fusion phones also connect directly into BT's network in the same way.

BT's new IPTV service (Vision) also connects to the same home hub. Developed in partnership with Microsoft, BT Vision – an example of quad-play – provides broadband video on demand via a Freeview digital terrestrial TV set-top box, and has increased its subscriber base to 150,000 in just over a year. BT's revenue comes from enhanced services, such as a VoIP facility to dial up family and friends while watching TV, or the ability to build personal schedules, use picture-in-picture channel surfing, and to see caller ID on TV sets. BT recently secured a content deal with Paramount, giving access to over 150 new films. It recently entered into a similar deal with Disney, for major US television series including *Desperate Housewives* and *Lost*.

For BT, in 2007, these activities generated revenues of £7.37 billion (36 per cent of total revenues), an increase of 17 per cent on the previous year (while traditional revenues fell 3 per cent).[265] However, these new services may initially have lower margins than traditional sources of revenue, require more complex delivery mechanisms, and often need partners to support them (such as IT support).

kit (SDK) that is downloadable by users, entrepreneurs and firms. No other telecommunications firm in the world has embraced this level of openness and access to users. As a result, BT has gained a competitive advantage in the sector by utilising user innovation in its advanced communications infrastructure.

A major element of BT's strategy of opening up to user-led innovation is Web21C SDK. This software tool allows users unprecedented access to BT's telecommunications infrastructure, and enables innovation by BT customers. It appeals to both large established firms who want fully to integrate telecommunications services in applications and to users inventing new applications that 'mash-up' the internet and traditional telecommunications services.[266] France Telecom and Vodafone[267] have also set up versions of open innovation programmes. However, critics have questioned whether these open innovation programmes are sufficient (when compared with other sectors, such as life sciences and consumer electronics) and whether programmes are a core part of innovation and growth strategies.[268]

3. Innovation in the telecommunications sector has been determined significantly by regulatory reform, intensified competition, technological convergence and consumer adoption of new forms of communication

3.1 Regulatory reform provided the catalyst for a more competitive, innovative sector

Until 1984 the telecommunications industry in the UK was characterised by a state-owned national monopoly. However, in 1982, the UK government decided to privatise and open up the sector to market liberalisation and competition. Consequently, in 1984 British Telecommunications was privatised. In parallel, AT&T in the US was broken up into one long distance and several regional Bell operating companies (RBOCS), enabling competition in both long-distance and local markets. The deregulation of telecommunications in the UK and US acted as models for other countries and became catalysts for the gradual deregulation of the sector and the creation of the competitive and innovative communications markets seen today.

The sector in the UK is regulated by the national regulatory authority, Ofcom. Ofcom is a 'super regulator', founded from the Communications Act 2003, from which it draws its statutory duties and responsibilities. Its formation reflected the need for an effective regulator to deal with the convergence of the communications markets in the UK. It was formed of five previous regulators: Office of Telecommunications (Oftel); Radiocommunications Agency (RA); Radio Authority; Independent Television Commission (ITC); and Broadcasting Standards Commission (BSC).

Regulation takes place under the European Regulatory Framework and is incorporated into UK law through the Communications Act (2003). The Communications Act gave a high priority to the promotion of competition in the market, whilst also citing innovation as a key priority.[269] In addition, Ofcom carried out a Telecommunications Strategic Review (TSR) during 2004-2005. The TSR was undertaken because: (i) regulators considered that there was not enough competition to allow sector-specific regulation to be withdrawn. Though the review considered some specific issues relating to mobile networks, the main focus was on fixed telecoms networks. This was because most existing regulation related to fixed networks, and it was in fixed networks that the most complex competition problems were evident; (ii) fundamental changes in technology and consumer behaviour were underway, which may have rendered existing regulatory approaches obsolete; (iii) other countries and markets were adopting different regulatory approaches, and Ofcom needed to consider international and sectoral best practice.[270]

The TSR led to a recognition that regulation should not inhibit innovation in a highly competitive sector and that Ofcom should be a 'light touch' regulator. The TSR intended that Ofcom should regulate and create an environment to stimulate competition and innovation and to implement this approach within the framework of the Communications Act. Outcomes of the TSR included ensuring that firms allowed consumers to switch providers easily, as well as highlighting large scale innovations such as next generation networks as a priority. Subsequently BT, Cable & Wireless and Colt were able to invest in NGNs, following completion of the TSR, with a degree of certainty regarding regulation.[271]

266. Lakhani, K. personal correspondence, 29th February 2008.
267. Vodafone's ßetavine programme is using the internet as a platform for research, innovation and collaboration.
268. Innovaro (2007) 'Innovation in the Telecommunications Maelstrom.' London: Innovaro Ltd.
269. Cleevely, M. (2006) 'The Role of Ofcom in Encouraging Innovation'. London: Ofcom.
270. Ofcom (2005) 'Final Statements on the Strategic Review of Telecommunications.' London: Ofcom.

3.2 Consequently, competition has increased significantly

Competition erodes the value of current products, therefore increasing the incentives for companies to find new sources of revenue through innovation.[272] Before the liberalisation of fixed telecommunications in the UK, BT had one competitor – Mercury Communications. Competition between the fixed-line suppliers has developed rapidly since the early 1990s. Although BT's share of telephone lines is static (around 80 per cent), its overall share of total fixed telephony revenues has fallen (to around 70 per cent).[273] Households can now choose their fixed link telephone supplier, where there was virtually no choice a decade ago. Business users in metropolitan areas now have an extremely wide choice of supplier, and competition has driven prices down and quality up. An increasing number of indirect access services[274] are now available, offering consumers very low prices for calls.

Competition has not only increased nationally, but also internationally, with firms from other countries penetrating the UK market. Throughout the 1980s and 1990s, national monopolies and national networks collaborated and worked together to provide international calls and services, with many foreign markets being largely closed to foreign operators. Since deregulation of national telecommunications networks in a number of countries, markets have opened up to competition from domestic and international operators, with firms incentivised to expand abroad to increase revenue and growth. For example, BT now operates in a number of countries worldwide, through internationalisation strategies developed during the 1990s, which included direct investments, strategic alliances and mergers and acquisitions.

In the mobile sector, 'developing world' operators are increasing in number and in their scale of operation; operators such as China Mobile and America Movil (Mexican) and Bharti Mittal (Indian), MTN (African). Such operators are not only leaders in their own countries but are increasingly active in western markets, with the advantage of lower cost products and services. In India, telecommunication equipment exports are estimated at $1 billion for 2008, but are predicted to grow to $2.5 billion by 2011.[275] For Western operators, with domestic markets saturated, the risk is 'second-tier' status if emerging markets are not part of expansion plans (for example, Vodafone is coping with slowing growth in European markets by buying mobile businesses in developing countries).[276]

3.3 Technological convergence is radically altering the sector

Convergence refers to the increasing ability of one specialist device to undertake several activities (for example, mobile phones playing music files).[277] This has been a major change from previous decades, when communications and content were specific to particular devices. By the late 1990s, the nature of content and services provision, over established and developing technologies, had changed and converged significantly with, for example: videos on the internet; television content distributed (to some extent) over mobile phones; and voice transmitted through the internet (VoIP).[278] For the telecommunications sector, telephony networks – enabled by greater bandwidths – are now able to carry music and video as well as text and voice.

Technological convergence is leading to sectoral convergence, with a blurring of the boundaries between the media and telecommunication sectors.[279] With converged communications, devices and online media, successful firms will be those able to manage many types of content and application across several technological platforms. Technologies, services and content will also have to be delivered so that they appear to consumers as integrated, easy-to-use offerings.[280] Telecommunication firms are also entering the media industry in a search for new revenue sources, as pure telecommunications revenues are squeezed by increased price pressures. For example, BT has entered the digital television market (IPTV) which combines free digital television with on-demand video and personal video recording. Mobile operators such as Vodafone, O2 and 3 are developing increasingly rich mobile video and music services.[281] Currently, fixed/mobile convergence (or the integration of wireless and wireline technologies) is one of the key strategic issues for telecommunications firms. If this is managed successfully, operators and carriers will be able to provide services that deliver user benefits irrespective of their location, access technology, and terminal.[282]

3.4 Consumer acceptance and adoption is helping to drive innovation

The advances in technology have been embraced by consumers of communications services at work, at home, and on the move. The profound shift in consumer behaviour – in how we communicate (voice, text, video), with

271. Cleevely, M. (2006) 'The Role of Ofcom in Encouraging Innovation'. London: Ofcom.
272. Ibid.
273. Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
274. Many new operators offer 'indirect access' connection to their networks. By simply dialling a four-digit prefix immediately before the number dialled, calls can be directed over the most cost-efficient route. Normally this prefix is dialled for you using a simple plug-in dialler, or by reprogramming the PBX. In both cases this service is usually provided free by the operator.
275. Engineering Export Promotion Council (2008) 'Annual Supplement 2008 to Foreign Trade Policy 2004-09.' New Delhi: Engineering Export Promotion Council.
276. Parker, A. (2008) Upwardly Mobile - Emerging Markets Shake Up the Old Order in Telecoms. 'The Financial Times.' 11th February 2008, Analysis: p.9.
277. Christensen, C., Raynor, M. and Verlinden, M. (2001) Skate to Where the Money will be. 'Harvard Business Review.' November, p.72.
278. Cleevely, M. (2006) 'The Role of Ofcom in Encouraging Innovation'. London: Ofcom.
279. Fairbairn, C. (2006) Serving the Public Good in the Digital Age: Implications for UK Media Regulation. In Richards, E., Foster, R., and Kiedrowski, T. (2006) 'Communications - The Next Decade: A Collection of Essays Prepared for the UK Office of Communications.' London: The Stationery Office. Chapter 2.
280. UK Trade and Investment (2007) 'ICT Marketing Strategies: Evidence Base' [CD-Rom] London: UK Trade and Investment.
281. Ibid.
282. Ibid.

whom (family, friends, communities of interest, strangers), and with what (fixed phone, mobile, the PC, laptop, PDA, PSP) – continues. For example:

- Mobile penetration is now over 100 per cent in the UK[283]

- 57 billion text messages were sent during 2007 in the UK[284]

- 23 per cent of 8-9 year olds in the UK now have mobile phones, and by the time children are 13 this proportion has increased to 70 per cent[285]

- The 16-24 age group spends proportionally more time online than using radio or TV[286] and over 70 per cent of the 16-24 age group use social networking web sites[287]

- There were 50 million blogs in 2006 with around 175,000 new blogs created each day[288]

These technological changes have led to expanded choice for the consumer (for example, new TV channels, easy access to information on the internet); the consumer taking control of content choices (for example, audiences are no longer dictated to by 'authorities' and professionals with the advent of the personal video recorder and internet libraries for example); and individuals contributing user-generated content in an interactive and iterative way. Sites such as MySpace, YouTube, Bebo and Facebook, and Second Life have given individuals the opportunity to connect in new ways, create communities of interest and social networks, share information and views and produce own-generated material and content.[289]

3.5 Skills weaknesses are a potential barrier to innovation

A potential barrier to the development of the sector and innovation in general, is that of skills weaknesses and shortages. Against a wider backdrop of a decline in IT-related education and gender imbalances in recruitment, for the IT and telecommunications sectors, firms have reported difficulties in attracting individuals with the right skills.[290] In a recent survey for e-skills UK, 22 per cent of the IT and telecommunications firms who were trying to recruit staff reported difficulties in attracting applicants with the right skills. For the telecommunications sector specifically, rapid technological changes and convergence are expected to impact on the existing and future telecoms workforce and the skills that will be needed. New technologies such as VoIP, WiMax, 3G and NGNs enable new applications but demand new and up-graded skills of IT and telecommunications workers.

More broadly, business and innovation specific skills are also needed in order to leverage technical innovation into business innovation. Telecommunications professionals will need to obtain new business-oriented skills to play a key role in the analysis, design and development phases of technological development along with skills to manage increasingly global supplier relationships.[291]

4. Innovation is hidden because of incremental development, new service offerings and the introduction of new forms of organisation and collaboration

4.1 Significant levels of traditional innovation in telecommunications is incremental in nature

Although radical changes have taken place within the sector over the last few years, a significant amount of incremental development to refine existing products and services is also undertaken by firms within the sector in order to remain competitive in the market. However, incremental improvements, such as a new pricing structure or a technological development that improved functionality on a mobile phone, would not be counted within traditional measures of R&D as they are not considered as significant advances. Such narrowly focused metrics may mean that some forms of innovation and value creation are not being adequately captured.

4.2 Organisational and business model forms of innovation are not sufficiently captured by traditional metrics

New organisational forms and collaborative arrangements have been adopted by firms in the sector and have enabled new, and more open, ways of operating with other firms, suppliers, consumers and technologies in the innovation process. However, such Type II forms of hidden innovation are not recorded in traditional measures of innovation, despite the potential of such forms to contribute significantly to innovation and performance.

4.3 Exploitation of existing technologies to support service innovation

A significant source of opportunity has opened up for the sector via technological

283. Office of Communications (Ofcom) (2007) 'The Communications Market 2007'. London: Ofcom. Chapter 4: pp.271-272.
284. Mobile Data Association (2008) 'Press Release Facts and Figures.' [online] Available from: http://www.themda.org/PressReleases/Page_Press.asp
285. Mellor, P. (2006) EU Investigates Mobile Phone Danger, Protecting our Children. [online] 'PC Advisor.' London: PC Advisor, July 2006.
286. UK Trade and Investment (2007) 'ICT Marketing Strategies: Evidence Base' [CD-Rom] London: UK Trade and Investment.
287. Ibid.
288. Cyber Journalist (2008) 'How Many Blogs are There? 50 Million and Counting.' [online] Available from: http://www.cyberjournalist.net/news/003674.php
289. Fairbairn, C. (2006) Serving the Public Good in the Digital Age: Implications for UK Media Regulation. In Richards, E., Foster, R., and Kiedrowski, T. (2006) 'Communications - The Next Decade: A Collection of Essays Prepared for the UK Office of Communications.' London: The Stationery Office. Chapter 2; Leadbeater, C. (2006) The Genie is Out of the Bottle. In Richards, E., Foster, R., and Kiedrowski, T. (2006) 'Communications - The Next Decade: A Collection of Essays Prepared for the UK Office of Communications.' London: The Stationery Office. Chapter 5.
290. e-skills UK (2008) 'Technology Counts IT and Telecoms Insights 2008.' London: e-skills UK.
291. Ibid.

convergence. There is great potential to exploit converging telecommunication technologies to support new services (such as triple play and TV services on mobile phones). Deploying technologies for new service provision (a Type III form of hidden innovation) is not currently captured in traditional metrics despite the potential contribution this can make to a firm's revenue and innovation portfolio.

4.4 Firm-level and localised innovation is important but is unmeasured

At the firm-level, telecommunication firms may be innovating on localised, individual projects through sharing experience and knowledge or working creatively in practice to solve small-scale problems. However, this form of hidden innovation (Type IV) may not be captured in a formal way by the firm or recorded in R&D metrics. Conversely, firms may have formal measures in place for capturing innovative and efficient processes in an effort to increase effectiveness, but this may still be unmeasured by formal and official metrics for innovation.

5. Innovation could be better measured by sector-specific surveys to capture innovation at a firm level and by including new forms of organisational and business model innovation

5.1 Sector-specific surveys could provide a more detailed source for capturing incremental and localised forms of innovation

Type I (incremental) and Type IV (localised) forms of innovation could be better captured in surveys specific to the sector. Some surveys already exist[292] and examine the productivity and competitiveness of the sector and its links with strategic management and leadership skills. Conceivably this type of survey could be expanded to include insights on innovative processes and practices within the sector. The Institute of Telecommunications Professionals (ITP) aims to improve working practices within the sector through information and networking activities; more importantly, it aims to inspire broader thinking and promotion of best practice within the sector. Surveying ITP members could be an initial way more formally to capture the innovative ideas and practices of individuals working within the sector (see also section 5.4).

5.2 Organisational and business model innovation could be better measured by the rate of adoption and the effect of such forms on an individual firm level and across the sector

As new organisational forms, more collaborative arrangements (such as open and user-led innovation) and new business models have started to be adopted by some firms in the sector, this Type II hidden innovation could be better measured at the firm-level by assessing the contribution and impact of such forms to firms' innovation performance and working practices. Assessments of sector-wide adoption rates of new organisational forms and innovative practices could also be added into analyses of innovation within the sector.

5.3 Levels of investment in services could be measured to better capture this important contribution to innovation

The technologies that have developed in the sector have enabled new service provision by firms (a Type III form of hidden innovation). Levels of investment that firms make in service innovation, and returns on such investments, should be accounted for and recorded in analyses of the sector to give a more accurate and fuller picture of innovation.

5.4 Firm-level estimates of innovation

Some firms in the sector have begun to put in place more formal measures for capturing innovative and efficient practices and processes in an effort to increase effectiveness and performance; such metrics could be more formally recorded in traditional measurements. For example, BT uses 'RFT' (Right First Time – meaning no repeat faults); 'RCT' (Reduced Cycle Time – reduced costs); and 'L2C' (Lead to Cash – the time it takes to convert a sale to revenue) measures to assess the effectiveness of some business processes.[293] Although, BT has yet to publish data on these metrics, and assuming these measures continue, they could potentially be reasonable measures of Type IV hidden innovation. As a way to incentivise and reward innovative behaviour and practices with its employees and suppliers, BT also has just set up (in 2007) 'Innovation Awards'. Such a practice could be encouraged across the sector. Internal measures other firms use within the sector to measure efficiency and performance, and the impact this can have on the innovation process, should be investigated further.

292. Such as e-skills UK's regular IT and Telecoms insight reports.
293. Ovum (2007) 'BT and its ICT- Two Case Studies.' London: Ovum Plc.; Ovum (2006) 'New Metrics for a New Age.' London: Ovum Plc.

6. Existing government policy has focused largely on regulatory activity, centred around creating a competitive environment, but policy could do more to support forms of hidden innovation

6.1 Existing policy has focused on the regulatory environment, which is centred on stimulating competition and promoting availability of technologies for economic and social benefit

In order to ensure that the UK remains a competitive place to live, work and conduct business, existing government policy (through the former DTI and now through BERR and the sector regulator, Ofcom) has been targeted around promoting an appropriate environment for the telecommunications sector.

Started by the deregulation process in the early 1980s, BERR's responsibilities continue to focus on ensuring that framework conditions for a competitive environment for fixed line and mobile telecommunications are in place.[294] Creating a more competitive environment has undoubtedly resulted in, for example, greater choice for the consumer of operator or network provider, lower prices for calls and new business entrants to the market who have brought new technological innovations (such as 3G) to the sector and wider society and economy.[295]

With the advent of broadband, government policy has focused on supporting the development of appropriate infrastructure for the widespread expansion and utilisation of broadband through telecommunication next generation networks – a part of the government's 'digital strategy' – to ensure that the UK remains competitive with other countries (such as Korea, Japan, the US and France) who are well advanced in investing in new fibre-based infrastructures. Initially, a part of the 1998 Knowledge Economy White Paper, the strategy aimed to make the UK 'digitally rich' (as it lagged behind European and developed world counterparts) by improving access and utilisation of digital TV, broadband, and creating a competitive and innovative deregulated mobile and fixed-line phone market. Deregulation also facilitated the use of WiFi by operators, facilitating mobility in communications. Now the digital strategy is carried on through the work of BERR and through the Information Age Partnership.[296]

With the creation of the 'super' regulator Ofcom in 2003 and the Telecommunications Strategy Review in 2005, the sector began to experience more 'light touch' regulation, with part of Ofcom's remit to stimulate and encourage innovation.[297] However, with technological and sectoral convergence, Ofcom needs to ensure that regulation keeps pace with new and emerging digital technologies and their development and how such technologies need to be regulated. It is possible that new regulatory models may be needed in the future to fit with converged communication technologies.[298]

6.2 Broad-scale support to ensure appropriate regulation and infrastructure of the sector is necessary, but policy needs to take a more holistic approach to realise the full value of the sector

Given the sector's social and economic pervasiveness, and its comparative importance as an enabler to other sectors, the sector is somewhat neglected in grand-scale support strategies compared with the aerospace and automotive sectors. However, a recent useful development has been the Knowledge Transfer Network (KTN) in Digital Communications[299] covering the telecommunications, IT and broadcasting sectors established in December 2007. Industry-led, with members from across the value chain, academia, the regional development agencies and devolved administrations, and formed with funding from the Technology Strategy Board (TSB), the Digital Communications KTN aims to focus on facilitating knowledge transfer across the sector, to act as a 'network of networks' and to promote innovation.

First, the KTN aims to establish technological and capability 'roadmaps' to identify new and emerging technologies and the capabilities that will be needed within the sector in the future to ensure effective implementation and that competitive advantages are realised for the UK. Issues that will also be covered include: barriers to innovation and development; the use and role of venture capital; skills needs and recruitment issues; and adjacent sector requirements. Second, such road maps will be benchmarked against other countries, with the aim to develop an overarching strategy for digital communications in the UK.

The Digital Communications KTN is a useful first step in developing a coherent and current understanding of the sector, the changes that have been occurring and the role that innovation plays in those changes. The KTN should provide a coordinated, holistic and industry-led voice for the sector.

294. Government policy has also focused on health and environmental issues regarding mobile phones.
295. For example, the UK was the first in Europe to enter the 3G market, stimulating competition from other operators. 3G offers the opportunity of greater capability in data transmission and new services such as video-clips and photo-messaging.
296. Cabinet Office Prime Minister's Strategy Unit and the Department of Trade and Industry (2005) 'Connecting the UK: the Digital Strategy.' London: HM Stationery Office.
297. Cleevely, M. (2006) 'The Role of Ofcom in Encouraging Innovation'. London: Ofcom.
298. New regulatory models may be needed to deal with broadcast and telecommunications convergence, for example; see Fairbairn, C. (2006) Serving the Public Good in the Digital Age: Implications for UK Media Regulation. In Richards, E., Foster, R., and Kiedrowski, T. (2006) 'Communications - The Next Decade: A Collection of Essays Prepared for the UK Office of Communications.' London: The Stationery Office. Chapter 2.
299. The term 'digital communications' reflects the changing nature of the underpinning technologies (which are no longer separate and distinct) and that the sectors are converging.

Policy should also consider the broader forms of hidden innovation and the value that this creates for the sector. Organisational innovations can provide firms with new opportunities for revenue and growth and can be just as important as technical innovations for successful commercial exploitation and operation. Firms should be encouraged to explore new business models and ways of working if this brings commercial value and increases sector performance. However, this places an important emphasis on their having the right skills.

As identified by the Digital Communications KTN, the skills that are becoming necessary to deal with technological advances and their commercial exploitation will become increasingly important, especially given an increasingly global competitive environment. Moreover, innovation within the sector will be improved if skills weaknesses and shortages are addressed. On the technical side, up-skilling to deal with emerging technologies (for example, VoIP, 4G, NGNs) will be necessary for technical personnel. On the business side, managers and business professionals will need to develop – alongside a technical understanding – deeper business and innovation skills to ensure that technological advantage is turned into commercial advantage.

To address the wider recruitment issues, new approaches are needed to attract and retain individuals into the sector in order to sustain its growth. For skills needs, initiatives should encourage employers to invest in skills and training to address employee skills weaknesses and gaps. A recent report by the telecommunications sector skills council (e-skills UK) recommends that policies should focus on:

- a clear and simplified national framework for professional skill progression (including technical, business and interpersonal competencies);
- the targeting of small firms, where recognition of the need to train and up-skill employees is traditionally low; and
- up-skilling of professionals from Levels 2 to 3 and beyond. Universities and colleges may have a bigger role to play in supporting this workforce development, whilst working in partnership with employers, to ensure that education and training meets required needs.[300]

300. e-skills UK (2008) 'Technology Counts IT and Telecoms Insights 2008.' London: e-skills UK.

Appendix D: Software and IT Services

Innovation through technological disruption, facilitating a role for hidden innovation in new organisational forms, business models and the provision of services

1. Software and IT services is a vitally important sector for the UK, as an enabler of other sectors and activities and in underpinning the knowledge economy

In the UK, the software and IT services sector involves: the development of system software; contract/bespoke software; systems integration; systems analysis and design; software architecture and design; project management and infrastructure design.[301]

Specifically, the sector can be broken down into three stages of activity. First, development: software is developed either for bespoke use (designed to fit the particular needs of a customer) or for off-the-shelf use (such as Microsoft's Office package). Software development is closely linked to the computer hardware industry, as software must be designed specifically to the hardware on which it will be installed.

Second, systems design: designing large and complex business IT systems requires expertise; consequently a consultancy industry has arisen around this need. Large international consultancies like Accenture specialise in providing IT solutions and advice on information management to large organisations.

Third, retail and implementation: computing customers will draw on a range of sources to complete their overall package – acquiring hardware and software through retailers, resellers or via IT consultancies.[302]

The UK sector employs around 600,000 people (with around half employed in software and half in IT services) in 100,000 firms,[303] with a GVA of £23 billion[304] with exports of £4.7 billion.[305] The UK market for software products and services is the largest in the EU[306] and growth is expected to continue in the medium term through to 2012.[307]

There are a number of significant clusters in the UK: in England, software and IT firms are based around Cambridge, the Thames Valley area, Manchester and the Midlands; in Scotland there are clusters around Silicon Glen and Dundee (which has a significant concentration of software games firms). Northern Ireland and Wales also have small but growing sectors of IT and software activity.

Key consumers of software in the UK are the financial services sector, the health services sector and the communications sector.[308] The UK's growth is also partly due to substantial investment over recent years in e-Government initiatives such as new IT systems for the NHS (£30 billion over the last ten years); Transport for London's Congestion Charging and Oyster Card projects; and 'Shared Services' (a process of sharing back-office resources across Councils and Departments).[309]

The sector comprises some very large, global players and a significant number of smaller, specialist software firms in the UK. Almost all the world's major software players have a substantial UK presence, whether as an R&D operation, a logistics distribution network, or sales and marketing operation, and include Accenture, EDS, Google, IBM, Infosys, Microsoft, Oracle, SAP, HP, EDS, CSC and Tata. Indigenous UK firms include Asidua, Autonomy, Capita, Lagan Technologies, LogicaCMG, Misys, nCipher, Northgate, RM, Sage, and Xansa.[310]

301. Related activities of the sector include: facilities management, consulting and training, supply of contract staff, office software and equipment, software maintenance, hardware design, manufacture and maintenance, information supply and distribution, communications services, research and development. See The Work Foundation (2007) 'Staying Ahead: The Economic Performance of the UK's Creative Industries.' London: Department for Culture, Media and Sport.

302. Ibid.

303. Office for National Statistics Labour Force Survey Jan-Mar 2007; Inter-Departmental Business Register (IDBR) '2004-2007 Analysis of UK Local Units in VAT based Enterprises.' Newport: ONS.

304. 2006 figures. Forecasts predict growth at an annual rate of 4-6 per cent until 2011 (this includes support services, project services, and IT outsourcing, but excludes business process outsourcing). See Holway@Ovum (2007) 'UK S/ITS Market Trends Report' (August). London: Ovum Plc.

305. Export figures from 2004. The global software and IT services sector generated revenues of $698 billion in 2006. A third of the total ($228 billion) was related to software products and $470 billion on IT Services. Ibid.

306. European Information Technology Observatory (EITO) (2007) 'European Information Technology Observatory Yearbook.' Autumn 2007. Brussels: EITO.

307. Ovum (2007) 'Ovum Global Software Forecasts (March).' London: Ovum Plc.; Datamonitor (2007) 'Global IT Services Forecasts (September).' London: Datamonitor.

308. Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.

309. UK Trade and Investment (2007) 'ICT Marketing Strategies: Evidence Base' [CD-Rom] London: UK Trade and Investment.

310. Ibid.

The UK has established strengths in the software and IT services sector in: accounting and finance software (such as Sage); asset management (for example, Misys); content management software (for example, Autonomy). Particular strengths are in software security (where the UK has the second largest market in Europe, accounting for 22 per cent of the total market).[311] The games software market is another: three of the best-selling games in the world were created in the UK. The UK is the largest market in Europe and the third largest market in the world.[312] The size of the UK games sales market in 2006, on sales of console, PC and handheld games software, console hardware, and console and PC gaming peripherals in the UK, totalled £2.18 billion. There is a significant cluster of games software firms in and around Dundee in Scotland.

2. Innovation in the software and IT services sector has enabled radical and emerging technologies which are facilitating new organisational forms and business models

2.1 Traditional innovation in the software and IT services sector is a mixture of radical and incremental innovation developed by large and small suppliers

2.1.1 R&D is used primarily for product development by large and small scale software suppliers

For firms in the software segment of the sector, product innovation is a main focus area of R&D, and R&D budgets can be a significant proportion of costs for large companies. For example, IBM spent $6.5 billion (6 per cent of revenues) on R&D in 2006, while HP spent $3.6 billion (or 4 per cent of revenues).[313]

The sector is also composed of a significant number of small firms, particularly in the UK[314] and the R&D Scoreboard for 2007 (based on 2006 data) demonstrates that R&D expenditure by the sector amounted to £1.2 billion, making it joint third (with the electronics and IT hardware sector) behind the pharmaceuticals and aerospace sectors. The top four UK firms in the software and IT services sector (Telent, Sage, Misys, and NDS) accounted for 40.6 per cent of R&D investment for the sector.[315]

Large, global technology suppliers, which dominate the sector, have research and development facilities increasingly located close to key skills sources (as in India), to partners (such as Accenture's Centre of Excellence at SAP's headquarters in Waldorf, Germany) or close to clients. Many of these suppliers, including IBM, Microsoft, Nortel, Northgate Information Systems, Sage, and Toshiba, maintain research laboratories in the UK.

R&D resources are used to: (i) investigate radically new and emerging areas of knowledge (over the medium to long term) and to develop the next wave of disruptive technologies (such as SOA and virtualisation – see Section 2.3); (ii) undertake incremental improvements in existing software products, over a shorter time frame, to maintain competitive advantage. Large suppliers may have technology offices for this purpose, which draw on and codify improvements and repeatable good practice.

Small firms are also important to innovation, as they can be more agile and dynamic than large firms and respond more quickly to changes in the market place. Such firms can often be at the forefront of research and development, generating new products, services and technologies. Consequently, large, global suppliers engage with small firms in their

NaturalMotion

One example of a university spin-out is NaturalMotion. Based on research conducted at Oxford University, NaturalMotion is now a leading software firm which has developed technology that will be used in the next generation of video games. Its breakthrough software, Dynamic Motion Synthesis (DMS), creates high-quality 3D character animation in real time by combining artificial intelligence, biomechanics, and dynamics simulation.[316] DMS can be used on PlayStation 3, Xbox 360 and PCs (using NaturalMotion's Euphoria product). NaturalMotion markets, sells and supports its products globally to customers in the games, film, post production and broadcast markets. Clients include LucasArts and Rockstar, the developer behind one of the world's best-selling computer games, *Grand Theft Auto*.

311. European Information Technology Observatory (2007) 'European Information Technology Observatory Yearbook.' Autumn 2007. Brussels: EITO.
312. Entertainment Leisure Software Publishers Association (2006) 'Frontier Economics Comparative Analysis of the UK's Creative Industries.' London: ELSPA.
313. IBM (2006) 'Annual Report 2006.' New York: IBM; Hewlett-Packard (2006) 'Annual Report 2006.' Palo Alto, CA: Hewlett-Packard.
314. Most of the sector's firms are listed on AIM and other small exchanges or are unlisted, see Department for Innovation, Universities and Skills/Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
315. Ibid.
316. NaturalMotion (2005) 'Dynamic Motion Synthesis'. White Paper. Oxford: NaturalMotion.

supply chains by buying products or services, or augmenting in-house skills and competencies. Large firms may go further by 'buying-in R&D' through acquiring small, innovative firms as a way to attain access to the next wave of new generation technologies and to maintain competitive advantage.

2.1.2 UK universities have a role to play in the innovation process

A number of UK universities have world-class research groups specialising in ICT-related research. Specialist software research groups exist at Southampton, Edinburgh, Nottingham, Newcastle, Imperial College, Surrey, Bath, Oxford, University College, Cambridge, Manchester, and Warwick Universities. Research carried out in such institutions may ultimately be developed by firms in the software and IT sector, or commercialised via university spin-outs. This form of R&D can be of crucial importance in making technological advances in the sector, which can radically alter and shape the future market place for software and IT.

2.1.4 Process innovation is a focus for IT services

While product innovation is the primary focus for the software segment of the sector, process innovation is more a focus for IT services, where the process, together with an IT professional's expertise, forms the service that is provided to clients. R&D budgets are also used for process innovation in global firms. For example, Accenture is investing $450 million in developing products and services around Service Oriented Architecture (SOA).

SOA is one example of process innovation in the sector, as an innovative new way of building and managing business applications. Other approaches such as 'Agile' and 'Lean' software development are also examples of process innovation. Lean is a generic streamlining approach for all production systems, but Agile is specific to product development environments.

Agile development is an alternative to traditional product development (which emphasise initial major planning). Agile promotes development iterations throughout the life-cycle of the project via feedback through tests and releases of the evolving software (consumers and clients form part of this feedback). One survey of 1,700 firms across 71 countries found that using Agile processes led to increased productivity for 55 per cent of respondents; reduced software defects for 54 per cent; and reduced costs for 28 per cent.[317] Other benefits reported were better alignment between IT and business goals and reduced project risk.

Fujitsu IT Services' 'Sense and Respond' methodology for IT Service management, and its 'Triole' methodology, is an example of a process innovation. The process aims to incentivise continuous improvement in service delivery. Fujitsu's Sense and Respond approach is grounded on the Lean and continuous improvement principles, with the aim of capturing, improving and measuring elements of service provision that create value to clients.

2.2 Innovation is changing in the sector, as technology suppliers realise the limitations of R&D, and process innovation becomes commoditised

Many suppliers of technology and IT services are increasingly faced with the limitations of R&D-driven product innovation. Large suppliers have become frustrated with the length, cost, and quality of the product development process. For example, Microsoft took five years and billions of dollars to develop Vista (the latest version of its operating system software).[318]

The relatively short life cycle of software products exacerbates this issue, and is one reason why some large scale suppliers acquire start-ups with innovative products and services – a process of buying-in R&D (see Section 3.2). A second reason is that product or service innovations (for example, virtualisation, SOA) are relatively rapidly matched by competitors who quickly launch similar products, eroding competitive advantage.[319]

Process innovation in the software and IT services industry continues to be strongly driven by intense competition, and price and margin pressures (see Section 3.4). These factors are forcing suppliers to gradually, but relentlessly, move away from a 'craftsmanship model' where a highly skilled (and highly paid) developer or consultant develops or delivers the software/service to a more industrialised and commoditised 'factory model', where less skilled (and lower cost) resources can deliver equal or better quality with predetermined process templates, industry maps or creative work packaging.[320]

317. VersionOne (2007) 'The State of Agile Development 2nd Annual Survey.' Alpharetta, GA: VersionOne.
318. Booz Allen Hamilton (2007) 'Money Isn't Everything. A Survey of 1000 Global Largest Spenders on R&D.' Virginia: Booz Allen Hamilton.
319. Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.
320. Ovum (2006) 'Productised Business Process Services: Redefining Software and Services.' London: Ovum Plc.

2.3 New services, organisational processes, business models and new ways of collaborating are increasingly important within the sector

2.3.1 The emergence of disruptive technologies is changing the nature of software and IT services provision and is facilitating the development of new services

Disruptive new technologies which have emerged from within and outside of the sector – technologies such as virtualisation software, Service Oriented Architecture (SOA) and Web 2.0 – are significantly changing the dynamics of the software and IT services sector and are enabling the development of new services.

Virtualisation software (a technology enabling a single physical machine to run multiple instances of software in parallel) is not only opening a new and growing market segment in software, but is reshaping the hardware and outsourcing markets. Virtualisation software enables client organisations to use fewer physical machines to deliver the same computing loads by using computing spare capacity. This puts pressure on hardware sales, and reduces outsourcing revenues of IT services companies (who are paid by number of machines managed).

Service Oriented Architecture (SOA) is a new approach to building and managing business applications by breaking them into loosely coupled units (such as Enterprise Resource Planning (ERP) along with Customer Relationship Management (CRM) applications). SOA is not only reshaping the packaged software applications market segment, but is providing new opportunities for IT services projects, as companies move to integrate legacy custom applications using SOA principles.[321] One study estimates that SOA could reduce development costs by 25 per cent (about $53 billion) over five years across the 2,000 largest firms worldwide.[322]

2.3.2 New technologies are also enabling the development of new business models and new forms of business practice

The software sector has traditionally relied on the dominant 'licence + maintenance' business model. This has been disrupted by the emergence of the internet which has enabled the development of the 'Software as a Service' (SaaS) business model. This is, in turn, causing disruptions in the organisation and implementation of IT service processes, as software development for large on-premises implementations are being reduced and altered.[323]

Software as a Service

Software as a Service (SaaS) is where software applications (such as customer relationship management, human resources, accounting and email) are hosted by a provider online, rather than installed on the user's premises, and priced on a per usage basis. Access to the web and a broadband connection are the only IT infrastructure needed. The model makes it easier to share data with third parties, enables backup data centres for disaster recovery, and crucially, for smaller businesses, offers access to enterprise level application services that would be difficult to achieve in-house.

SaaS is predicted to capture more than a quarter of the $200 billion business software market by 2011.[324] The market leader, Salesforce.com (a US firm founded in 1999), serves more than 38,000 other firms and has one million paying users for its 'on-demand' Customer Relationship Management (CRM) software, with revenues around $700 million in 2007.

Siebel Systems, Microsoft, Oracle and SAP have also entered the SaaS market. Tata Consultancy Services (TCS), India's largest service provider, is introducing a hybrid SaaS/services model that it calls 'IT-as-a-service', which is being aimed primarily at the local SME market and is predicted to be worth up to $9 billion a year.[325]

However, in the UK, SaaS does not yet appear to be challenging the dominant licence and maintenance model; its adoption amongst small UK firms appears to be limited. For example, one survey found that around 70 per cent of small software firms were continuing with the traditional business model (licence sales, maintenance, advice and integration). This may become increasingly outmoded, as awareness amongst potential users increases and the future predicted growth of SaaS occurs.[326] One notable exception is Huddle, a UK start-up established in November 2006, which combines online collaboration, project management and document sharing using social networking principles.

321. Ovum (2007) 'SOA Vendor Strategies.' London: Ovum Plc.
322. Aberdeen Group (2006) 'The SOA in IT Benchmark Report.' Boston: Aberdeen Group.
323. Ovum (2007) 'SaaS: Opportunity or Threat for IT Services Vendors?' London: Ovum Plc.
324. Desisto, R. Pring, B. Lheureux, B., and Karamouzis, F. (2006) 'SaaS Delivery Challenges On-Premise Software.' Stamford, CT: Gartner.
325. All, A. (2008) 'India's Tata Consultancy Services Introduces Hybrid SAAS Model.' [online] Available at: http://www.itbusinessedge.com/blogs/sts/?p=324
326. Intellect (2007) 'Software and IT Services Report – The Future.' London: Intellect.

Value-based pricing models represent both a business model innovation in the IT services industry, and an enabler for collaborative innovation between suppliers and clients in improving efficiencies and effectiveness. Value-based pricing is a commercial model in an IT services contract where the supplier is paid depending on the business outcomes it delivers for the client (for example, transactions processed) rather than on the more traditional contractual arrangement of fixed price or time and materials. For example, IBM has contracted with India's Bharti Telecom to manage their whole IT and telecommunications infrastructure and applications in return for a percentage fee of Bharti's revenues. Driven by competitive pricing, and scarcity of skills in certain localities, IT services firms see value-based pricing as a tool for driving 'non linear' revenue growth, that is, not directly related to the number of people or costs they incur. Value-based pricing is also seen by suppliers as a key incentive for collaborative innovation[327] (see section 5.4).

2.3.3 New forms of collaboration and sources of innovation are emerging

Facilitated by the internet, new forms of collaboration are occurring, which is leading to the development of new and more open practices in the innovation process. Open source software (OSS) has facilitated this form of collaboration. Web 2.0 technologies are also enabling collaboration and participation and are changing the dynamics between the software and service provider and the end-user.

Open source software (OSS) is built on the principle that the source code of a program should be readily accessible, so that users have the right to copy, modify, maintain and redistribute, without paying royalties or fees. Examples include Linux, Firefox and Wikipedia.

Open source software can facilitate innovation. Open standards in OSS can be the basis for collaborative innovation as source codes are openly documented, published without restriction and so freely available for adoption. Subsequently, standards can evolve through collaboration with organisations and communities and create and add value. This could potentially enable breakthroughs in innovation by fostering and generating a broader range of ideas and creativity from a wider ecosystem of contributors: collaborating with partners, clients and individuals for innovation can help solve real business challenges.

IBM, Sun and Novell have endorsed and contributed to open source software by releasing industry code to be augmented by individuals and academics; adopting open source applications for enterprise use; and sharing intellectual assets. IBM has also developed a 'patent commons' initiative by pledging 500 patents to the open source community. IBM maintains that using OSS has indirectly created more value than by limiting the use to inventors.[328]

Web 2.0 technologies, using the internet for new forms of collaboration and participation,

327. Ovum (2007) 'Innovation in IT: Vendor Strategies.' London: Ovum Plc.

328. Cohn, O. (2005) 'Value Creation through Collaborative Innovation.' Haifa Research Lab: IBM Corporation.

Autonomy

Founded in 1996 and built on ground-breaking research carried out at the University of Cambridge, Autonomy's technology uses a unique combination of mathematical principles (Bayesian Inference and Shannon's Information Theory) to form a conceptual and contextual understanding of any piece of electronic data, including unstructured information, whether it is text, email, voice or video. This is known as 'meaning-based computing'. Autonomy's products can deal with tasks such as enterprise search, taxonomies, compliance, customer relationship management and customer experience management.

Autonomy has utilised an innovative business model in its development. The firm has leveraged its IP by avoiding the small individual user, instead embedding its software in over 300 other software firms who then license Autonomy's technology to power their own software products. Clients include Citrix, Computer Associates, EDS, IBM Global Services, Novell, Veritas, BAE Systems, Ford, Ericsson, Shell, the BBC, and public sector agencies including the US Department of Defense, NASA and in the UK, the Houses of Parliament. Autonomy has rapidly become the market leader in this area and has generated annual revenues of over $250 million.

are changing the collaboration software market, as well as opening new project services opportunities for IT services firms.[329]

Traditionally, most software applications have been developed by major suppliers, such as Microsoft, SAP, Oracle or IBM. With broadband connectivity now common, a firm can now choose to buy from existing large suppliers or from the increasing independent software sector. By amalgamating software from these various sources (a process referred to as 'mash-ups'), the internet is facilitating innovative approaches.

Web 2.0 will become increasingly prevalent in the business-to-business environment – the dawning of 'Enterprise 2.0' services and applications – with an emphasis on open and collaborative ways of working with the end-user. Rather than software being delivered in a 'discontinuous and periodic update' approach, as is currently used, the availability and use of software is likely to become more fluid with applications constantly updated and fine-tuned on a rolling basis. End-users will become an integral part of the development process.[330]

3. Software and IT services innovation is determined by global competitors, concentration and convergence within and outside the sector and education and skills weaknesses

3.1 Success and survival are key…

Commercial success and survival are the key drivers for innovation in the software and IT services sector. Successful innovators, particularly small start-ups, can earn millions or even billions of dollars. Google, which was only formed in 1996 on the basis of an innovative search technology, is today the largest technology firm with a market capitalisation of $219 billion.[331] For large IT suppliers, the motivation to innovate is continued market relevance. The sector is moving at such a rapid pace that the risk of changes in demand, competitive pressures, and technology obsolescence are very real. Combined, these factors drive the continued acquisition of promising start-ups by dominant companies in the sector.

3.2 …which is driving industry concentration

The software and IT services sector is dominated by a number of very large global suppliers (such as Accenture, IBM, Microsoft, Oracle, SAP, HP and EDS). These firms have been undertaking acquisitions of both small players with promising products and also medium-sized competitors (as with Oracle's acquisition of Siebel, Retek and PeopleSoft), leading to continued industry concentration.[332] Yet, start-ups with innovative products in new areas (like VMware in virtualisation) continue to mushroom and challenge global giants. Conversely, many of the successful start-ups end up being swallowed by one of the global players – a large firm strategy of buying-in innovative R&D.

3.3 Convergence of technology is increasing competition from within and outside the sector

SOA and SaaS are driving convergence between the software and IT services sub-sectors, firms, products and services. New sector entrants, such as telecommunications companies (BT, Deutsche Telekom, France Telecom and AT&T) are also entering the IT services market, particularly in the infrastructure management area. Online brands such as Google are entering software markets via the SaaS model, enabled by telecommunications firms with their hosting and high bandwidth connectivity services. Furthermore, pure business process outsourcing (BPO) providers such as Capita are increasingly competing with IT outsourcing firms as business process outsourcing contracts often include management of both the technology and the process. The combination of slowing growth, intense competition and new entrants from multiple directions are all cutting prices and margins, and rapidly commoditising existing software products and IT service offerings.[333]

3.4 Globalisation, off-shoring and the rise of emerging markets offer both opportunities and threats to the UK sector

In the early 1990s, driven by globalisation, competition and cost considerations, American and European software and IT firms began to locate some routine tasks and activities (IT help desks and call centres) 'off-shore' in low-cost locations. India was the favourite choice; it was English-speaking, numerate and had comparatively cheaper labour. This began the development of a fledgling IT industry in India, facilitated by the liberalisation of the telecommunications sector in the late 1990s, which led to declining bandwidth costs.

More recently, in the lead up to the year 2000, US and European firms, experiencing a shortage of qualified software engineers in their own markets to address the IT issues

329. Carter, S. (2006) 'SOA and Web 2.0: The Language of Business.' Palo Alto: IBM Press.
330. Intellect (2007) 'Software and IT Services Report – The Future.' London: Intellect.
331. Based on the NASDAQ share price of $693 on 30th November 2007; see also Vise, D. (2005) 'The Google Story.' London: Macmillan.
332. Intellect (2007) 'Software and IT Services Report – The Future.' London: Intellect.
333. The term 'red oceans' of highly contested market spaces for highly competitive markets, and 'blue oceans' for emerging niche areas where competition is low or non existent has been used to identify uncontested market spaces; see Chan Kim, W., and Mauborgne, R. (2005) 'Blue Ocean Strategy: How to Create Uncontested Market Spaces and Make the Competition Irrelevant.' Boston, MA: Harvard Business School Press.

predicted with the 'Y2K' threat, combined with escalating costs of in-house IT, were forced to look for developers and IT professionals in emerging (and cheaper) markets such as India.[334]

During this time, India had nurtured a highly educated pool of skilled software and IT experts, leading to the development of home-grown firms such as Infosys, Tata and Wipro. Such firms offer principally custom and packaged application development, testing and maintenance services (but also IT consulting, infrastructure outsourcing and business process outsourcing services) at significantly lower prices than their US or European counterparts. This (labour) cost advantage has enabled these firms to grow into multi-billion dollar organisations (for example, Wipro is worth $25 billion) and become powerful competitors in the software and IT industry to US and European counterparts.[335] The Indian software and business process outsourcing industry is expected to achieve $60 billion in exports of software and services by 2010; the UK is the second largest market for the Indian software sector after the US, at 18 per cent of total exports.[336]

Other competitors are also emerging from Latin America, Eastern Europe and China. China is predicted to be a particularly strong future competitor, potentially even replacing India as the choice location for off-shoring software and IT activities. Costs of off-shoring development to India have risen 15-20 per cent each year. Off-shoring in China is rising at an annual growth rate of 8 per cent in 2003 to 11 per cent in 2006. Even Indian software development firms now have large hubs in China, or plans to develop them.[337] China is predicted to develop its own software industry even faster than India did. Issues of literacy are being addressed, and 35 national training schools are aiming to train 800,000 software engineers. In China, exports increased by an average annual rate of 37 per cent between 2000 and 2006; and in computer and information services (including software development) it was 40 per cent.[338]

Off-shoring has undoubtedly provided UK firms with cost advantages. However, against a global backdrop of emerging markets, UK software and IT services firms must continue to harness and combine creativity, skills and innovative capability to remain competitive on the global stage.

3.5 Educational, recruitment and skills weaknesses are of critical importance for the sector

In addition to the issues of offshore relocation,[339] the UK software and IT services sector also faces major educational, recruitment and skills weaknesses, which has the potential to significantly impact not only innovation within the sector, but its future development.

First, there has been a decline in the number of people choosing to study the subject at school and university, and of those that do study IT-related subjects, fewer are choosing to enter and work in the sector. It has been estimated that employment in the UK's IT industry is set to grow around five times the national average, and that approximately 150,000 new entrants to the IT workforce are needed each year. However, there is a severe mismatch in the future workforce. Each year, fewer young people choose to study technology-related subjects at school and university. Between 2001 and 2006, 43 per cent fewer students took A-levels in computing and the number of individuals taking IT-related degrees almost halved between 2001 and 2005 (from 27,000 to 14,700). Few technology graduates choose to enter the IT sector and embark on a career in IT (estimated at only three out of ten graduates).[340]

Second, there are questions over the nature and quality of educational provision and concerns that the educational system fails to 'pull through' young people from school to university to the work place. For example: the GCSE in ICT is heavily focused on the acquisition of user skills rather than deeper study of computing and software technology; there is also a need to increase the number of young people studying STEM subjects, as these subjects are often required for a career in the sector; at the university level, concerns are that degrees do not keep pace with how quickly the sector, and the required skills for this, is evolving (for example, the current software language did not exist three years ago) and that graduates and new recruits do not always have the necessary 'work-ready skills'.[341]

Third, for the existing workforce, issues of re-skilling and up-skilling will need to be addressed, given the rapidly changing nature of the sector. This may mean that there is an increasing need for IT professionals to become 'lifelong learners' and to undertake continual professional development to update skills requirements. However, for some employers – particularly SMEs – this may prove difficult,

334. It has been estimated that net savings to the US economy, brought about by off-shoring, could result in $390 billion saved by 2010.
335. Ovum (2006) 'The Impact of Global Sourcing on the UK Software and Services Industry. A Study for the Department of Trade and Industry.' London: Ovum Plc.; Nasscom (2007) 'Strategic Review 2007: the IT Services Industry in India.' New Delhi: Nasscom.
336. NASSCOM (2008) 'Strategic Review 2008.' New Delhi: NASSCOM.
337. Ernst, S. (2007) China to Catch Up with UK in Five Years. In Dialogic (2007) 'Developing the Future: A Report on the Challenges and Opportunities Facing the UK Software Development Industry.' London: Microsoft.
338. World Trade Organization (2007) 'International Trade Statistics 2007.' Geneva: WTO.
339. Ovum (2006) 'The Impact of Global Sourcing on the UK Software and Services Industry - A Study for the Department of Trade and Industry.' London: Ovum Plc.; Confederation of British Industry and LogicaCMG (2006) 'Building a Globally Competitive IT Services.' London: CBI.
340. Price, K. (2007) To Succeed in the Global economy the UK Must Commit to Technology Skills. In Dialogic (2007) 'Developing the Future: A Report on the Challenges and Opportunities Facing the UK Software Development Industry.' London: Microsoft.

as they may not have the resources to provide such training.[342]

Lastly, skills shortages – the greatest gaps are in high-level technical skills such as computing and software engineering – are often filled by overseas developers and engineers (in 2005, around 21,000 software specialists from overseas came into the UK compared with around 2,000 in 1995). Whilst this undoubtedly brings its advantages – job gaps are filled, skills needs are met, new and different sources of knowledge and international experience are brought into the sector – it also highlights the very real skills gaps for the UK sector.

Together, these factors are creating a future skills challenge for the software and IT services sector in the UK in general, and specifically, for innovation. Skills, education and training develop the knowledge and flexibility to adapt and respond to market trends, act competitively and to drive innovation. Without individuals with the right skills sets – both technical and business-oriented – innovation, and the sector, will not flourish.

3.6 The issue of software piracy is a major concern to software suppliers and can limit resources for innovation

It is estimated that globally, 35 per cent of software on all computers has been obtained illegally, equating to £20 billion of lost revenues as a result of piracy in 2006 (for the UK, the figures are 27 per cent of software obtained illegally and around £840 million of lost revenues).[343] The scale of intellectual property (IP) infringement and the loss of revenues have an effect on resource availability and, arguably subsequently, resources for innovation as firms have less financial capacity to invest in research and development.

To a lesser extent, IP also acts as a barrier for collaborative innovation between a technology supplier and a client in the IT services industry. The issue often concerns ownership of IP developed during an IT project. For example, a considerable number of process maps, software modules and industry maps are created during SOA implementation, and a lack of clarity regarding who owns the IP, and how the benefits are shared from it, can cause friction in the supplier and client relationship and the level of collaborative innovation generated. Protection and clarity on IP is central to innovation in any market, and infringement can substantially reduce the incentives for innovation.

4. Innovation is hidden because of incremental development within the sector and because new services, business models and forms of collaboration are not captured by traditional metrics

4.1 Some traditional innovation in software and IT services is incremental, iterative development, which goes unrecorded by formal measurements of innovation

The *Frascati Manual* only acknowledges software development that represents a 'scientific and technological advance' as R&D and hence as innovation.[344] Therefore, innovation that is iterative and incremental (Type I hidden innovation) in nature – whether improving an existing software programme, or enhancing the efficiency of an operating system – may not be counted as innovation, despite the benefits incremental improvements may make to a firm.

4.2 Innovation in organisational forms and business models are not well captured by traditional metrics

New, and more open, forms of collaboration via Web 2.0 and OSS can facilitate the innovation process. New business models can enable software and IT firms to improve revenue, sustain competitive advantage or increase performance. But new organisational and business models (Type II hidden innovation) are not sufficiently captured by traditional measurements.

4.3 The novel combination of existing technologies and processes to deliver new service innovations in the sector does not get counted in traditional indicators

The use of existing technology or software for a new application or purpose is not considered to be an investment in innovation. This means that combining existing technologies to deliver an innovative new service, such as Software as a Service (Type III hidden innovation) would not be considered 'innovative' by traditional metrics, despite the benefits and enhancements this may bring to firms developing such innovative services, and their recipients.

4.4 Locally-developed, small-scale innovations that take place 'under the radar' of traditional indicators

As the sector comprises a large number of small firms, innovation could be hidden primarily because it occurs informally, in the day-to-day learning practices and processes undertaken within SMEs to solve client needs. Very small firms are also unlikely to have formalised R&D

341. Bowkis, M. (2007) 'Software Industry Summit 2007.' London: Department for Culture, Media and Sport.
342. e-skills UK (2008) 'Technology Counts IT and Telecoms Insights 2008.' London: e-skills UK.
343. Business Software Alliance/IDC (2007) 'Global Software Piracy Study.' Washington, DC/ Framingham, MA: BSA/ IDC.
344. Organisation for Economic Co-operation and Development (2002) 'Frascati Manual 2002, Proposed Standard Practice for Surveys on Research and Experimental Development.' Paris: OECD.

budgets. This Type IV hidden innovation will therefore not be measured formally.

When working collaboratively with a client, large-scale suppliers may also deliver improvements and efficiencies to its customers when implementing software and IT solutions. Innovative approaches developed during a supplier-client engagement, through informal working practices and collaborative processes (Type IV hidden innovation) will also be unrecorded by formal measurements of innovation.

5. Innovation could be better measured by analyses that are sector-specific and which capture innovation at the firm level and encompass new forms of organisational practice

5.1 Sector surveys could be used to capture and evaluate incremental and localised forms of innovation

Sector-specific surveys could be used to capture more accurately wider measures of performance, efficiency and innovation. Surveys such as IBM's Global CEO study and the Economist Intelligence Unit benchmarking survey of the IT sector could be adapted and expanded to include a specific focus on measurement of incremental and localised innovations and the importance of this type of innovation to the sector's performance and efficiency (Type I hidden innovation). Innovations in processes, such as the Agile, Lean and Triole examples, which demonstrate incremental attempts to improve efficiencies for customers, could also be more accurately recorded and measured.

5.2 Metrics should include firm-level and sector-level rates of adoption of new organisational forms and collaboration

As new organisational forms, business models and different ways of collaborating (Type II hidden innovation) emerge within the sector, the rates at which new organisational practices are being adopted by firms and across the sector could be measured and incorporated into analyses of innovation. The impact that such innovative organisational forms have on performance and working practices within firms should also be assessed in new measurements.

5.3 Levels of investments in services should be measured

New software and IT technologies have, in turn, facilitated the development and provision of new types of services (such as Software as a Service – Type III hidden innovation). Levels of investment that firms make in these services and the return on such investment should be recorded by new metrics. Other wider impacts that new service provision has within the sector (for example, impact on other firms) should also be measured.

5.4 Firms are developing their own metrics for innovative practices, which could be used to measure localised innovation

Whilst small-scale, localised innovations are difficult to observe and measure (Type IV hidden innovation) at a firm-level, some suppliers are developing their own metrics for measuring innovation. These take the form of: number of ideas generated, developed, refined and delivered, and return on these; number of patents; and revenues from new or innovative service lines. Infosys, for example, uses revenues from services launched in the last five years as a key metric. Other firms, such as Atos Origin and LogicaCMG, also track innovation by assessing the revenues associated with new services.[345]

Innovative approaches, delivered through a supplier-client engagement can also be measured in a number of ways. For example, one emerging approach is to derive a 'balanced scorecard'. Typically, these involve a combination of quantitative (for example, service level agreements targets, shareholder value delivered) and qualitative measures (number of ideas that led to improvements) aimed to augment the more rigid performance metrics[346] and the associated rewards and benefits that are part of many IT contracts. Another approach is to measure business outcomes via value-based pricing reward schemes, where a supplier will be rewarded with a percentage of client revenues generated. Lastly, end-user ratings (by clients) of IT suppliers' innovation efforts can also be used as a measure.[347]

6. Innovation could be improved in the sector by programmes of support that embrace hidden innovation and business capability in IT professionals

6.1 Existing programmes of support are focused on pure research and product development and collaboration between academia and industry, but there is a need to support and develop small software firms in order to compete with emerging markets

Existing government programmes of support for innovation within the software and IT

345. Ovum (2007) 'Innovation in IT: Vendor Strategies.' London: Ovum Plc.
346. Examples include number of service calls answered, servers managed, percentage of time an application was available.
347. Ovum (2007) 'Innovation in IT: Client Perspectives.' London: Ovum Plc.

services sector are focused on pure research conducted at universities intended to produce the next generation of software and IT technologies. More recent forms of support are attempting to link industry more closely with academic research in the exploitation of that research.

A number of UK universities have world-class research groups specialising in ICT-related research (for example, software research groups exist at Southampton, Edinburgh, Nottingham, Newcastle and Imperial College universities) and such groups have each received grants of £3 million from the Engineering and Physical Sciences Research Council (EPSRC) for carrying out R&D work for the ICT sector.

More recently, Knowledge Transfer Networks (KTNs) are helping link industry more closely with academic researchers. A number of KTNs are directly relevant to the software/computer services sector: Cyber Security, Digital Communications, Displays, and GRID Computing.[348]

This form of government support is valuable and necessary and has a role to play in the innovation process but there is also a strong argument for new policy, supporting broader forms of innovation.

Whilst UK software and IT services firms benefit from cheaper skills and labour in their back-office operations in India and China, these countries are rapidly developing their own software and IT services sectors. They are now competing with UK firms on the world stage. With the increasing growth and prominence of these markets, the UK must continue to ensure that firms compete more fiercely and develop strengths in higher-value activities. Creativity, skills and innovation must be combined and harnessed to develop competitive advantages in a global economy (see Section 6.2).

As users of software and IT services, SMEs are benefiting from global sourcing through reduced prices of software and greater choice of standardised, cheaper IT products and services. However, smaller software and IT services suppliers are less able to exploit the global sourcing trend, due to the prohibitive costs in setting up off-shore centres relative to their size, and the challenge of identifying and creating appropriate partnerships.[349] This issue is essential to address, and policy should encourage and support those SMEs who want to establish off-shore operations in emerging markets to ensure that opportunities are not missed.[350]

While the UK has around 100,000 small software firms, it lacks 'gorillas' – firms such as Microsoft and Google – which grow very fast from start-up into major global enterprises.[351] In the UK, the sector is dominated by foreign firms; only four of the top 20 software firms and seven of the top 20 computer services providers are British. Whilst this phenomenon is not unique to the software sector, and reflects the comparatively small local market size of the UK, this lack of home-grown 'gorillas' can restrict market growth and encourage high exit rates (successful firms in the software sector have often been bought out, for example, Lionhead Studios by Microsoft). Poor contract enforcement of collaborative relationships and partnerships and lack or management training for growing firms are also factors which mean that firms in the UK often remain small.[352]

6.2 Programmes of support should ensure that, along with technical skills, business-oriented skills are developed in the sector, as this has the power to release wider forms of innovation, crucial to the sector's future

6.2.1 Address educational, recruitment and skills weaknesses within the sector

Innovation in the software and IT sector will be improved if education, recruitment and skills weaknesses are addressed. A number of proposals put forward by the sector skills council (e-skills UK) and other interested bodies (such as Intellect and the British Computer Society) to address these issues, have suggested that the first step is to improve the sector's image as a vibrant and exciting industry in which to work.[353] The sector needs to transform the attitudes of young people (and particularly women) in order to counteract recruitment difficulties.[354]

Educational courses have to become more relevant to employers' needs, and can be achieved by working more closely with employers. This is beginning to happen. For example, the Diploma in IT aimed at the 14-19 age range, has been developed in conjunction with the sector skills council (e-skills) and employers.[355] University courses should combine technical IT knowledge with business know-how, and could offer more work-based learning during degree programmes. The e-skills UK-developed Information Technology Management for Business degree course also demonstrates how this can be achieved. Designed in conjunction with employers,

348. Technology Strategy Board (2007) 'Technology Strategy Developing UK Capability Key Technology Area – Information and Communication Technologies.' Swindon: TSB.
349. Intellect (2007) 'Software and IT Services Report – The Future.' London: Intellect.
350. Ernst, S. (2007) China to Catch Up with UK in Five Years. In Dialogic (2007) 'Developing the Future: A Report on the Challenges and Opportunities Facing the UK Software Development Industry.' London: Microsoft.
351. Owen, G. (2004) 'Where are the Big Gorillas? High-technology Entrepreneurship in the UK and the Role of Government Policy.' Working Paper. London: Inter-Disciplinary Institute of Management, London School of Economics.
352. National Endowment for Science, Technology and the Arts (2008) 'Unlocking the Potential of Innovative Firms.' Policy Briefing. London: NESTA.
353. Price, K. (2007) To Succeed in the Global Economy the UK Must Commit to Technology Skills. In Dialogic (2007) 'Developing the Future: A Report on the Challenges and Opportunities Facing the UK Software Development Industry.' London: Microsoft.
354. At the school-level, an example of a pilot scheme run by e-skills UK and the South East England Development Agency (SEEDA), and in particular to target the gender imbalance that exists within the sector, is CC4G – after school clubs aimed to provide compelling, fun and educational activities for 10-14 year old girls, accessing around 7,000 young women in the region.

and incorporating business, technology, interpersonal skills and project work and 'Business Guru' lectures from IT firms and extensive project within businesses, the course has been available since 2005 and runs at 22 universities (including Reading, Greenwich, Central England and Northumbria) and has around 1,000 enrolled students.[356] (See also section 6.2.2).

In turn, employers could develop, enhance and invest more in existing education and training programmes for employees and managers, and work more closely with schools and higher education institutions.[357] For small firms, greater collaboration and co-operation with large firms and academia could assist with training and education (through increased use of knowledge transfer partnerships, for example).[358]

6.2.2 Need for deeper business-oriented skills

To enable greater development and utilisation of broader forms of innovation within the sector, a wider understanding and knowledge of business-oriented skills will be needed by IT and software professionals.

Utilising new technologies with business know-how can enable the development of new products, services and processes and improve working practices for companies in the software and IT services sector. These forms of innovation are likely to be crucial to the sector in the future.

The novel application of technology across the sector will not only require in-depth and up-to-date technical skills, but also a sophisticated set of business-oriented and management skills and understanding encompassing communication, team working, project management skills and a broad knowledge of IT and business practices.[359] IT and software professionals need to be encouraged and supported to develop these skills. Combining knowledge of technology with business skills and applying such integrated higher skills can give a firm an opportunity to engage more effectively with clients, develop greater levels of innovation and achieve sustainable competitive advantage.[360]

However, the UK software and IT services sector needs rapidly to develop and improve employees' integrated technical and business skills so that the UK has the IT professionals it needs to succeed across all sectors of the economy. The US, Singapore and Australia already have training curricula addressing the development of these high-level skills, and the UK must do so too, if it is to remain competitive and thrive.[361] The proposals suggested by the sector skills agency go some way to addressing this issue, but more must be done to ensure that the UK does not get left behind.

6.3 Ensure that greater systems of control are enacted to counter the effects of software piracy

Software piracy needs to be addressed within the sector by more stringent systems of control. Software theft can harm technology suppliers and affect consumers (both individuals and enterprises) who may be at risk from unwittingly purchasing defective, counterfeit products leaving them unprotected and unsupported. Software piracy has a significant impact beyond the sector itself in lost tax revenues, wages and jobs.[362] Ultimately, this impacts on levels of innovation within the sector too.

In response to software piracy, governments must combat copyright theft by first, increasing public awareness and education of the issue and second, by instigating a more robust approach to intellectual property law and enforcement.[363]

355. Price, K. (2008) How the IT Sector Helped to Shape Diplomas. In Ryan, C. (2008) 'Staying the Course: Changes to the Participation Age and Qualifications.' London: The Social Market Foundation. Chapter 9.
356. e-skills UK (2005) 'The Sector Skills Agreement for IT 2005-2008 Summary.' London: e-skills UK.
357. Intellect (2007) 'Software and IT Services Report – The Future.' London: Intellect. p.14.
358. Dialogic (2007) 'Developing the Future: A Report on the Challenges and Opportunities Facing the UK Software Development Industry.' London: Microsoft.
359. Price, K. (2007) To Succeed in the Global Economy the UK Must Commit to Technology Skills. In Dialogic (2007) 'Developing the Future: A Report on the Challenges and Opportunities Facing the UK Software Development Industry.' London: Microsoft.
360. Dialogic (2007) 'Developing the Future: A Report on the Challenges and Opportunities Facing the UK Software Development Industry.' London: Microsoft.
361. The Economist Intelligence Unit (2007) 'The Means to Compete. Benchmarking IT Industry Competitiveness.' London: The Economist Intelligence Unit.
362. It has been estimated that over a four year period, the UK could miss out on £1 billion in lost taxes, the creation of over 13,000 new jobs and an extra £4.46 billion to the economy unless software piracy is taken more seriously and a reduction in counterfeit software takes place, see Business Software Alliance/IDC (2007) 'Global Software Piracy Study.' Washington, DC/Framingham, MA: BSA/IDC.
363. Business Software Alliance (2007) 'White Paper: Necessary Elements for Technology Growth.' Washington, DC: Business Software Alliance.

Appendix E: Electronics and IT hardware

Innovation through technological development but with an increasing role for hidden innovation through adoption of new business models and a focus on high-value activities

1. Electronics and IT hardware is vital and its activities are pervasive to all sectors of the UK economy

The electronics and IT hardware sector involves the design and manufacture of electronic products and services. The sector includes the sub-groupings of: machinery components (for example, microprocessors); telecommunications equipment; consumer electronics; medical equipment; instrumentation; process control; optical and photographic equipment; electronic systems design; photonics.

Electronics and electronic components lie at the heart of most modern products (typically representing over 20 per cent of their cost),[364] with electronics, photonics and electric systems underpinning activity in every industrial sector and throughout the consumer market.[365]

The sector generates £14.8 billion in GVA, or 1.3 per cent of total UK GVA.[366] It contributes £27 billion a year to GDP, and accounts for 6 per cent of UK manufacturing. The UK has strong export markets in manufacturing and metrology equipment and processes and film deposition, for example. The sector employs around 216,000 people in over 10,000 firms: approximately 90 per cent of these firms have fewer than 50 employees. UK electronics production ranked seventh in the world in 2004, and was second in Europe (behind Germany). It is often suggested that the UK electronics industry has declined significantly, but it would be more accurate to say that there has been an evolution and re-focusing of the industry to fulfil a more global role (see Section 2).[367]

The sector, once dominated by large national champions such as ICL, GEC and INMOS, now has a much more dynamic, distributed composition with a small number of large firms, many small firms, but very few medium-sized firms. During the 1960s the sector was home to major electronics firms serving both domestic and international markets, and manufacturing a range of goods. Primary strengths existed in semiconductors, printed circuit boards and computer hardware.

Competition from high-technology economies[368] and developing nations, fuelled by commoditisation and lower labour costs, has seen electronics manufacture in the UK recede into the aerospace and defence sectors[369] (see Section 3.1). But this has also led to the emergence of a new breed of specialist, high-value firms.

Regional clusters have been established close to the sites of former national champions like ICL and GEC and key universities. The clusters draw on the expertise and skills of former employees and current researchers. Dominant areas include Bristol (Silicon Gorge), Cambridge (Silicon Fen) and to a lesser extent Edinburgh (Silicon Glen). Particular strengths in the UK electronics sector now lie in semiconductor design, photonics, and the manufacture of low-volume, high-value goods for international markets.

2. Innovation in electronics is increasingly distributed across the supply chain but has led to innovative new business models and to the UK developing high-value strengths

2.1 Traditional innovation continues to be a research-intensive activity, with both radical

364. Department of Trade and Industry (2004) 'Electronics 2015 – Making a Visible Difference.' Electronics Innovation and Growth Team Report. London: The Stationery Office.
365. This has made it increasingly difficult to delimit the UK electronics sector and represent it through trade association bodies and statistics, as highlighted in recent government reports; see Department of Trade and Industry (2004) 'Electronics 2015 – Making a Visible Difference.' Electronics Innovation and Growth Team Report. London: The Stationery Office, Chapter 3; also Department of Trade and Industry (2005) 'Competitiveness in the UK Electronics Sector.' Sector Competitiveness Studies No. 1. London: The Stationery Office.
366. Office for National Statistics (undated) 'Gross Value Added for 2005 & 2006 at Current Basic Prices: By Industry.' Newport: ONS.
367. Department of Trade and Industry (2004) 'Electronics 2015 – Making a Visible Difference.' Electronics Innovation and Growth Team Report. London: The Stationery Office, Chapter 3; also Department of Trade and Industry (2005) 'Competitiveness in the UK Electronics Sector.' Sector Competitiveness Studies No. 1. London: The Stationery Office.
368. The high-technology economies in the East traditionally include Japan, Taiwan and Korea, and play host to a high number of integrated circuit and TFT-LCD fabrication facilities. These began life as low wage/cost regions but emerged as highly skilled, highly research-intensive economies strongly supported by government interventions (tax incentives/loans) and state research institutes.
369. Considered more secure markets that are less likely to extend their supply chains overseas for security reasons.

and incremental forms evident in the sector
UK electronics continues to be a research-intensive undertaking, with R&D expenditure in 2006 at around £1.5 billion or 4 per cent of sales.[370] This annual investment is equivalent to around 7 per cent of total business expenditure on R&D in the UK and involves around 140 individual firms, or 16 per cent of all of the UK's research-active firms (those spending more than £100,000 a year). This broad grouping of electronics firms ranks third equal behind the two dominant sectors, pharmaceuticals and aerospace.

UK electronic equipment businesses are increasing their research intensity. Although their sales have dropped by 20 per cent between 2002 and 2006, their R&D spending only fell by 11 per cent over the same period, producing relative growth in R&D spend. By contrast, the smaller and more research-intensive hardware sector registered good sales growth of 12 per cent in this period, but reduced R&D expenditure by almost 10 per cent. However, the 2006 figures show an increase in annual R&D expenditure for the first time in several years, suggesting more positive R&D expenditure growth for the hardware sub-sector.

Electronics equipment and hardware firms are among the top 15 most research-intensive UK-owned firms, with four firms in the top seven, including ARM, CSR, Renishaw and Spirent Communications.[371]

2.1.1 Radical innovation and the importance of the university spin-out
Several new advances within the industry have resulted from the commercialisation of university research. These innovations emerged from academic research and were commercialised through spinouts to local science parks. It is through this route that many radical innovations have been brought to market, some of which have changed the shape of the marketplace.

A good example is Cambridge Silicon Radio (CSR), which evolved out of Cambridge Consultants in 1998. CSR initially developed Bluetooth systems to provide wireless technology for laptops and mobile phones, based on the founding team's university research. CSR's product was considered a radical and disruptive breakthrough, as it married the traditionally separate technical worlds of semiconductors, computing, consumer electronics, software, radio transmission and cellular telephony. In the late 1990s, few manufacturers had all the necessary technical expertise; the complexity of the standard was a potentially serious inhibitor to the widespread take-up of Bluetooth. CSR is now the biggest global designer and supplier of single chip wireless devices for mobile applications, with approximately 50 per cent market share and over 900 Bluetooth consumer products using CSR chips. The firm has used externally owned foundries for its wafer fabrication operations (the 'fabless' model) and has worked closely with major equipment manufacturers such as Intel, Nokia and Sharp in the development of award winning Bluetooth, GPS and WiFi products.[372]

2.1.2 Market pull and incremental innovation
The sector also relies heavily on incremental innovations to remain competitive. As consumer electronics have grown in importance and international competition has become more intense, the UK sector has been exposed to a highly dynamic and free flowing environment dictated by marketing and consumer wants. To remain responsive to market changes, electronics firms are constantly improving their products incrementally whilst looking ahead to the next technological cycle. This enables firms both to maintain their market share and to avoid competition from low-cost economies that mass-produce past innovations.

An example is the development of personal music players. These have advanced considerably from the Sony Walkman cassette player to the more advanced MP3 players. Each technology was developed and evolved through incremental improvements within their cycle before being eventually superseded by demand for the next generation, which would again follow improvements in size, battery life and features. The latest cycle is characterised by improvements in the capacity, size, and screen of MP3 players such as the Apple iPod or Microsoft Zune player.

2.2 Significant changes in the electronics supply chain have led to new forms of organisational and business model innovation becoming increasingly important for the sector

2.2.1 The UK has seen a shift in the value chain from carrying out the majority of functions towards an emphasis on service, design and support roles, resulting in fundamental changes to the sector
The electronics sector was once a highly vertically integrated industry with large firms dominating the market and carrying out the full

370. These figures are taken from the 2007 R&D Scoreboard and encompass two broad product groups, 'Electronic & Electrical Equipment' and 'Technology Hardware & Equipment'; see Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.

371. Ibid.

372. Janson, E. (2006) Single Chip Success. 'Igenia.' 27, June 2006, pp.20-23.

array of functions. Innovation was insular and closed. Following increased globalisation, these functions have been dispersed to economies and firms best suited to dealing with each aspect of the chain.

Raw material supply and component manufacture has shifted to low-cost or high skill/capital-intensive environments such as Eastern Europe and the Far East.[373] The UK has repositioned itself to perform higher-value functions such as design[374] and low-volume, high-value-added products and prototyping. A leader in Europe, the UK is now home to over 150 independent design houses. Recent growth in this market reflects over 20 years of experience, much of which stemmed from original national champion firms.

Innovative new firms such as ARM, CSR and Digico now lead the way in this truly global environment. Many international equipment manufacturers such as Fujitsu, Sharp, Philips, and Analog also have design operations located in the UK. Many UK-based firms and business units fill supporting functions such as testing and validation services and consultancy (Austin Semiconductors Europe, for example, operates an integrated circuit test facility in Hampshire).

2.2.2 Innovation in electronics is much broader than technological change alone. New forms of innovation – from novel business models to novel business partnerships and supply chains – are increasingly evident in the sector

2.2.2.1 New business models

Following the disappearance of the large British firm and the increase in overseas competition, UK electronics firms have adopted innovative new business models. While chip manufacture has moved to lower labour cost regions, there has been a rise in the number of higher-value activities such as design and intellectual property (IP) licensing. This has spawned models such as 'chipless' – companies that develop and market semiconductor IP and 'fabless' – semiconductor firms that use externally owned foundries for their entire wafer fabrication operations.

These models fit into one or more global virtual organisations.[375] Firms can vary in size, though many remain small as there is little need to grow to compete. Design can be carried out by a few flexible professionals without a large organisational structure.[376] These models can enable a 24-hour global operation by having different firms operating in different time zones.

These flexible business models particularly helped innovative start-ups, as they no longer need to develop capabilities, or incur the costs of additional functions. They can concentrate on their primary expertise within the supply chain. This is especially important in electronics as the cost of investigating and developing new technologies has increased year on year.[377] Users of these business models include ARM, ARC, Wolfson and Xilinx. By focusing on high-value activities, firms have been able to remain competitive by adopting new sustainable models and joining together in wider virtual organisations.

ARM

ARM is a British technology firm founded in 1990 following a spinout from Acorn Computers. Its technology is based on 32-bit microprocessors and can be found in almost all modern mobile devices.[378] They account for over 75 per cent of all 32-bit embedded Central Processing Units in the market today. However, ARM does not produce physical chips. Instead it licenses its technology to other chip manufacturers such as Intel, AMD, and Samsung under the chipless model. ARM generates its revenue by charging royalties from chip manufacturers; in 2005, 1.7 billion chips were produced based on the firm's designs. ARM has adopted the chipless model in order to remain flexible and avoid competing in markets where costs can be driven down by lower cost regions.

This business model has been highly efficient at delivering value. For example, ARM has a growth rate approximately twice that of the semiconductor industry as a whole.[379] The firm estimates that in 2006, 1.5 billion people – a quarter of the world's population – bought an ARM-powered product, generating more than £263 million in revenues, yet the firm employs fewer than 1,500 people.[380]

373. China alone is predicted to produce $326 billion (£155 billion) of electronic equipment by 2009, growing at a compound annual growth rate of 9.4 per cent since 2004. Other key players include Taiwan, Japan, Korea, USA and Germany.
374. Eighty per cent of semiconductor manufacture cost is incurred during the design phase, see Electronics Knowledge Transfer Network [online] Available from: http://www.electronics-ktn.com/Default.aspx
375. A group of individual firms, usually geographically dispersed, working together towards a common goal, carrying out functions traditionally carried out within one physical, or heavily vertically integrated entity.
376. For example, Frontier Silicon develop and design semiconductors for digital radio, television, and mobile television from bases in the UK and Ireland, then have these manufactured in Korea and China for leading brands such as Sony and Philips.
377. For example, there are now only a few global firms that could singularly bear the costs of establishing a new chip fabrication facility (around £3 billion).
378. The firm originally identified the market for its processors through a collaborative risk sharing partnership with a mobile phone manufacturer with the requirement to produce low power consumption microprocessors. Prior to this, processor design was carried out within large firm R&D facilities striving for greater speeds and capabilities for stationary computing applications. Following the rise in mobile devices such as walkmans, phones, and digital cameras there was a need to produce chips that could run off mobile power sources.
379. ARM (2007) 'ARM Holdings Plc Reports Results for the Fourth Quarter and Full Year 31 December 2007.' Cambridge: ARM.
380. ARM (2007) 'ARM Annual Report and Accounts 2006.' Cambridge: ARM.

2.2.2.2 The rise of collaborative partnerships – changing research and development practice
In traditional electronics manufacturing, R&D often took place within large internal facilities. Large teams of scientists and engineers were employed to explore and exploit commercial and technological opportunities. Today, innovation increasingly takes place through collaborative partnerships and strategic alliances. These often cross disciplines and national boundaries. R&D will typically involve engineers, marketing and sales people, as well as external stakeholders such as suppliers and end-users.

There are two main reasons why this happened. The first is that the electronics sector has been keen to share the risk and costs of new technologies. But the second reflects an overall structural shift. As the supply chain has become less vertically integrated, it has become increasingly necessary to involve external firms, and even sectors, to exploit capabilities that are no longer located in-house. A current example is Apple's iPhone, which incorporates technology from more than 15 separate firms including CSR and Wolfson.

2.2.2.3 High-value, low-volume markets and the importance of end-users
Firms are now accessing new niche markets where they compete on quality and function, rather than simply on price. Central to this environment is an understanding of customer needs. Innovative arrangements see firms working closely with potential owners to ensure that strict specifications are met. This 'user-led innovation' is a recognition that end-users are not all the same, they will have individual preferences and are willing to pay a premium for this customised service.[381] Specialist electronics firms in the UK produce a number of products for international markets including mixing desks for the creative industries, control systems for mineral exploration and medical monitoring systems for health services.

3. Innovation in the electronics sector is determined by competition, cost and risk which can be both barriers and drivers

3.1 Competition is increasingly global in nature

Innovation in the UK electronics sector is largely driven by global pressures. The cost competitiveness of developing nations and their ability to commoditise products has led to a decline in UK electronics manufacturing. For example, China is the world's largest electronics manufacturer, with more than $300 billion in products in 2006.[382] It accounted for 18 per cent of global electronics output in 2005, compared to just 4 per cent in 1997. Half of Chinese suppliers of electronic components, consumer electronics, and computer and telecommunications products expect more than 20 per cent growth in export sales during 2008; a quarter expect an increase of 10-20 per cent.[383] More than 80 per cent of suppliers anticipate increasing their production capacity by 20-50 per cent. The EU is the main destination for these exports.

In a sector dominated by small firms, businesses have to make continuous improvements to existing products or discover new technologies to remain ahead. By

381. Von Hippel, E. (2005) 'Democratizing Innovation.' Cambridge, Massachusetts: The MIT Press.
382. Reed Electronics Research (2006), 'Yearbook of World Electronics Data, Volume 3 - Emerging Countries 2006/2007.' Wantage: Reed Electronics Research.
383. Global Sources (2008) 'China Supplier Survey, 2nd Half 2007.' Singapore: Global Sources.
384. Unico/Universities UK/Research Councils UK (2007) 'Impacts: Successes from UK Research.' Cambridge/London/Swindon: Unico/Universities UK/Research Councils UK.

Wolfson Microelectronics

Wolfson, which spun out of the University of Edinburgh in 1985, originally started as a design house for leading equipment manufacturers in Europe. It became a market leader in the customer design of integrated circuits. In 1996, Wolfson changed its approach to become a fabless semiconductor firm, subcontracting all its product fabrication, assembly and testing. With this new strategy. Wolfson became a global leader in the supply of mixed signal integrated circuits found in consumer electronics devices such as Apple's iPod music player and the Xbox games console. Employing around 200 people, it was listed on the London Stock Exchange in 2003 with an initial market value of £214 million.[384]

A fabless business model has the advantages of access to world class manufacturing without the need for high capital investment and manufacturing support costs. This allows the firm to focus on its core competencies of product definition, design and marketing. Wolfson utilises several foundries and assembly and test facilities, mostly in South East Asia.

385. In the last two UK Community Innovation Surveys, cost and risk factors have ranked highest amongst perceived barriers to innovation within the electronics sector. This is particularly acute for SMEs, where funds are limited and available venture capital (between proof of concept and full launch) can be difficult to acquire. See Department for Business, Enterprise and Regulatory Reform (2001; 2005) 'UK Community Innovation Survey.' Division 4 Statistics SIC 30 and 33. London: BERR.

386. The idea that disequilibrium in the market, brought about by a new innovation resulting in a temporary monopoly, stimulates innovation within other firms in an attempt to capture or recapture a lead position; see Schumpeter, J. (1943) 'Capitalism, Socialism and Democracy.' London: Allen & Unwin.

387. Department for Education and Skills (2006) 'The Supply and Demand for STEM Skills in the UK Economy - Research Report.' London: The Stationery Office; Department for Education and Skills (2003) 'Skills Strategy White Paper "21st Century Skills - Realising our Potential".' London: The Stationery Office.

388. House of Lords Select Committee of Science and Technology (2002-3) 'Chips for Everything: Britain's Opportunities in a Key Global Market.' Session 2002-3 (2nd Report). London: The Stationery Office.

389. A good example is the way that mobile phones or laptops become smaller or lighter in response to demand, but retain the same basic features.

390. Department of Trade and Industry (2006/7) 'Electronics Systems Design – A Guide to UK Capability.' London: The Stationery Office.

391. Future Horizons (2007) 'Annual Semi-conductor Report.' Sevenoaks: Future Horizons.

392. Moor, J. (2006) 'UK Semiconductor Design Evolves and Grows Stronger.' 7th August. National Microelectronics Institute [online] Available from: http://www.nmi.org.uk/press_releases

moving into more specialised, higher-value functions such as design, and adopting new organisational models, the UK electronics sector has avoided exposure to many of the competitive pressures from both low-cost and high-technology economies.

3.2 The pressures of cost and risk can act as barriers for innovation

The cost and associated risks of pursuing advances within the sector can act as a major barrier to technological innovation.[385] But paradoxically, cost and risk have driven organisational innovation in electronics, as firms turn to partnerships and strategic alliances to spread the cost and risk of innovation. A key facilitator has been improved telecommunications, which has enabled networked organisations and partnerships that no longer need to co-locate.

Through their radical innovations, spinouts and very small firms not only provide the necessary churn and disequilibrium to drive innovative activity,[386] they can reduce the costs and risks associated with pursing innovation; they can also enhance the capability of larger firms. Indeed, innovative SMEs are often incorporated into firms following a successful demonstration of a new technology. CSR's recent acquisition of Cambridge Positioning Systems to increase its GPS capabilities is one example. ARM also follows an 'innovation by acquisition' process by acquiring innovative SMEs to increase their capabilities.

Conversely, large firms may be reluctant to deal with small firms as they may have concerns about the long-term financial viability and capacity of a single small scale supplier. They may prefer to deal with a similar sized firm to protect against losing their main source of knowledge or a key firm going out of business. The fragmented composition of the sector may be a barrier to small-firm development and innovation. Building trust and collaborations within the sector could start to spread some of this risk.

3.3 Potential skills shortages could inhibit the sector's future

The available labour market within the UK will have a major impact on the future success of the electronics market. The UK's stock of science and engineering graduates compares well internationally, and the stock of graduate scientists in the UK labour force has been growing steadily. However, there are evident challenges, with the number of British students opting to study engineering and physical sciences, particularly chemistry, on the decline.[387] A Select Committee report[388] found that universities view the greatest difficulty for recruitment of new entrants was in the computer departments, closely followed by electronics. This trend is reflected in A-level choices too, and while non-nationals appear to be filling the gaps presently in the public and private sectors, there is a potential risk of future skills shortages in key areas, such as materials science. This could impact negatively on the UK electronics industry through capacity constraints and act as a barrier to innovation.

3.4 Users and consumers as drivers of innovation

There growth of consumer electronics has changed the focus of the electronics market. It has become more dynamic as marketing and brand image have become more important. This environment drives incremental innovation given the need to enhance and adapt existing products to differentiate from competitors and appeal to consumer requirements.[389] Such a setting requires manufacturers continually to anticipate emerging technologies, capabilities and designs whilst developing existing product lines. This drives open innovation and presents opportunities for start-ups and incumbent firms. It also prompts new alliances and leads some firms to grow quickly. However, these market characteristics mean that such alliances can be short-lived unless firms can keep up with the pace required by the major manufacturers and consumers.

The consumer electronics market has led to a growing number of UK-based design houses. Design is clearly important in a market based on brand and consumer emotion. The UK has a strong international reputation and image for electronic and semiconductor design.[390] Sharp's UK design unit is investigating advancement in liquid crystal display (LCD) technologies such as 3D displays for mobile phones. The UK is now home to 31.9 per cent of the chipless, fabless and integrated circuit design firms in Europe[391] and contributes approximately 15 per cent of the world's ASIC (Application Specific Integrated Circuit) semiconductor design starts.[392] Expert opinion is divided on whether design will eventually follow other functions and be outsourced overseas.

3.5 Regulation can be both a driver and barrier to innovation

UK and European environmental regulation is a major consideration for electronics. New EU directives[393] have implications for both manufacturers and designers, bringing more stringent requirements on packaging, recyclability, and the control of hazardous substances.

Regulation can both hinder and drive innovation. In the first instance it can limit the scope and parameters of a product, in the second it can act as a reason to innovate to find new solutions and alternative options. One example has been the pursuit of lead-free electronics production, with a variety of lead-free solder alloys having been trialled and released, but often with significant compromise on cost, process efficiency or joint reliability; and more recently through the development of novel oxides and alloys and nano-composites.[394] Another is a project called 'Reflated' (a collaborative research partnership)[395] which is investigating ways of recycling and reusing liquid crystal displays (such as those found in watches, phones and laptops). Over three billion devices with LCD displays were manufactured in 2006 and their environmentally acceptable disposal is a growing problem. At this early-stage of the project a number of innovative processes have already been developed. These are being scaled up and market tested.[396]

4. Innovation is hidden because of incremental innovation, the adoption of new organisational forms and composition of the sector

4.1 The importance of incremental innovation to the sector

Electronics firms rely heavily on incremental product innovation to remain competitive. The pressure to enhance and adapt existing products requires speedy reaction to changes in the market and the incremental development and refinement of products. Similarly, firms may use existing electronic technologies in new or novel ways, contributing to the innovation process. This Type I hidden innovation is not recorded in narrow measures of R&D.

4.2 Organisational forms of innovation are not measured in traditional metrics

New organisational forms have enabled innovations that are not reflected in traditional measures. The drive to reduce costs and overheads has seen the increasingly widespread adoption of fabless and chipless models as the cost of a silicon fabrication facility has dramatically increased. These new models, considered Type II hidden innovations, are innovative in their own right and have fostered further innovative practices such as collaborative networks, strategic alliances and cross-disciplinary operations to address the requirements of the modern electronics environment.

4.3 The sectoral composition of the sector, with many small firms, may mean that innovation is going unmeasured

4.3.1 Day to day problem-solving within SMEs

Much electronics innovation could be hidden primarily because it occurs on a day-to-day basis within SMEs, with little or no declarable R&D budget. This Type IV hidden innovation is widespread given the composition of the sector, and often takes the form of informal learning and the development of internal processes to tackle customer needs on a case-by-case basis. Often an SME's primary concern is survival: R&D and innovative activity may only occur when needed, rather than as a formal function.

Further, as previously highlighted, the overall electronics industry is mainly comprised of micro SMEs which are not fully represented in the Community Innovation Survey, which only considers firms with more than ten employees. The survey includes various indicators such as type, source of information, and modes of innovation, but will leave the majority of the sector invisible to measure.

4.3.2 Patenting issues

Smaller firms can struggle to meet the costs and, sometimes, the requirements of patenting procedures. This leaves many inventions invisible to measurement. Fears of piracy in emerging economies cause many firms to rely on secrecy as their main IP protection, rather than declaring and codifying them through a patent. This can leave much of the sector's technological innovation hidden. The defence of a patent infringement is beyond the means of many SMEs, especially if the infringement occurs overseas.

393. WEEE Regulations 2006 - SI 2006 No. 3289 – The Waste Electrical and Electronic Equipment Regulations 2006, based on Directive 2002/96/EC of 27th January 2003 (OJ No. L173, 13/2/2003) and Directive 2003/108/EC of 8th December 2003 (OJ No. L345, 31/12/2003) – affecting design for end-of-life disposal. The EuP Directive 2005/32/EC, establishes a framework for setting of eco-design requirements for energy-using products, aiming to improve the environmental performance at a very early-stage in the product design (examples include lighting and on standby power). RoHS Directive – 2002/95/EC covers the restriction of the use of certain hazardous substances in electrical and electronic equipment.

394. Novel oxides is one of eight streams being investigated in the Science City Bid 2 collaborative package between Warwick and Birmingham universities.

395. The partners include: the Technology Strategy Board, recyclers, technology developers, a specialist chemical processor and an engineering equipment manufacturer.

396. Department for Innovation, Universities and Skills (2008) 'Innovation Nation.' London: The Stationery Office.

5. Innovation could be better measured by adapting existing tools and indicators, by incorporating the value of new organisational forms and by tracking small-firm activity

5.1 New measures that better capture UK strengths and levels of incremental innovation should be developed

Type I hidden innovation could be measured through new indices combining existing data sets or by including new questions within established business surveys. For example, the UK is strong in electronics design, which it then licenses to other firms and manufacturers. Capturing this would require the measurement of this flow of knowledge within the UK and internationally to manufacturing economies. Currently this data is not collected; however, the Office for National Statistics (ONS) annual survey of R&D expenditure might prove a suitable vehicle for such an enquiry, and should aim to represent smaller firms within its sample. Similarly, given the positive perception of UK design internationally, it might be possible to measure the brand value of design house contributions to give an indication of their success.[397] Given that firms in the sector rely heavily on incremental product innovation to remain competitive, sector-specific surveys could be the best way to capture the extent and value of this form of innovation.

5.2 Organisational and business model innovation could be better measured by the rate of adoption within the sector and the effect of such organisational forms on firms

Strategic alliances and partnerships now take place across the sector. These collaborative arrangements (Type II hidden innovation) highlight a fundamental shift to open innovation, one that is central to the sector's innovation potential. However surveys do not investigate this issue directly: number, type and 'value-added'/achieved outcomes could potentially be recorded as measures of effectiveness of such arrangements to individual firms. A measure for the sector as a whole might be the rates at which such alliances are formed.

As we have seen with ARM and CSR, new organisational models have allowed firms to become more flexible to their environments and absorb new capabilities by internalising innovative new start-ups. The ONS aggregates statistics on the number and value of deals in the UK (mergers and acquisitions); it may be possible to develop this further at the sectoral level. However, the data do not automatically distinguish 'innovative' acquisitions from all acquisitions, and the impact on the acquiring business is not elaborated. Additional data on value-added and productivity might be necessary to create a useful indicator.

5.3 New measures of innovation could track small-firm activity

Given the importance of the small-firm to the electronics sector, the number of start-ups and spin-outs created at a sectoral level could be measured. New businesses have been critical to the renaissance of the UK electronics industry and they continue to be a potential source of important new technologies and successful business models.[398] However, existing data on start-ups do not lend themselves easily to analysis of innovators by sector, as only basic characterisation and operational statistics, such as address and turnover, are gathered. Better sample sizes and more specific data on the innovativeness of companies might be explored with ONS and others.

Equally, existing statistics on survivability appear to correlate well with dynamism, where the innovativeness of an industry might be measured by the number of new firms starting up and entering the sector indexed against survival rates.[399] Firm growth rates can be a good indicator of innovations past and present, so identification of the fastest growing firms in the UK might highlight high growth areas within the sector.[400] The ONS is also reporting aggregate data on high-growth firms, which could be disaggregated. Additionally, the BERR value-added scoreboard offers potential for further analyses at a sectoral and firm level. These data could be matched with several other innovation indicators to develop a useful index of total innovation effort and outcomes.

Firms could be surveyed more formally to measure innovative and efficiency practices and processes within SMEs (Type IV hidden innovation) and the innovation that goes on 'below the radar'.

6. Innovation could be improved by greater support for hidden innovation and small firms within the sector and by increasing skills capabilities

6.1 Existing UK measures focus on 'traditional' innovation

6.1.1 Strong broad national approaches…

Broad domestic national measures range from

397. Work being undertaken by Jonathan Haskel and a team at the Centre for Research into Business Activity at Queen Mary, University of London are attempting to measure intangible assets (including brand value) and assess their contribution to innovation and productivity.
398. A new 'best way' of organisation within a specific sector and context, rendering previous models obsolete.
399. BERR VAT statistics can be used to identify the number of start-ups each year.
400. Deloitte Technology Fast 500 EMEA ranking is published every year to identify the fastest growing high-technology companies in the EMEA region.

R&D tax credits to support for collaboration with the university/research institute sector to support for clusters/networks in strategic and emerging fields.[401] Given the pervasiveness of electronic components and the difficulties with delimiting the sector, electronics has suffered from a lack of visibility, fragmentation and support.[402] Sector-specific attempts to redress these issues have occurred recently with the creation of the BERR Innovation and Growth Team, the development of the Electronics Leadership Council and the Photonics Leadership Group, and specific electronics Knowledge Transfer Networks. Electronics is now increasingly better supported than many other sectors in the UK, aside from pharmaceuticals, biotech and aerospace.

6.1.2 …but regional approaches must be strengthened and better coordinated

There are a plethora of innovation support schemes available in the regions, with plentiful opportunities for electronics companies to secure business-development advice, coaching and financial assistance. The English regions and the devolved administrations all seek to support prospective innovators, through measures such as the grant for R&D (formerly SMART), the Manufacturing Advisory Service and regional venture capital funds. ICT firms can access all these schemes. There are also numerous one-off innovation support schemes, from the collaborative innovation centres (CICs) in Yorkshire to the Emerging Technologies scheme (ETS) in the South East to the Intermediary Technology Institutes (ITIs) in Scotland. In almost all cases, they have targeted strategic technologies and industries; most encompass one aspect or another of electronics and are actively engaged with local electronics firms. There are numerous general business support schemes too, such as Electronics Yorkshire, open to electronics firms.

However, these schemes tend to be smaller, more particular and often shorter lived than their national equivalents. User surveys suggest this ‘fluidity’ reduces their visibility and attractiveness, leaving most schemes patronised by a rather small proportion of the total business population, while most of their peers proceed without any meaningful support. The current business support simplification process is expected to reduce fragmentation and confusion, while improving efficiency and effectiveness of delivery. It should increase effective support.

6.2 Increase support for ‘non-traditional’ innovation

It is clear that support and policy measures have a somewhat technological character which suits certain types of firm better than others. Potentially, it is easier for firms to find support for more traditional research and technology projects than it is to find support for innovative business models or risk-sharing partnerships. Export credit guarantees, launch aid in aerospace, or government procurement of technology can help small firms to reduce risk and nurture critical, new and novel applications.

Helping firms and entrepreneurs to explore and experiment with new business models or commercial strategies could be hugely important, as the growing concentration on IP and design could present longer-term risks, as other European and international electronics firms are aggressively challenging the UK’s strength in higher-value activities.

6.3 There is a need to improve sector-specific SME support measures

The small size and knowledge-based nature of many UK electronics firms also seems to be a complicating factor, since targeted innovation programmes can often favour larger, more established firms with a national brand and a substantial physical presence. Given the importance of young and small firms within the innovation landscape, there could be a case for more sector-specific policies to alert firms to opportunities for support and to help them access and make good use of what can be complex and costly schemes.

The balance of support could be modified too, with greater support for new firms and their faster maturation (success or failure). There should also be more support for commercialisation activities such as proof of concept schemes, tactical and legal advice, to help innovative firms choose the best strategy to protect their IP. Promising technologies could be nurtured and their owners mentored to help them locate sufficient funding and target the most relevant markets.

6.4 Maintain and develop skills for the sector’s future

By moving into more specialised, higher-value functions, the UK electronics sector has been able to avoid exposure to many of the competitive pressures from low-cost economies. However, with the increasing output of highly skilled engineers and designers in these countries, the UK will have

401. For example, BERR continues to sponsor the electronics industries in the form of networking and advice, and addressing information failures. The Technology Strategy Board (TSB) has the ICT field as a major focus, with the sector accounting for 15-30 per cent a year of its spending. It has six Knowledge Transfer Networks which operate primarily in the electronics area, which aim to assist with information services and networking activities when building supply chains. The Engineering and Physical Sciences Research Council (EPSRC) spends as much as £300 million a year on grants to the academic partners of its collaborative research projects and networks, which operate across its broad remit, and engage with, amongst others, UK electronics firms.

402. Department of Trade and Industry (2004) ‘Electronics 2015 – Making a Visible Difference.’ Electronics Innovation and Growth Team Report. London: The Stationery Office. Chapter 3; Department of Trade and Industry (2005) ‘Competitiveness in the UK Electronics Sector.’ Sector Competitiveness Studies No. 1. London: The Stationery Office.

to continue innovating and producing skilled individuals to avoid becoming priced out of its new market.

The Electronics and Innovation Growth Team (EIGT) has made a series of recommendations designed to overcome issues concerned with leadership, diversity, skills shortages, image, lack of visibility[403] and sectoral evolution (which have shifted industry skill needs).[404] BERR is working closely with various stakeholders to tackle the anticipated skills gap in electronics with industry placements, recruitment incentives, and support for schools seeking to stimulate interest in electronics. Failure to recruit suitably qualified individuals will act as a barrier to innovation.

6.5 The sector will have to innovate to cope with coming technological disruptions

A number of emerging technologies are set to lead to new market opportunities in the electronics sector over the coming decade.

Electronic devices will expand their functionality: chips with moving parts are already becoming the basis for new technologies, such as acceleration sensors in the automotive market and electronic and photonic nano-devices in data processing and storage. The increased functionality of individual devices will be accompanied by innovations in their packaging (such as bonding chips together into a 3D array), which could affect and improve applications such as mobile phone cameras and medical devices. Because of Moore's Law,[405] miniaturisation is not thought to be sustainable. After 2015, there are likely to be opportunities for disruptive technologies such as carbon-based semiconductor devices (for example, nanotubes and polymer transistors) and quantum electronics (quantum dots and wires). The UK electronics sector currently has strengths in device and system-level design and must ensure that it is well placed to continue building on its strengths to exploit new and novel innovations.

Innovations in new materials and substances are also set to emerge with the advancement of micro-structured optical 'meta-materials' such as photonic crystals.[406] Plastic electronics is an emerging field and one which is set to disrupt electronic circuits and flat panel displays, where new plastic and flexible materials will be used instead of glass structures. This will mean changes to the manufacturing method, and new capabilities will be needed. Plastic electronics has been highlighted as an area of high risk/high reward and the UK holds a leading position in this area, with a strong research base (for example, at the Centre for Advanced Photonics and Electronics at the University of Cambridge and Cavendish laboratories). Around 30 UK firms have benchmarked world-class R&D in plastic electronics and hold much of the IP and knowledge of this field. Home-grown companies such as Plastic Logic and Xaar have leading positions in developing and marketing early products. The key challenge for policy will be to ensure that the UK builds upon this world-leading position and that firms are supported to develop and grow to capitalise on this market for the overall benefit of the UK.

One final issue is the imperative for using less electrical power and energy against the wider backdrop of reducing carbon emissions and sustainable development. The sector will need to find ways to minimise the consumption of electrical power through innovative approaches in device efficiency and system design.

403. Department of Trade and Industry (2004) 'Electronics 2015 – Making a Visible Difference.' Electronics Innovation and Growth Team Report. London: The Stationery Office. Chapter 3; Department of Trade and Industry (2005) 'Competitiveness in the UK Electronics Sector.' Sector Competitiveness Studies No. 1. London: The Stationery Office.

404. For example, the EIGT recognise that the electronics sector is perceived as short-termist in its recruitment policies, expanding in line with industry cycles and reducing numbers in downturns. Despite a number of sectors employing this flexible workforce model, it has led to negative press and has had an impact on the attractiveness of a career in the electronics sector.

405. In 1965, the founder of Intel, GE Moore predicted that the number of transistors which could be placed on a transistor would keep growing exponentially, doubling every couple of years. According to sector experts, Moore's Law is likely to have at least another decade to run, before silicon-based hardware begins to reach its physical limits.

406. The Economist Technology Quarterly (2007) 'Crystal Clear.' 8th December, p10.

Appendix F: Automotive

Innovation focused on incremental product development alongside process innovation, but with a resistance to new business models

1. Automotive remains a major manufacturing sector for the UK economy, with foreign-owned manufacturers and renowned strengths in specialist areas

While there are no indigenously-owned 'volume' vehicle manufacturers left in the UK, the country is host to a wide range of foreign-owned and indigenous firms across all sectors of the industry.

Automotive manufacturing adds £9.8 billion in value to the UK economy; the retail and service/maintenance sectors generate a further £22 billion GVA. Automotive manufacturing accounts for 1.1 per cent of GDP, 6.2 per cent of manufacturing value-added and 12.4 per cent of total UK manufactured exports.[407] (This compares to automotive representing 3 per cent of Europe's GDP[408]).

The sector includes around 3,300 firms employing 221,000 people. More than 40 firms manufacture vehicles, including mass market ('volume') vehicles, niche vehicles, and heavy trucks.

Seven of the global top ten vehicle manufacturers operate in the UK. The UK is also home to the world's most successful motorsport industry as well as a range of smaller manufacturers serving specialist markets such as sports cars, luxury cars, and London taxis.

The remaining firms are producers of components and smaller vehicle subsystems. There are 2,600 component firms, 90 per cent of which are SMEs, employing around 132,000 people.[409] The West Midlands remains the heart of the industry in the UK with around 23 per cent of the sector located in the region.[410]

The component sub-sector is however increasingly dominated by large multinational firms. Many of these 'super tier 1' firms were previously owned by major manufacturers.[411] Nineteen of the top 20 global tier 1 suppliers and around 20 leading independent automotive design firms also have a base in the UK.[412]

The UK industry is highly export-oriented, with volume products mainly to Europe and specialist products worldwide including to North America. 1.65 million vehicles were manufactured in 2006 (nearly an all-time high), 73 per cent of which were exported.[413] UK automotive exports, including cars, commercial vehicles and a wide range of components, generate more than £20 billion annually. This makes automotive the UK's biggest manufacturing export sector.

Engine development and manufacture are major UK strengths. Three million automotive engines were produced in 2006; the UK is a significant net exporter of engines. Substantial new investments have been made at a number of locations both in developing existing facilities and establishing new ones. By far the most important producer in the UK is Ford, with two major plants at Bridgend and Dagenham, producing around 25 per cent of their global engine supply in the UK. There is also a significant UK presence in contract engine design and testing. Major suppliers include Cosworth Technology, Lotus Engineering, MIRA, Millbrook, Pi Tech, Prodrive, Ricardo, TRW Conekt and Zytek.

Related to this, the UK's long-established independent design engineering sector works

407. Department of Trade and Industry (2006) 'Driving Force: Success and Sustainability in the UK Automotive Industry.' London: DTI.
408. European Commission (2005) 'CARS 21, A Competitive Automotive Regulatory System for the 21st Century, Final Report.' Brussels: European Commission.
409. Department of Trade and Industry (2006) 'Driving Force: Success and Sustainability in the UK Automotive Industry.' London: DTI.
410. See Appendix B, Case Study 1, in Athey, G., Glossop, C., Harrison, B., Nathan, M., and Webber, C. (2007) 'Innovation and the City, How Innovation has Developed in Five City-Regions.' London: NESTA.
411. 'Tier 1' firms integrate whole systems for direct supply to a vehicle manufacturer. 'Tier 2' firms supply component parts or support services to Tier 1 suppliers. 'Tier 3' firms supply raw materials for the supply chain or more generic engineering components and services.
412. Department of Trade and Industry (2006) 'Driving Force: Success and Sustainability in the UK Automotive Industry.' London: DTI.
413. Ibid.

with vehicle manufacturers from around the world and offers a full spectrum of services from concept design to limited-series vehicle production. This includes vehicle and engine test facilities, design engineering consultancies, specialised new technology R&D companies and university research centres. In addition, Nissan chose London as the location for its European design centre (see 2.1.4).

The UK has specific and under-recognised areas of leadership. For example, Smith Electric Vehicles, based in Washington, Tyne and Wear, is the world's largest manufacturer of road-going electric vans and trucks.

Finally, 'Motorsport Valley' is the premier site in world motorsport production.[414] It is one of the few globally dominant UK regional clusters in any sector. The UK motorsport industry employs over 40,000 people, of whom 25,000 are engineers, in more than 3,000 firms.[415] The engineering sector of the industry has a turnover of £2.9 billion (with motorsport-related services earning a further £1.7 billion).[416] More than 50 per cent of this is in export sales. Of the 22 constructors who provide cars to the four global series in 2006, eleven were based within the UK.[417] For the 2008 season, seven of the 11 Formula 1 teams are based in the UK. Moreover, some motorsport firms have sought to exploit their specialised design and technology expertise outside the sector; for example, McLaren Applied Technologies (formed in 2004) works with a diverse range of industries and develops commercial applications for technology developed within the McLaren Group.

2. Innovation in automotive focuses on incremental product development with some major process changes but limited innovation in business models

2.1 Traditional innovation in mass market automotive is focused mainly on incremental product development with long lead times

2.1.1 Core product technology is the main focus for innovation

The car has not greatly changed as a piece of technology since the onset of mass production in the 1920s. It is comprised of two core technologies: an all-steel body that is pressed, welded and painted; and an internal combustion engine (petrol or diesel) that is cast and machined. Alternatives to these two core technologies have so far remained marginal to an industry largely concerned with economies of scale.

Traditional innovation focuses on continuous incremental improvement to core product technologies, with an essentially conservative product design, due to product complexity, high capital costs, and market competition. Suppliers of components and materials are often responsible for important innovations, while manufacturers often focus on process innovations.

Homogenous charge compression ignition engines

An emerging example of incremental innovation is the homogenous charge compression ignition (HCCI) engine. Honda has been leading its development.[418]

The idea of an HCCI engine is hardly new as a technical concept, and is often described as combining the advantages of diesel and petrol. With the homogenous charge, fuel and air are mixed before combustion, thereby allowing a more uniform burn and reducing particulate formation. With high compression, the very 'lean' mixture[419] ignites within the cylinder without the need for a spark plug. Overall, the greater efficiency of the combustion process and the relatively low temperatures inside the cylinder result in low nitrogen oxide (NOx) emissions compared with spark-ignition petrol and direct injection diesel engines. Moreover, HCCI can be scaled to almost any size or application from motorbikes to large ships, and need not be tied to the traditional fuels of petrol and diesel.

An attractive aspect of this technology is that the engines could draw on modifications to existing designs, and could in theory be produced at low-cost in existing facilities.

414. Motorsport Valley is typically characterised by a 100-mile crescent from Surrey up through the Northamptonshire/Oxfordshire heartland across the south midlands and over to East Anglia; see Motorsport Research Associates (2003) 'A Study into the UK Motorsport and Performance Engineering Cluster, Final Report.' Motorsport Research Associates.
415. Motorsport Research Associates (2003) 'A Study into the UK Motorsport and Performance Engineering Cluster, Final Report.' Motorsport Research Associates.
416. The total turnover the motorsport sector, that is, including events, television viewing, and so on, is estimated at 5 per cent of GDP (£6 billion) in the UK – the highest in the world; see Henry, N., Angus, T., Jenkins, M., and Aylett, C. (2007) 'Motorsport Going Global, The Challenges Facing the World's Motorsport Industry.' London: Palgrave Macmillan.
417. Henry, N., Angus, T., Jenkins, M., and Aylett, C. (2007) 'Motorsport Going Global, The Challenges Facing the World's Motorsport Industry.' London: Palgrave Macmillan.
418. In 2005 GM announced a $2.5 million, three-year research programme with Stanford University and Bosch to investigate HCCI technologies with respect to sensors, controls and actuators. Ford has a similar programme underway with MIT. Jaguar Land Rover has also conducted extensive research into HCCI with Birmingham University and other partners.
419. A lean mixture has a high ratio of air to fuel.
420. Based on a study of the top 850 UK spenders on R&D, see Department for Innovation, Universities and Skills/Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR.

Even so, R&D in automotive can be moderately high. The sector spends 5.2 per cent of all R&D in the UK, or just over £1 billion each year, equivalent to an R&D intensity of 4.3 per cent.[420] Even a manufacturer with a strong reputation for long-term R&D investments such as Toyota has a global R&D intensity of 'only' 3.7 per cent.[421] As might be expected, high performance engineering areas such as motorsport have much higher R&D intensities, often exceeding 30 per cent (in part because of their comparatively low sales). Because of its scale, the automotive sector is the largest R&D investor in Europe (20 per cent of total European manufacturing R&D) with an annual investment of around €20 billion.[422]

The majority of R&D spend is undertaken by vehicle manufacturers rather than supply chain firms. By far the biggest spender is Ford, with £584 million, 54 per cent of all automotive R&D in the UK.[423] The importance of locating R&D activities near to assembly operations varies with type of R&D; vehicle assemblers consider it important in near-to-market stages of vehicle development, but far less important for 'basic' R&D.[424]

By far the largest component of manufacturers' R&D expenditure is on new vehicle model development rather than longer-term innovation; one study suggests that 93 per cent of R&D expenditure is devoted to product development, with only 3 per cent for early-stage technology development, 3 per cent for the invention of new concepts, and 1 per cent on basic research.[425]

The development of a car – from design to production logistics – takes up to five years. The product cycle (the time a model is kept in production) can be up to seven years. The concept phase and production cycles of engines and transmissions can be longer, between seven and ten years. Manufacturers and their suppliers plan and allocate production capacity well in advance to accommodate production and renewal of their ranges. As a consequence, 60 per cent of the cars that will be on sale in 2012 are already in production today, while another 30 per cent are in advanced stages of development.[426] This gives the sector an almost in-built innovation cycle centred on model renewal programmes. It is difficult and expensive for the manufacturers to change designs and specifications once a model is in production.

Given this conservatism and incrementalism, the sector has fewer links with universities than some other sectors. Where they exist, they focus on three areas: engineering, including concurrent engineering; design, including rapid prototyping and tooling; and materials, including new manufacturing materials and processes.[427] Major assemblers including Nissan UK, Ford and others are active sponsors of research. Beyond these, few tier 1 firms are engaged in research activities in the UK.[428]

2.1.2 Process technology is the other main area of automotive innovation

Many important innovations have occurred in process technology or new materials, even around core technologies such as the all-steel

Ultra Light Steel Auto Body (ULSAB) consortium

ULSAB was designed to demonstrate the ability of steel to deliver a significant weight reduction in vehicle bodies with reduced cost without compromising safety and performance.[429] It was undertaken by vehicle designers and thirty-five steelmakers from around the world. ULSAB was not about researching new technologies or materials; rather it was a platform which allowed the steel industry to demonstrate best practice materials and processes within one vehicle and a holistic design.

The project reduced the weight of car bodies by up to 35 per cent. It cut costs by 14 per cent and improved rigidity. ULSAB relied on innovative processes and materials including: sandwich (laminate) steel which comprises two sheets of CR steel; hydroforming which involves the three dimensional forming of hollow tubes or sheets to make parts with complex shapes and varying wall thickness; and laser seam welding which offers single side access to the weld, greater vehicle dimensional accuracy, and greater stiffness. Various aspects of the ULSAB approach are already in production, but major investments in new process technologies will have to be made if ULSAB is to be delivered fully.

421. Toyota (2007) 'Annual Report 2007, Building a Platform for Growth.' Toyota City: Toyota.
422. European Commission (2005) 'CARS 21, A Competitive Automotive Regulatory System for the 21st Century, Final Report.' Brussels: European Commission.
423. Department for Innovation, Universities and Skills/ Department for Business, Enterprise and Regulatory Reform (2007) 'The 2007 R&D Scoreboard.' London: DIUS/BERR. This differs from the 80% that has sometimes been suggested, see paragraph 9, House of Commons Trade and Industry Committee (2007) 'Success and Failure in the UK Car Manufacturing Industry: Government Response to the Committee's Fourth Report of Session 2006–07, Third Special Report of Session 2006–07.' London: The Stationery Office.
424. Automotive Innovation and Growth Team (2002) 'Design, Development and Manufacture Report.' London: AIGT.
425. National Institute of Standards and Technology (2005) 'Understanding Private-Sector Decision Making for Early-Stage Technology Development.' Gaithersburg: NIST.
426. European Automobile Manufacturers' Association (undated) 'Lead-time is Essential and Will Not Prevent Emissions from Going Down.' Brussels: ACEA.
427. Automotive Innovation and Growth Team (2002) 'Design, Development and Manufacture Report.' London: AIGT.
428. Automotive Innovation and Growth Team (2002) 'Design, Development and Manufacture Report, Issue 8: Lean Manufacturing Knowledge & Lean Production Dissemination in the UK.' London: AIGT.
429. The results of Phase 1 of ULSAB, which sought to demonstrate technological potential, were announced in September 1995. The entire design process was conducted on computer. Phase 2, which sought to develop actual vehicles, started in 1996, with actual bodies constructed by 1998. Alongside this, Phase 2 developed more detailed cost models of the ULSAB vehicle, a computer-based styling exercise to show how a completed body and closures might look, and a crash analysis. Phase 3 will see the transition of the design approach into volume vehicle production.

body, leading to productivity gains and cost savings.

A recent study of emerging product technologies reinforces the impression of largely incremental development in core technologies.[430] The 33 predicted 'blockbuster' technologies (with the potential to earn revenues of €1 billion a year or 100 per cent market penetration by 2015) include active power steering, battery energy management, electromechanical braking, electronically controlled air suspension, and NOx catalytic reduction and storage. Suppliers are behind the greatest number of these innovations, but the biggest single innovators are vehicle manufacturers.

2.1.3 Disruptive technologies have emerged but remain at the margins

Alternative ways to run vehicles are being developed. Fuel cells may be the best long-term solution because they do not use fossil fuels (a fuel cell is an electrochemical device that combines hydrogen and oxygen to produce electricity, with water and heat as its by-products). However, they are many years from being realised. Other technologies are already available.

For example, hybrid electric vehicles (HEVs) combine a conventional propulsion system with an on-board rechargeable energy storage system to achieve better fuel economy than conventional vehicles without being restricted to short journeys like battery electric cars. The first hybrid motor was developed in 1901 by Ferdinand Porsche. There was some development through the 1960s and 1970s, but HEVs only became commercially successful in the late 1990s when the Toyota Prius and then the Honda Insight were launched. In 2005, Toyota announced its intention to produce 600,000 hybrid cars by 2010 (and more recently, a million hybrids a year within a decade).

Another firm, Zero Pollution Motors (ZPM), expects to produce the world's first air-powered car for the US in early 2010 (see also 6.1).[431] ZPM is the US licensee for Luxembourg-based MDI, which developed the Air Car as a compression-based alternative to the internal combustion engine. The New York-based start-up is aiming to produce a 75-hp equivalent, six-seat modified version of MDI's CityCAT that could travel 1,000 miles at up to 96 mph on each fill-up (one tank of air and approximately 8 gallons of conventional petrol, ethanol or biofuel). MDI's dual-energy engine

430. Diem, W. (2007) 'Wyman Study Identifies 33 'Blockbuster' Technologies.' AutomotiveWorld.com, 1st August.
431. Sullivan, M. (2008) Air-Powered Car Coming to U.S. in 2009 to 2010 at Sub-$18,000, Could Hit 1000-Mile Range. 'Popular Mechanics.' 22nd February.
432. BEVs actually predate gasoline and diesel vehicles. Between 1832 and 1839, Scottish businessman Robert Anderson invented the first crude electric carriage. In 1835, Professor Sibrandus Stratingh of Groningen, the Netherlands, designed a small-scale electric car.
433. Paine, C. (2006) 'Who Killed the Electric Car?' Culver City: Papercut Films.

Battery electric vehicles

Battery electric vehicles (BEVs) – or electric cars – work from chemical energy stored in rechargeable battery packs. They use electric motors and motor controllers instead of internal combustion engines. BEVs produce no exhaust fumes (though of course the original electricity generation may have produced greenhouse gases) and can be cheaper to make and maintain than internal combustion engine vehicles because they have many fewer parts.

Historically, plug-in BEVs have been limited by high battery costs, limited travel distance between battery recharging, charging time, and battery lifespan.[432] Advancements in battery technology have addressed many of these problems. Toyota, Honda, Ford and GM produced BEVs in the 1990s to comply with the California Air Resources Board's Zero Emission Vehicle Mandate. However, the major US manufacturers have also been accused of deliberately sabotaging their own electric vehicle production efforts so as not to threaten their existing business model.[433]

Yet, the next few years may see a resurgence in BEVs, especially using the latest lithium-ion batteries (replacing nickel-metal hydride batteries, previously the cheaper option). In 2008, Tesla Motors, a Silicon Valley start-up company producing high performance, consumer-oriented electric vehicles, will deliver its Tesla Roadster. The Roadster (based on the Lotus Elise) is a performance sports car that can accelerate from 0 to 60 mph in less than four seconds (a similar performance to a Lamborghini Murciélago) with a top speed of 125 mph (limited for safety) and a range of 245 miles. Lotus will assemble the Roadster in the UK. Tesla claims that the Roadster offers double the efficiency of popular hybrid cars, while generating only a third of the carbon dioxide.

uses compressed air fed from Airbus-built tanks to run its pistons. The Air Car variant has a supplemental energy source for speeds above 35 mph: a custom heating chamber heats the air to increase volume and so the car's range and speed. The Air Car is expected to sell for $17,800.

2.1.4 Software is making traditional innovation more efficient

Innovations in process organisation can apply to other areas of the business, notably R&D. The automotive sector has adopted many of these practices, for example the use of Product Lifecycle Management (PLM) software and 'Innovation Technology' (IvT).[434] PLM software manages every aspect of a product's life cycle, from concept and design, to manufacturing, maintenance once the product is sold, and through to its eventual retirement. IvT includes eScience (computer-intensive science that is conducted through highly distributed networks), virtual reality, simulation and modelling techniques, and rapid prototyping.[435]

Such software tools can greatly reduce vehicle development times, a vital metric with volatile markets and rapidly changing consumer tastes.

2.2 Organisational and business process innovation has played a significant role in improving productivity, with new business models emerging at the margins

2.2.1 Organisational and business process innovation has been crucial in improving productivity in the sector

Despite the focus on product development, automotive has long been at the forefront of strategic and organisational innovation. Its practices have subsequently been adopted by other sectors, among them: the mass production assembly line; component and material standardisation; the integration of all stages of manufacturing from raw material to finished product; the de-skilled division of labour into short-cycle repetitive tasks; and the use of financial packages (consumer financing) to enhance product demand.

2.2.1.1 Lean production has been the most important contemporary non-technological innovation

Many of these practices have been popularised in the West as 'Lean production',[436] and have extended well beyond the automotive sector (see for example Appendix B on the aerospace sector). Process improvements, particularly Lean manufacturing, have been the largest contributor to productivity growth in the sector.[437]

434. Waurzyniak, P. (2007) Enter the Virtual World. 'Manufacturing Engineering.' 139 (4), pp.67-76.
435. Gann, D. and Dodgson, M. (2007) 'Innovation Technology: How New Technologies are Changing the Way We Innovate.' London: NESTA.
436. Womak, J. T., Jones, D. T., and Roos, D. (1990) 'The Machine That Changed the World.' New York: Rawson.
437. McKinsey Global Institute (2005) 'Increasing Global Competition and Labor Productivity: Lessons from the US Automotive Industry.' New York: McKinsey Global Institute.
438. MCAD (2007) Managing Tolerances at Nissan. 'MCAD.' June, pp.36-39.

Nissan Qashqai

Nissan Design Europe digitally mastered the development of its Qashqai compact hatchback/SUV crossover car (rather than developing a scale model prototype). This produced higher quality development while reducing lead-time and costs.[438]

Although the automotive industry is one of the leaders in the use of digital tools, it still tends to rely on physical prototypes complemented by digital models. Nissan aimed to reverse this, since physical prototypes take more time and money to build and are less useful in predicting the effects of variations in production on the quality of the vehicles that roll off the assembly line.

3D computer-aided engineering and visualisation software called aesthetica (developed by Icona Solutions) allowed Nissan's designers to visualise extremes in production variations before committing to how the car would be tooled. Fifty thousand variations, called variation control exercises, were simulated. The software also enabled designers to uncover issues in the design that would not have been identified using existing digital processes.

The Qashqai is the first Nissan vehicle to be designed, developed and manufactured entirely in the UK – and the first to use this software.

2.2.1.2 Effective supply chain management by vehicle manufacturers is crucial

Generally, vehicle manufacturers provide suppliers with a specification for their parts in terms of performance, the space dimension within which the part has to fit, and anticipated cost. The vehicle manufacturer's main task is to integrate these components.

Given the increased complexity of modern vehicles, integration has become more challenging. Vehicles need repeated testing and redevelopment to ensure that the vehicle as a whole works and that it can be built in a logical and cost-effective manner. Vehicle manufacturers take many steps to reduce this burden. Many parts are transferred from one model to the next. 'Platform strategies' allow parts and vehicle architectures to be shared across multiple brands: one example is Volkswagen's MLP (Modular Longitudinal Platform); the Volkswagen group has four volume brands in Audi, Seat, Skoda and VW, and MLP is being used increasingly across these brands.

As a result, supply chain management has been a prominent area for innovation. Procurement has developed from the traditional model (a large number of suppliers chosen on price from a local cluster), through Lean (as above), towards the 'extended enterprise' approach (a few select suppliers with whom the manufacturer works very closely to optimise the whole supply chain).

2.2.1.3 There is an increasing but variable role for suppliers in product innovation

Manufacturers now also expect this smaller group of suppliers to undertake R&D and manage their own supply base, though this trend has been more limited than has sometimes been suggested.[439]

Many vehicle manufacturers and tier 1 suppliers have overestimated their suppliers' competencies and underestimated the required levels of expertise and investment required. This has meant that expected savings from devolving design and development to suppliers have not yet materialised. Suppliers still perform only 15-30 per cent of 'design effort'.[440] Of this, tier 2 suppliers or lower account for very small amounts of design effort (5-10 per cent).

As a result, many vehicle manufacturers are now bringing activities back in-house. Manufacturers are now more careful to whom they devolve work and what kind of work they devolve; careful assessments are made of each supplier, their track record and level of competence. Most product innovation is trusted with a small number of so-called 'tier 0.5' suppliers; firms with a credible level of expertise and competence at managing integrated projects. GM has announced that it will no longer outsource major systems to suppliers, while Nissan has embraced a more innovative approach with its 'plant within a plant' system whereby the build of the Micra CC has been outsourced to Karmann inside the Nissan Sunderland plant.[441]

Toyota Production System

Since the late 1980s, a second wave of transformation in the industry emerged as vehicle manufacturers and others sought to emulate the Toyota Production System (TPS).

TPS organises manufacturing and logistics to eliminate waste and inconsistency in products by emphasising continuous improvement, teamwork, just-in-time inventory, and becoming a 'learning organisation' through relentless reflection.[442] This has helped Toyota greatly to reduce lead-time and costs while improving quality.[443] Output per worker is consistently significantly higher in Lean manufacturers (double that of others, in many cases), and Toyota has the highest consistent output of any major Lean automotive manufacturer.[444] In North America, the difference between the most productive major automotive manufacturer (Toyota) and the least productive represents 5.17 labour hours per vehicle (or about $300).[445] In the first quarter of 2007 Toyota overtook GM in global sales for the first time.

Toyota developed the TPS as a reaction to what it perceived as the wasteful overproduction of US automakers (particularly Ford), but was also inspired by visiting the Piggly Wiggly supermarket chain, which only reordered and restocked goods once they'd been bought by customers.[446]

439. Prior to this the general practice was for vehicle manufacturers to design all of the car and its constituent components, and to ask suppliers to quote a price for the production of those components against an anticipated volume.
440. Automotive Innovation and Growth Team (2002) 'Design, Development and Manufacture Report.' London: AIGT.
441. Wells, P. (2005) Nissan Sunderland's 'Plant Within a Plant. 'World Vehicle Manufacturers Analyst.' 84, pp.23-24.
442. Barton, H., and Delbridge, R. (2006) Delivering the "Learning Factory"?, Evidence on HR roles in Contemporary Manufacturing. 'Journal of European Industrial Training.' 30 (5), pp.385-395.
443. Further analysis of Toyota's approaches has also highlighted the Toyota Product Development System, which coordinates the activities of a large number of people to enable work to progress simultaneously instead of serially, hence making the firm one of the quickest in the world in product development. Toyota calls this 'Value Innovation.' See Liker, J. K., and Morgan, J. M. (2006) 'The Toyota Product Development System.' Shelton: Productivity Press.
444. According to an analysis of units per employee per year based on data collected by the automotive analysts Ward, see Vaghefi, M. R., Van Deusen, C., and Woods, L. (2007) Motor Drive. 'Business Strategy Review.' Autumn, pp.28–32.
445. Harbour Consulting (2007) 'The Harbour Report™ North America 2007.' Troy, Michigan: Harbour Consulting.
446. Piggly Wiggly was also the first true self-service grocery store.

2.2.2 New business models are emerging from new firms

As is often the case, new technologies require organisational and business model innovation to complement them. For example, the Project Better Place initiative (another start-up) focuses on the integration of existing technologies and systems to provide the infrastructure and scale necessary to make electric cars a viable alternative to fuel-based vehicles. Its business model is adapted from mobile phone operators; Project Better Place intends to establish a network of charging spots and battery exchange stations to provide ubiquitous access to electricity, starting in Israel. Project Better Place will offer consumers several subscription-based ownership models, by sourcing the electric cars and batteries that will be compatible with the charging network, and subsidising vehicle costs through leases and credits.[447] Prototype vehicles are intended to be introduced in early 2008 and the company hopes to begin commercial sales and service by 2010. Renault has announced that it will supply cars for this network, using lithium-ion batteries developed by NEC Corp. and Nissan.

3. Automotive innovation is inhibited by structural issues in the industry but environmental regulation has become increasingly important

3.1 Conservatism due to high capital intensity and low margins

The automotive sector is a mature industry; it has a relatively concentrated structure characterised by high capital intensity. It is also insufficiently profitable, lumbered with structural problems: over-capacity throughout the value chain; high fixed costs in manufacturing, product design and distribution; inflexible production systems; and inflexible product designs.[448] In effect, the mass market production model is being kept alive by discounting and incentives, paid for by lucrative financial services and aftermarket sales (maintenance, repair and parts supply).[449]

These factors, together with the need to protect brand reputations, contribute to a prevailing conservatism. And this conservatism is reinforced by the high price of the product that results in customer caution. The result is that innovation tends to be channelled towards reducing per-unit costs, or increasing per-unit revenues and margins. This has led to process innovations that reduce costs or new in-car features such as satellite navigation that differentiate products in less significant and less risky ways.

The high barriers to market entry for radical new entrants make it difficult for disruptive business models to emerge that can challenge the entrenched positions of major manufacturers. Yet the sector's relatively narrow approach to innovation appears unable to restore profitability, hence the need for radical alternatives.

3.2 The sector has been resistant to new business models

Despite the conditions prevailing in the industry, new business models are resisted by the current infrastructure (existing manufacturing plants, dealership networks, and suppliers). For example, suppliers might hesitate in taking on risky product development for an untried new entrant, or at least be unwilling to do so at reasonable cost.

Yet, the sector has a large number of marginal, experimental and innovative businesses. Some, such as TH!NK from Norway, have a long and convoluted history trying to introduce a highly innovative product to the market (in this case, a battery electric vehicle made of lightweight materials).[450] Aside from a few high-value vehicles it is very difficult for a new entrant with limited geographic market coverage and an unknown brand to persuade consumers of the merit of purchasing a high-cost product.

Equally, no vehicle manufacturer has yet tried to realise a business model that would threaten its own existing business, however weak that business may be. Perhaps the nearest example is that of the MCC Smart project (or fortwo as it is now known), where over time the more radical aspects of the business plan have been diluted.

3.3 Environmental and safety regulation has become increasingly important

Twenty-two per cent of the world's greenhouse gas emissions result from the transportation sector; an even higher proportion of urban emissions in large cities are attributable to vehicle emissions. There are approximately 700 million cars on the world's roads which emit more than 2.8 billion tons of CO2 per year. An average car produces four tons of CO2 every year, which stays in the atmosphere for 45 years after it leaves the car's tailpipe. In the UK, vehicles are responsible for over a quarter of particulate emissions and almost half of total nitrogen dioxide emissions. These have

447. See www.projectbetterplace.com

448. For example, of major US manufacturers, on each vehicle sold in North America in 2006, Chrysler Group lost $1,072, GM lost $1,436, and Ford lost $5,234; see Harbour Consulting (2007) 'The Harbour Report™ North America 2007.' Troy, Michigan: Harbour Consulting.

449. More than half of all cars purchased in the UK are provided with funding at the point of sale (so, excluding personal loans or direct loans). The involvement of manufacturer 'captive' finance companies has led the marketing of finance to become intertwined with that of new cars, with offers of low or zero interest rate deals used as a means to promote models. See Automotive Innovation and Growth Team (2002) 'Distribution, Competition and Consumer Group Report.' London: AIGT.

450. Orsato, R., Wassenove, L., and Wells, P. (2008) 'The Bumpy Ride of TH!NK.' INSEAD Case Study. Fontainebleau: INSEAD.

451. Automotive Innovation and Growth Team (2002) 'Environment Report.' London: AIGT.

been linked to damage to both air quality and health. Although average emissions per car are falling due to engine and fuel improvements, these reductions will largely be offset by increases in traffic.[451]

Yet according to one study for government, which examined the 'innovation system' for low carbon transportation: "Uncertainty as to the likely strength of long-term policy for CO2 reduction in the transport sector means automotive and fuel firms are uncertain as to the priority to attach to carbon reduction/fuel efficiency goals relative to other objectives."[452] This is exacerbated by insufficient coordination of the R&D efforts in all of the technology areas required.

Furthermore, the production and disposal of vehicles have environmental impacts, even though manufacturers have made production processes less harmful by phasing out mercury and CFCs. Manufacturing itself of course contributes to greenhouse gas emissions and results in a number of waste products (water, volatile compounds and solid waste). Additionally, once vehicles reach the end of their life, though most of the material can be recycled, 25 per cent typically ends up as waste.[453]

Regulation by national governments and international bodies has been an important driver of incremental innovation in this area. Regulations have covered safety, exhaust emissions and recycling; they will in the future limit CO2 output. For example, the recent EU End of Life Vehicles Directive requires re-use and recovery of materials to rise to 95 per cent by 2015.

Regional policy is becoming more influential, for example, Transport for London's congestion charging zone and intended emissions regulation in US states such as California.

However, there have been significant political and lobbying battles over the content of regulations (such as the question of whether there should be voluntary agreements or legislation in the EU). The industry is pushing for alternative measures, such as better traffic management, smoother roads, and teaching drivers the benefits of fuel-efficient driving.

452. E4tech (2007) 'A Review of the UK Innovation System for Low Carbon Road Transport Technologies, A Report for the Department of Transport.' London: E4tech.

453. Automotive Innovation and Growth Team (2002) 'Environment Report.' London: AIGT.

4. Innovation is hidden because there are significant levels of more incremental product and process development

4.1 Non-cutting-edge product development is prominent in the sector

The moderate R&D intensity in the mass market sector compared to some other advanced engineering sectors, yet a sector that is focused on incremental product development, implies a significant degree of technological innovation that is not captured in narrow measures of R&D (Type I hidden innovation).

This is likely to be particularly true of technologies that are developed first by competitors before being adopted by other manufacturers. Most core product technologies eventually become standard across all brands and models, from variable value timing for engines, through process technologies, to 'surprise and delight' features such as satnav. Much innovation is therefore 'catch-up innovation' – new to the firm but not necessarily new to the sector.

Furthermore, most SME suppliers may not have formal or significant R&D programmes, but they still develop and refine their products.

4.2 Organisational and business process innovations are not sufficiently recorded in traditional metrics

Lean manufacturing is an obvious example of both a process and an organisational innovation (Type II hidden innovation). Yet investments in developing such practices are not regarded as innovation. Similarly, innovations in supply chain management, despite their importance to vehicle manufacturers.

4.3 The use of software and other supporting technologies has been valuable in improving quality and efficiency

The use of software in areas such as 3D design and product development is making traditional innovation more efficient. But such software may have been developed first in other firms and often in other sectors (in this case, the aerospace sector). This then represents an example of Type III hidden innovation; the exploitation of software in automotive would not be typically recorded as innovative by traditional metrics.

4.4 Localised generated innovations are incredibly important for some firms
As in other areas of engineering, the emphasis on continuous improvement, especially through Toyota's approaches, can cumulatively improve production techniques, efficiency and productivity. Yet such 'micro-innovations' are not captured in traditional metrics (Type IV hidden innovation).

5. Innovation could be better measured by drawing on industry surveys, better incorporating organisational innovation and tracking outcomes

5.1 Industry surveys are a more detailed source for Type I hidden innovation
There is a huge wealth of very specific industry data, collected internationally, on everything from engine manufacture to inventory, the use of materials and development programmes, which could be used to analyse innovation capacity and performance.

For example, a regular survey of the motorsport sub-sector captures technological and non-technological business trends, such as levels of investment in technologies beyond R&D, areas of specific focus for innovation, and linkages with other sectors.[454]

5.2 Organisational and business process innovations could be better recorded by the adoption of specific organisational forms
Given the importance of organisational innovations such as Lean (Type II hidden innovation), the adoption of such structural changes (and their impact) could be incorporated into analyses of innovation in the sector. The extent has already been recorded in studies of the automotive supply chain. Similarly, industry surveys can record how much more efficient and effective technologies such as the latest design software are being used.

5.3 Localised innovation can be estimated at the firm level
Micro-innovations (Type IV hidden innovation) are by definition difficult to count, but individual firms can certainly evaluate their effectiveness on their own efforts at continuous improvement.

One study estimates that Toyota, through its inclusive approach to improving production techniques, implements one million new ideas each year (3,000 each day). Most are inevitably small but effective solutions to real world problems.[455] But their cumulative impact can of course be seen in the large efficiency and productivity gains made by such manufacturers.

5.4 Tracking outcomes would also be a meaningful way of measuring innovation
Given the increased social and environmental demands on vehicle manufacturers, there could be a greater emphasis on performance data linking innovation activities to improved outcomes. For example, in terms of sustainable production, one trade association survey tracks inputs into production such as: total combined energy use; energy used per vehicle produced; total combined water use; and water use per vehicle produced.[456]

Similarly, recording 'customer fulfilment' in a standardised way could be the focus for the sector's improvement and innovation efforts.[457] Such a measure would represent a fundamental change in perspective, in that it asks: 'Did the customer get the right car, in the right place, at the right time?' It has been estimated that half of all cars in the UK do not arrive 'right first time on time' into the hands of the customer (though there are significant variations between manufacturers).[458]

6. Innovation could be improved by strengthening design capabilities but also organisational and business process innovation to respond to the sector's major challenges

6.1 Retaining high-value-added activities requires improving R&D and design capabilities
More basic and labour-intensive aspects of the production process have shifted to emerging nations including Eastern Europe because of lower labour costs. It has been estimated that UK-based assemblers source well below 50 per cent of their components in the UK. Where UK-based suppliers retain work, it is often only by transferring their own purchases abroad. UK-based suppliers are not just losing work to lower wage countries; much business has gone to firms elsewhere in Western Europe.[459]

This is why it may not be sensible to assume that the industry's current preference for building close to market means that significant vehicle production is unlikely to shift from the UK to lower-cost countries.[460]

454. Experian (2007) 'Motorsport 100 Research Findings.' London: Experian.
455. May, M. E. (2007) 'The Elegant Solution: Toyota's Formula for Mastering Innovation.' New York: Free Press.
456. The Society of Motor Manufacturers and Traders (2006) 'UK Automotive Sector Sustainability Report, Production, Consumption and Disposal Eighth Report.' London: SMMT.
457. Roberts-Dear, R. (2007) 'The Consumer Experience of Buying New Cars.' Solihull: International Car Distribution Programme.
458. Automotive Innovation and Growth Team (2002) 'Distribution, Competition and Consumer Group Report.' London: AIGT.
459. Automotive Innovation and Growth Team (2002) 'Executive Summary.' London: AIGT.
460. Paragraph 2, House of Commons Trade and Industry Committee (2005) 'UK Automotive Industry: Government Response to the Committee's Eighth Report of Session 2003–04. First Special Report of Session 2004–05.' London: The Stationery Office.

In this context, retaining and enhancing R&D and technology development in the UK is obviously important. The UK is already weaker as a result of the absence of indigenously-owned mass manufacturers. Given the foreign ownership of the major vehicle manufacturers and many tier 1 suppliers, many of their design and engineering centres are outside of the UK. This makes it more difficult for many UK suppliers to become involved in early parts of the R&D process, and to access foreign manufacturers generally.[461] Following production activities, many European and US firms are relocating R&D activities to emerging locations (such as central and eastern Europe, India and China).

Increasing levels of design devolution from assemblers to the supply chain mean that the ability to design new products is growing in importance. Increasing the dependency between assemblers and 'design capable' suppliers would therefore generate a reluctance to switch sources of supply. More UK suppliers need to be able to position themselves in this way.

6.2 This means that supply chain weaknesses need to be addressed

Some parts of the UK automotive sector are undoubtedly world class. In part, this is because of the UK's openness to foreign direct investment, which has also helped to transfer world class practices here.

But for major vehicle assemblers, the primary issue remains the quality and management practices at the first and second tier suppliers.[462] The UK automotive supply chain has been regarded as poor in areas such as strategy and planning, leadership, programme management, process engineering, continuous improvement and Lean, and customer care.[463] Thirty per cent of supply chain firms have no business plan, and fewer than 50 per cent have workforce training plans.

Skills weaknesses have been identified in: team leadership; Lean; top and senior organisational management; and Level 3, 4 and 5 occupational skills.[464] Vehicle assemblers predict that advanced engineering systems will become increasingly more integrated (and virtual) and that this will require the development of new engineering management competence in the UK to assist vehicle assemblers.[465]

6.3 More broadly, the current dominant technology and business model in automotive is not sustainable, financially or environmentally

To cite one example, two-thirds of new car buyers in the UK have their vehicles supplied from stock – from the pool of cars already manufactured and located either at dealerships or manufacturer distribution centres.[466] Reducing the number of vehicles held as unsold stock would bring an immediate financial benefit to the whole production and distribution chain, and would be far less environmentally wasteful. To this end, the sector needs to shift from its traditional reliance on 'pushing' stocks of cars down the distribution chain to customers to building a system where cars are customised to the customer's preferences and the process is geared to meeting them.[467]

Given that the industry suffers from global over-capacity and with manufacturing best practice rapidly diffused around the world, being Lean will not be enough. At some point, there is likely to be a radical realignment of the global automotive sector.

Alternative business models have already been developed. One is the Indego concept, which re-imagines the industry without its existing encumbrances.[468] This anticipates almost 22 per cent operating margins (when 5 per cent is considered good by industry standards), through innovations such as: repeated leasing of the vehicle through the life cycle; other consumer costs such as periodic maintenance already bundled into the package offered; a hyper-Lean production system with high levels of outsourcing in development and production; product minimalism with 'good enough' quality; and direct sales and distribution.[469]

Such a model might appeal to an established vehicle manufacturer wanting to introduce a new brand or enter a new market, an emerging vehicle manufacturer or contract assembler (for example, in China), or even a new entrant from outside the sector. The existing industry could be threatened if an emerging manufacturer or new entrant successfully introduced such a model in a relatively short period of time, having a major disruptive impact (much as low-cost airlines have had in their sector).

The recent launch of the Nano, the 'people's car' in India, by Tata Motors at a cost equivalent to £1,277 demonstrates the likelihood of this happening.[470] The Nano is the world's lowest-priced passenger car,

461. Ricardo UK/Skills4Auto (2006) 'Vision for the UK Automotive Industry in 2020, Focusing on Supply Chain and Skills & Technology.' Shoreham-by-Sea/Birmingham: Ricardo UK/Skills4Auto.
462. Automotive Innovation and Growth Team (2002) 'Design, Development and Manufacture Report.' London: AIGT. More recently, see Department for Business, Enterprise and Regulatory Reform (2008) 'Report on the Business Environment for Japanese Automotive Supply Companies in the UK.' London: BERR.
463. Ricardo UK/Skills4Auto (2006) 'Vision for the UK Automotive Industry in 2020, Focusing on Supply Chain and Skills & Technology.' Shoreham-by-Sea/Birmingham: Ricardo UK/Skills4Auto. Similarly, see Automotive Innovation and Growth Team (2002) 'Design, Development and Manufacture Report.' London: AIGT.
464. As identified in the Sector Skills Agreement for the Aerospace, Automotive and Electronics sectors, completed in January 2006; see Sector Skills Council for Science, Engineering and Manufacturing Technologies (2006) 'SEMTA Sector Skills Agreement, Electronics, Automotive and Aerospace Industries.' London: SEMTA.
465. Automotive Innovation and Growth Team (2002) 'Design, Development and Manufacture Report.' London: AIGT.
466. As noted in Cardiff University/The University of Bath/The International Car Distribution Programme (undated) 'Towards a Customer Driven System, A Summary of the 3DayCar Research Programme.' Cardiff/Bath/Solihull: Cardiff University/The University of Bath/The International Car Distribution Programme.
467. Automotive Innovation and Growth Team (2002) 'Distribution, Competition and Consumer Group Report.' London: AIGT.

undercutting by half the former lowest cost car available in India. Tata initially plans to build 250,000 Nanos annually, rising to one million units a year. In addition, Tata will start producing the world's first commercial air-powered vehicle, the Air Car, for India in 2008.[471] Developed by ex-Formula 1 engineer Guy Nègre for MDI, this uses compressed air as opposed to the gas-and-oxygen explosions of internal-combustion models to push the engine's pistons.

Tesla Motors and their ilk show that Silicon Valley is emerging as a source of small pioneering ventures that might induce innovation in automotive, by commercialising new technologies, products and business models that could eventually reshape the sector. In contrast, the (British) Morgan LifeCar – a lightweight zero emission performance vehicle using a radically small fuel cell – will remain only a demonstration concept car.[472]

6.4 The UK needs to develop a broader programme of support to help retain higher-value-added activities and anticipate coming changes in the industry

6.4.1 More strategic funding of new technologies, especially low-carbon technologies, is important

The Foresight Vehicle Steering Group was set up to guide and support UK R&D in the supplier sector to help it meet forthcoming environmental and business challenges.[473] The Foresight Vehicle programme brings together universities and vehicle manufacturers in new collaborative relationships.[474] Five key sub-sectors have been targeted: engine powertrain; hybrid, electric and alternative fuel vehicles; software, sensors, electronics and telematics; advanced structures and materials; and design and manufacturing processes. The latter Thematic Group has been established to promote the research, development and adoption of efficient, world-class design and manufacturing processes. As the name implies, the Design and Manufactoring Process strand is process-oriented, whereas the other Thematic Groups are primarily product-based.

In addition, the Low Carbon Vehicles Innovation Platform was launched by the Technology Strategy Board (TSB) in 2007 to accelerate the market introduction of low carbon road vehicles. Its first activity was a collaborative R&D programme with £20 million of support from the Department for Transport (DfT) and the TSB, focused on bringing forward vehicle technologies that could be viable candidates for commercialisation over the next five to seven years. The next step is the TSB's launch of a Low Carbon Vehicles Integrated Delivery Programme with an initial investment of £40 million jointly supported by the TSB, DfT and the Engineering and Physical Sciences Research Council (EPSRC). It will provide greater coordination of activities from university research to future potential procurement opportunities, speeding up the time it takes to get low-carbon vehicle technologies into the market place.

Yet the development and introduction of a low-carbon transport system still requires a long-term government-led strategy. The recent King Review of low-carbon cars recommended bringing existing low emission technologies from 'the shelf to the showroom' as quickly as possible by: ensuring a market for low emission vehicles; moving the short-term focus back to automotive technology from biofuels; developing the UK as a location for high technology companies in the field, with good businesses support mechanisms encouraging inward investment and supporting key areas of underpinning science and engineering.[475]

6.4.2 New business models, business practices and approaches are crucial, especially across the whole supply chain

Focusing on technology alone is not enough. Innovation also requires the right business practices and business models.

The Automotive Innovation and Growth Team (AIGT) in 2002 suggested that additional assistance is needed to improve the performance of domestic suppliers through local initiatives and assembler-focused programmes of improvement.[476] The AIGT also argued that the sector would benefit from a new approach to the training of management grades in order to redesign and implement changes to the automotive supply chain that will enhance the performance of the sector.[477]

There has been some progress, but more could be done. Following the AIGT reports, the Supply Chain Groups programme was established in 2003, jointly funded by the then Department of Trade and Industry, the English RDAs and the devolved regional assemblies.[478] This programme, focused largely on process improvement through Lean manufacturing, came to an end in March 2008, after having supported 62 projects, involving 575 suppliers employing 160,000 people, and facilitated major productivity improvements of up to 40 per cent.[479] The New Automotive

468. Indego was developed by the consultants ATKearney in conjunction with ex-Ford of Europe board member Martin Leach (later at Maserati, then at LDV), see Dunne, P., and Young, S. (2004) Thinking Beyond 4,000 Pounds of Metal. 'Executive Agenda.' VII (4), pp.25-31. It was based on the concept of 'micro factory retailing', see Wells, P. and Nieuwenhuis, P. (1999) Micro Factory Retailing: A Radical Business Concept for the Automotive Industry. 'Sewells Automotive Marketing Review.' 5, pp.3-7.

469. Similarly, the '3DayCar' concept. The largest overall time saving in this approach would be achieved by switching to a system of direct order input to assembly line 'slots'. See Cardiff University/The University of Bath/The International Car Distribution Programme (undated) 'Towards a Customer Driven System, A Summary of the 3DayCar Research Programme.' Cardiff/Bath/Solihull: Cardiff University/The University of Bath/The International Car Distribution Programme. The project was supported through the Design and Manufacturing Processes strand of Foresight Vehicle.

470. In 2008, Tata also bought Jaguar and Land Rover from Ford.

471. Sullivan, M. (2007) World's First Air-Powered Car: Zero Emissions by Next Summer. 'Popular Mechanics.' June.

472. The LifeCar is a join project between RiverSimple, Cranfield University, QinetiQ, Oxford University, Linde AG and Morgan Motor Company, supported by a then DTI grant.

473. Foresight Vehicle (2004) 'Foresight Vehicle Technology Roadmap.' London: The Society of Motor Manufacturers and Traders. The Foresight Vehicle programme was launched in November 1997 as the flagship automotive R&D programme intended to fund pre-competitive research. All projects are collaborative undertakings between business and academia; the great majority of them are led by industry.

474. The Foresight Vehicle Initiative is the prime knowledge transfer network for the automotive industry. It is now administered by The Society of Motor Manufacturers and Traders (SMMT), formerly by the then DTI.

Innovation and Growth Team (NAIGT), as part of its wider strategic review of the challenges facing the sector in the future, will examine and make recommendations to government regarding future programmes by March 2009.[480] In particular, it has been charged with investigating how the UK industry should respond to low-cost competition and the move to low-carbon transport.

6.4.3 A broad approach to improving skills in the sector is required

UK government has accepted the recommendations of the most recent House of Commons report on the sector, that industry and government should put extra effort into improving skills throughout the sector, increasing the commitment to R&D, adopting Lean manufacturing techniques and strengthening local supply chains.[481] These are the same areas identified by the AIGT in 2002.[482]

The Automotive Academy was opened in 2004. The Automotive Academy system was a new approach to providing skills and training for the UK automotive industry workforce with core funding provided by UK government (£12 million). The Automotive Academy is now being merged into a new body, the National Skills Academy for Manufacturing (NSAM).

The sector needs to equip graduates with the technical skills of engineering whilst also developing the necessary managerial and inter-personal skills. It needs 'business engineers', with the continuing professional development to take a systems view of the industry and its processes, whilst developing their technical and managerial capabilities. BERR is currently working with the National Skills Academy for Manufacturing and the SMMT Industry Forum to develop a new approach which will use the focus of supply chain improvement programmes to enhance leadership and management skills, in addition to the previous emphasis on process improvement.

Another skills issue is the need to give much greater responsibility to frontline teams for technical problem-solving, which helps to identify the real quality issues with manufacturing processes and to release engineers' time to engage in project activities. This is known as Total Productive Maintenance (TPM) and is another concept that originated in Japanese manufacturing, especially at Toyota and Denso. TPM approaches the engineering skills issue from the bottom-up rather than a purely 'graduate elitist' approach.

475. HM Treasury (2007) 'The King Review Part I: The Potential for CO2 Reduction.' London: Her Majesty's Stationery Office; HM Treasury (2008) 'The King Review of Low-Carbon Cars, Part II: Recommendations for Action.' London: Her Majesty's Stationery Office.
476. The Automotive Innovation and Growth Team (AIGT) was the first of several IGTs to be initiated by the then DTI. Sir Ian Gibson, former Chief Executive of Nissan's UK and European operations, was appointed as its Chairman. The primary role of the AIGT was to identify the key drivers which would determine competitiveness over the next 5-15 years and to develop a vision for the sector in the UK.
477. Automotive Innovation and Growth Team (2002) 'Design, Development and Manufacture Report.' London: AIGT.
478. In addition, there has been significant regional funding available to the sector. In 2000–2006, £100 million was offered in regional grants under the Regional Selective Assistance (RSA) and Selective Financial Investment in England (SFIE) schemes to automotive manufacturers and suppliers in England. In the same period, nearly £150 million was paid out, including stage payments on offers made prior to 2000.
479. Department for Business, Enterprise and Regulatory Reform (2008) 'Report on the Business Environment for Japanese Automotive Supply Companies in the UK.' London: BERR.
480. Department for Business, Enterprise and Regulatory Reform (2008) 'Business Minister Shriti Vadera Announces New Investigation into Automotive Industry.' Press release, 7th April. London: BERR.
481. House of Commons Trade and Industry Committee (2007) 'Success and Failure in the UK Car Manufacturing Industry: Government Response to the Committee's Fourth Report of Session 2006–07, Third Special Report of Session 2006–07.' London: The Stationery Office.
482. Automotive Innovation and Growth Team (2002) 'Executive Summary.' London: AIGT.

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