Hidden wealth: the contribution of science to service sector innovation

EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

RS Policy document 09/09
Issued: July 2009 RS1496

ISBN: 978-0-85403-754-4

The Royal Society
Science Policy
6–9 Carlton House Terrace
London SW1Y 5AG
Tel +44 (0)20 7451 2500
Email science.policy@royalsociety.org
Web royalsociety.org

Design by Franziska Hinz, Royal Society, London
Copyedited and Typeset by Techset Composition Limited

Hidden wealth: the contribution of science to service sector innovation

Contents

Foreword

Science has shaped the modern world. To many people this is a statement of the obvious—innovations such as air travel, satellite imagery, nuclear power and a host of other new products all clearly arise from developments in science, technology, and engineering, plus use of their common language of mathematics (STEM).

The link between science (in its widest sense) and the manufactured world is now taken for granted. But between half and three-quarters of all wealth world-wide is now created not by making physical things but by performing services. How has science contributed to this growth of wealth and enhanced quality of life via services? That is the challenge that this report seeks to address, especially for Britain.

We are in global competition to sustain and develop our economy and way of life. Constant innovation is required if we are not to become part of a commoditised society where goods and services are simply produced wherever is cheapest. For this reason, we set out to answer a simple question: where has science—in the widest sense—already contributed well to fostering innovation in the services sector and where and how might new policies enhance the situation? Along the way, we have reviewed a huge range of evidence drawn from a multiplicity of sources, spoken to many experts, and tested out ideas with critical friends. Given the breadth of the services sector, we have inevitably had to be selective.

What emerges from looking backwards is that science has underpinned the enormous expansion of the services sector, often in ways that are unrecognised. The single most important 'enabler' has been the advent of the world wide web and the internet: in every area from accountancy and banking to retail and transport these, combined with other science, have supported a transformation of the way we work, play, research, study, and buy. This has occurred even though the science is now hidden from the layman's view and the results are part of the 'taken for granted' world.

Few advances are unambiguously good. This applies most clearly to nuclear fission but is true also with regard to services. Moreover, circumstances change. As we began our work, the economies of the world were still expanding and many commentators saw no major threats to global prosperity. The services sector in particular was expanding rapidly world-wide, notably manifested in an increasing number of financial centres being created in the Middle and Far East, in Latin America and Europe. As we concluded our work, the global and almost all national economies were in or moving towards recession. This report was compiled amidst the most turbulent period of economic history since at least the Great Depression of the 1930s. We have inevitably had to question whether science has materially contributed to the current financial crisis and also whether the new world order will be very different to that which we report. We devote a section to the banking sector since this has been the fastest growing part of the UK economy and where mathematics and technology have made a major contribution in recent years. Our conclusion is that, though the causes of the current crisis are multi-factored, simplistic use of such tools in the pursuit of wealth and management failings have been one element of the outcome and we propose ways in which matters can be improved in the future.

Our main conclusion, however, is that services are very likely to remain central to the new economy, not least because we are at or near a tipping point: innovations now underway seem likely to change dramatically the way we live and to generate many services (though few can be predicted in detail at present). The combination of ever-advancing new technological developments with new discoveries in the life and physical sciences will deliver change and opportunity on a scale and at a rate of change hitherto unseen. We anticipate services delivered much more cheaply, to better quality and personalised to millions of individuals where that is desired. While much of this will be provided by the private sector, government can enhance its own services hugely by cloning the best of private sector developments to maximise value for taxpayers' money and to strengthen democracy. Increasingly, however, these new services will provide acute challenges such as in privacy and ethics. We are clear that the most effective and successful way to bring about these changes is through a multi-disciplinary framework of collaboration: traditional science is a necessary but not a sufficient condition for success. Ever better collaboration between STEM practitioners and social scientists and those in the humanities will be essential if the services are to be acceptable and fit for purpose. Changes in our educational system would also make a material contribution to such success.

It has been easy to be gloomy over the last 18 months. But the history of capitalism is one of growth and crises. If we look around the world, though there remain many huge challenges of poverty, hunger, disease, and lack of education, much has been achieved in recent years through the development of science, innovation, and international collaboration. Continuing global population growth and rising aspirations amongst the developing world will fuel the demand for services in future. We are convinced that innovation, underpinned by science, has a critical role to play in meeting this latent demand in a way that is as sustainable as possible. We trust that this report convinces our readers of this and commend our recommendations to those to whom they are addressed.

David Rhind
June 2009

Membership of working group

The members of the working group involved in producing this report were as follows:

Chair
Professor David Rhind CBE FRS FBA

Members	
Professor John Burland FRS (Observer)	Emeritus Professor of Soil Mechanics, Imperial College London
Professor David Gann	Chair in Technology and Innovation Management, Imperial College Business School
David Harding	CEO, Winton Capital Management
Professor Jeremy Howells	Executive Director, Manchester Institute of Innovation Research
Michael Hume	Research Adviser, External Members, Monetary Policy Committee, Bank of England
Professor Frank Kelly FRS	Professor of the Mathematics of Systems, University of Cambridge and Master of Christ's College
Dr Michael Lyons	Chief Researcher, Services and Systems Science, BT Group Chief Technology Office
Sir John Taylor OBE FRS	Chairman, Roke Manor Research
Professor Jeremy Watson	Director of Global R&D, Arup

Secretariat	
Nona Ahamat	Policy Adviser
Nicola Berkley	Policy Adviser
Tony McBride	Senior Policy Adviser
Dr Rachel Quinn	Head of Strategy
Dr Alex Weir	Policy Adviser

This report has been reviewed by an independent panel of experts and also approved by the Council of the Royal Society

Review Panel	
Dame Ann Dowling DBE FREng FRS	Professor of Mechanical Engineering, University of Cambridge
Richard Halkett	Director of Strategy & Research, Global Education, CISCO
Professor Christopher Snowden FRS FREng FIET FIEEE FCGI	Vice-Chancellor and Chief Executive of the University of Surrey
Sir Callum McCarthy	

Executive summary

The UK economy is in flux. The financial turmoil of the past two years, and the depth of the resulting recession, has injected fresh urgency to debates about the structural mix of the UK economy and future sources of wealth creation. Yet services will certainly continue to dominate economic activity for the foreseeable future. Agriculture accounts for around 1.5% of employment, manufacturing for around 10%, and services for over 80%. Services include some of the highest performing sectors of recent years—financial services, business support services, retail and the creative industries among them.

Traditional innovation models and policies tend to focus on a narrow conception of innovation—mainly the support of research and development (R&D) in manufacturing industries. The UK lacks a structured policy approach to the promotion of innovation in services. The absence of a coherent policy threatens to undermine the ability of firms based in the UK to develop and maintain leading positions in highly competitive and globalised service industries.

One gap in our knowledge concerns the contribution of science to innovation in the services sectors. Recent studies of services innovation have recognised the importance of technology, but have downplayed the wider significance of science, technology, engineering, and mathematics (STEM), and R&D in particular, arguing that much innovation in these sectors takes place in other ways. This report examines the contribution of STEM to innovation in services, now and in the future, and identifies ways in which this can be strengthened.

The evidence we have collected shows that STEM is deeply embedded in the UK service sectors and that its impact on service innovation processes is extensive, widely diffused and often 'hidden'.

- STEM capabilities are often internalised within service organisations—mainly in terms of 'human capital' or embedded technology, which underpins high levels of innovation. In some cases, these capabilities are organised in the form of traditional R&D. Frequently, however, they take place in a distributed manner that bears little resemblance to traditional R&D: in the market, in real-time, with users and customers;
- STEM is also integral to the infrastructure that enables and supports innovative services. Computing, communications, IT, the internet, massive databases, and large-scale computer modelling underpin many areas of service innovation. These underlying enablers have driven unprecedented change and innovation in services over the past two decades, impacting the way that they are delivered and consumed (through the enablement of disruptive business models) as well as the internal processes of firms themselves;
- Services rely significantly on external STEM capabilities to support or stimulate innovation—indeed they tend to innovate in more external and interdependent ways than manufacturing firms. This can take the form of bought-in expertise or technology and collaborations with suppliers, service users, consultants or the public science base. Through these 'open innovation' models, service organisations respond to the knowledge, science, and technology that they see being developed elsewhere (eg in other companies or universities), and use collaboration to solve their problems in innovative and competitive ways.

Scientific and technological developments (many of which originated in fundamental 'blue skies' research), have precipitated major transformations in services industries and public services, most notably through the advent of the internet and world-wide-web. Other examples include the technique for DNA fingerprinting, invented by Sir Alec Jeffreys FRS, which is now used in health, policing, security, and environmental services; the game theory and mathematical modelling by UCL economists which underpinned the government's auction of 3G radio spectrum and raised £22.5bn for the taxpayer; and the search algorithm that was the initial basis of Google's success.

However, the full extent of STEM's current contribution is hidden from view—it is not easily visible to those outside the process and is consequently under-appreciated by the service sector, policymakers and the academic research community. This blind spot threatens to hinder the development of effective innovation policies and the development of new business models and practices in the UK.

STEM will be essential to future waves of service innovation. Many services are on the cusp of a transition, driven by technological advances, to more personalised and interconnected systems. New advances in STEM will be required to understand, manage, and create value from these complex systems. Physical and life sciences are opening up completely new service possibilities (eg the reduced cost of gene sequencing, which allows for personalised genomics), with the result that the economic value of STEM will increasingly be realised through services.

STEM will also play multiple roles in enabling, stimulating and supporting service-based responses to the big, intractable, social, economic, and environmental challenges that we face. These developments represent considerable opportunities for the UK but unless appropriate policies are put in place now, there is a risk that we will fail to realise the benefits.

We recognise that STEM is deeply embedded in service organisations and that the drive for future competitiveness will come largely from within service supply chains. As the service economy matures, it is likely that these capabilities will become more visible. We focus our recommendations on those areas where public policy can create additional value from Government investments in STEM.

Build research agendas and communities

At present, the academic services community is fragmented and engagement with services firms is patchy. Greater convergence is required in order to:

- Establish international research communities in services innovation;
- Develop collaborative international research agendas in services-related fields;

- Ensure that opportunities to exploit STEM in services are properly recognised;
- Align research and market opportunities;
- Ensure parity of esteem between services-related research and other forms of academic research.

The UK's Technology Strategy Board and Research Councils should initiate services-related Grand Challenges, using the established framework of Innovation Platforms and cross-Council themes or develop new mechanisms if appropriate. This will engender closer cooperation, promote the sharing of knowledge, and potentially accelerate business entry into new and emerging markets.

Develop multi-disciplinary capabilities

In 2006/07, the services sector was the destination for 82% of graduates entering full time employment who had a 'core' STEM first degree. The statistics and testimonies from employers show clearly that STEM trained personnel are highly valued by services firms in many different sub-sectors. The application of deep disciplinary knowledge and the ability to undertake rigorous analysis is important. But for many employers, the main contribution of STEM is the deployment of generic skills in numerate analysis, mathematical and computer modelling, database design and management, and data mining.

However, there is some dissatisfaction with the quality and quantity of STEM skills available to employers in services. We have been struck by the importance attached to multi-disciplinary skills and by the strength of criticisms of a 'silo mentality' in UK universities.

This is of concern given anticipated developments in services and the role that STEM is expected to play in creating value from increasingly complex service systems. This will require teams of people who combine deep knowledge of particular STEM subjects with abilities gained from disciplines such as economics, social sciences, management, or law. The ability to take account of the 'human dimensions' in complex systems (eg people who have the mathematical tools to model complex systems involving millions of users, but who also have knowledge of social sciences and human behaviour), will be critical.

It will be challenging to design courses that equip people with such a broad range of knowledge and skills within the limited time available in undergraduate degrees. To inform the development of more suitable courses at undergraduate and postgraduate level, we recommend a large-scale exploration of STEM skill needs in service sectors to be undertaken by Sector Skills Councils and overseen by the UK Commission for Employment and Skills. Funding and Research Councils and universities should also consider ways to make existing courses more relevant to the service sectors. It is crucial to retain a mix of approaches to higher education provision, in which there is a role both for specific STEM degrees and more multi-disciplinary courses.

Providers of STEM courses must ensure that graduates are better equipped for the challenges of the modern working environment by reviewing the training they provide in information communication technology (ICT) and analytical skills, increasing the use of case studies and guest lecturers from the services sector, and allowing students to attend lectures on a variety of subjects as part of degrees in a core STEM discipline. Service sector firms should also provide more work placements for STEM students and seek opportunities to inform curricula development.

Increase the scale of knowledge exchange

Most interaction between service organisations and the public science base is informal and indirect (eg through the supply chain). Service companies are, on the whole, not well connected with the academic STEM community. We are concerned by the results of two major surveys that strongly suggested that barriers to collaboration were actually increasing. There is much potential for improvement here: various organisations made clear to us their desire for closer working relationships and many others demonstrated the benefits that flow from such collaborations. However, there are a number of barriers to effective engagement, including mismatch of expectations, differing cultural norms, poor understanding of services innovation processes in academia, low esteem for services-related research, and poor alignment of objectives between businesses and academia.

We recommend that the Technology Strategy Board reviews the Knowledge Transfer Partnerships (KTP) programme for its accessibility to services and to KTP associates with STEM backgrounds. Universities and funding bodies should support the exchange of senior academic and research staff into services and vice versa, via fellowship schemes or other means.

Case studies

Given the economic importance of the banking and public sectors in the UK and the significance of innovation in these settings, we have looked in detail at the distinctive role of STEM in these domains.

Banking

The UK has enjoyed a huge competitive advantage in financial services over an extended period, bringing substantial advantages to the UK economy. Developments in ICT and financial modelling have fostered particularly rapid innovation, enabled by STEM-trained staff, notably computer scientists and mathematicians.

However, vast imbalances in capital funds between countries, the mispricing of risk, and the collapse of the US sub-prime mortgage market, triggered a global banking crisis in Autumn 2007 that led to a sudden, massive, and ongoing reduction in credit availability with dire consequences for governments, taxpayers, consumers, companies, and banks world-wide. This financial crisis has led, in turn, to a near-global recession in 'the real economy'.

There are a wide range of opinions on the causes of the crisis, but some commentators have attributed at least some blame to the inappropriate use of mathematical tools whose properties and consequences were not properly understood by those responsible for managing their exploitation. It is clear that many and various flaws in the banking sector culminated, ultimately, in systemic failure. Aside from a cavalier approach to risk, these flaws included the reliance on apparently complex (but, in some cases, actually simplistic) tools and financial products, low levels of understanding and oversight by senior management, and the inappropriate regulatory and geopolitical framework that underpinned global financial systems.

We make four recommendations for enhancing the role that STEM might play in ensuring greater stability of the financial systems of the future. First, we recommend the creation of world-leading centres of modelling and risk assessment relevant to and engaged with financial services institutions like banks. Second, the Research Councils, the Bank of England and the Financial Services Authority should explore ways for the science base to contribute to more effective modelling of systemic risk in financial services. Third, the Financial Services Authority and the Financial Services Skills Council (FSSC)—supported by the influence of the City of London Corporation and other relevant bodies—should institute and mandate competency levels for those with managerial roles in the understanding of mathematical modelling and risk in complex systems. Finally, the Higher Education Funding Councils and the FSSC should review the contents of financial engineering and related courses in the UK and, in association with Higher Education Institutions, ensure the provision of appropriate curriculum elements such as considerations of risk, safety tolerances, testing, adherence to published standards, wider understanding of economic contexts, and also any ethical considerations.

Public sector innovation

Recognition of the importance of innovation in government has grown in recent years. Some public agencies have recognised the role of STEM in delivering high-quality public services and have successfully engaged the STEM supply chain in their innovation processes. But these examples are the exception to the rule—initiatives to foster innovation within Government have mostly ignored STEM.

In view of the importance of the public sector to national prosperity, we recommend that the Cabinet Office and the Department for Business, Innovation, and Skills (BIS) should establish a team, drawn from central and local government and from the science base, to undertake detailed work on how STEM can be exploited more successfully to foster public sector innovation. We urge BIS and the Funding Councils to emulate the success of the Higher Education Innovation Fund with partners from the public services and the science base.

We were made aware of problems arising from public sector competition with the private sector in regard to the exploitation of the government's information holdings. We note the government's publication of changes to the Ordnance Survey (OS) business model and welcome the intention of making OS information more readily available. But we urge the Shareholder Executive and HM Treasury to move towards a situation where there is one model for the supply of government information, thereby simplifying matters for commercial organisations and facilitating innovation.

We also recommend to the UK Research Councils that they should explore with the CBI and other relevant bodies the scope for freeing commercial data for academic and other research.

Improve understanding of services and service innovation models supported by STEM

Service innovation models remain poorly understood by policymakers, researchers, and funders and there is a relative dearth of academic, case study, and statistical information available for analysis. Unless policymakers develop an improved understanding of increasingly distributed 'open' innovation processes in services it is unlikely that innovation policy will be able to support innovation practice. Given the economic importance of these sectors, this knowledge gap needs to be addressed as a matter of urgency.

We urge research funders, led by the Economic and Social Research Council, to develop the body of academic research into services innovation. The findings from this research should be promoted to knowledge exchange professionals whose role it is to facilitate industry–university links.

We also make recommendations to the Office for National Statistics regarding the coverage and nature of official statistics for services, in order that they can better underpin the development and evaluation of policies.

In conclusion

Innovation policies have tended to focus on the support of R&D in manufacturing industries. But it is now recognised that other approaches are required to support innovation in services.

Many of the findings of this study are, however, also applicable to aspects of manufacturing. As the boundaries between manufacturing and services continue to blur, we expect to see greater convergence of innovation models, particularly around 'high value manufacturing' and the 'servicisation' of products. Traditional forms of innovation and R&D policy for manufacturing may become rapidly outmoded and there may be as many lessons here for that sector as for services.

The main message of this study is that the contribution of STEM to service innovation is not an historic legacy, nor simply a matter of the provision of 'human capital'—important as the latter may be. STEM provides invaluable perspectives and tools that will help to nurture emergent service models and define future generations of services for the benefit of businesses, government, and citizens.

The success of the UK Government's innovation strategy will rely on a broadening of its perspectives. The Government must develop a more sophisticated approach to studying the relationship between knowledge creation and economic impact, and give greater coverage to those parts of the economy that have thus far been relatively neglected, namely services and much of the public sector. But ongoing attention to the supply of knowledge and skills—and particularly the role of science—must be central to the innovation agenda if success is to be assured. The Royal Society looks forward to playing an active role in the further development of the UK's science and innovation strategy.

1 Introduction

The best way for the UK to compete, in an era of globalisation, is to move into high-value goods, services, and industries. An effective science and innovation system is vital to achieve this objective.

(Lord Sainsbury of Turville 2007, p3)

1.1 Background to the study

Over the last 50 years, the service sector in the UK has grown hugely such that it now accounts for around three-quarters of jobs and GDP. Innovation (the successful exploitation of ideas; see Section 1.5) is a crucial driver of economic growth, especially in high-wage 'knowledge economies'. So innovation in services is particularly important for the UK. There have been similar trends in all major developed economies.

Service industries and supply chains in areas such as healthcare, education, environmental sustainability, energy, construction, transport, and logistics are developing on an increasingly international scale, and markets themselves are increasingly globalised. As such, they represent significant market opportunities for innovative UK firms operating in these spheres.

Traditionally, Government policy to stimulate innovation in the economy has focussed on investing in publicly funded science and technology, improving links between universities and industry, and encouraging businesses to boost their research and development (R&D) spending. However, recent studies of the nature of innovation in services have questioned the importance of R&D and science and technology in this sector (eg NESTA 2006, 2007), arguing that much innovation takes place in other ways and is 'hidden' from policymakers.

We agree that a large amount of innovation in services does not take the form of formal R&D, but we believe that these analyses have gone too far in downplaying the role of science and technology in services. To date, no policy studies have systematically examined the contribution of science, technology, engineering, and mathematics (STEM) to innovation in services; this is what we have set out to do in this report.

In this chapter, we describe what we mean by services, innovation, STEM, and the research base. We also outline how we went about the study with reference to what previous reports have said about the role of STEM in services innovation. In Chapter 2, we describe our main findings regarding the contribution of STEM to innovation in services, drawing upon evidence collected in this study and new analyses of publicly available surveys and datasets. In Chapters 3 and 4, we discuss the role of STEM in two specific sectors: the banking industry, in light of the recent financial crisis, and the public sector, the expenditure of which accounts for 43% of GDP. Chapter 5 examines what services may look like in the future and the role that STEM might play in their development. In Chapter 6, we discuss in detail the major findings of our study, focussing on areas where we observed problems or barriers to the full realisation of the value of STEM, and make a number of recommendations. Finally, Chapter 7 collates the main conclusions and recommendations of the report.

1.2 The nature of services

Services include some of the most innovative and highest performing sectors of recent years—business support services, communications, healthcare, retail, financial services, and the creative industries among them, as well as public services (see Box 1.1).

The latest figures from the Office for National Statistics (ONS; see Box 1.2 for detailed commentary on these statistics) show that the services sector accounted for three-quarters of UK Gross Value Added[1] (GVA; Figure 1.1a) and 81% of jobs in the economy (Figure 1.1b). So far as exports are concerned, the total value of goods exported from the UK in 2008 was £251bn while that from services was £166bn. The equivalent net values of goods and services, however, were –£92.9bn and +£48.9bn—so it is fair to say that services added more externally earned value to the UK economy than did manufacturing. The services sector therefore accounts for most of the economic activity in the UK and covers a very wide range of activities, which themselves entail different types of transformation processes (see Table 1.1).

During the course of our analysis, we found it useful to make a broad distinction between different types of services organisations based on the relative importance of STEM to their businesses. We identified two types of organisations:

- Type 1: Organisations in which STEM is the core business and whose revenues are based on their ability to deliver

Box 1.1 Diversity within services

The term 'services' describes a wide variety of activities and sectors (see the ONS 'Index of Services'[2] for more details). Examples of service activities include investment banks providing financial advice to clients, design consultants providing engineering expertise to construction firms, retailers providing online shopping and delivery of goods, or health and social care companies providing remotely monitored care for the elderly.

Services organisations span a multitude of sectors, including:

- Finance;
- Business support;
- Communications;
- Healthcare;
- Retail;
- Creative industries;
- Education;
- Transport;
- Logistics.

1 GVA measures the contribution to the economy of each individual producer, industry, or sector in the United Kingdom.
2 http://www.ons.gov.uk/about-statistics/user-guidance/ios-methodology/index.html

Table 1.1. A typology of services (from Howells & Tether 2004)

	Service type	Service description	Service example
1	Physical service	Services engaged in the physical transformation of goods	Road transport, handling and storage
2	People-oriented service	Services which are aimed at the transformation of people	Care for the elderly
3	Information processing service	Services engaged in the transformation of information	Data processing
4	Knowledge-creating service	Services engaged in the provision of knowledge based services	Design and related services

STEM expertise, outputs, and solutions (eg contract research organisations). In these organisations, the customer is, more often than not, buying STEM expertise;

- Type 2: Organisations in which STEM may be a useful tool for meeting other business objectives or developing and delivering services (eg providing insurance, retailing goods and services, or financial trading), but is not a core output of the business. In Type 2 organisations, the customer is buying a service but is largely unconcerned with its STEM content.

There are many other ways to divide and sub-divide service organisations, but we found the distinction between Type 1 and Type 2 oraganisations to be useful in the course of this study.

Services may be considered intangible as they are frequently co-produced (see, for example, den Hertog 2000) by the provider of the service and consumer (eg a design consultant working with a client manufacturing company to produce a new design). Services are, therefore, often produced and consumed simultaneously. This means it is very difficult to define a service product and observe a moment at which the service product changed significantly.

Research has highlighted the wide range of activities that are encompassed by services and has shown that services ought not to be thought of as a homogenous group of activities. To account for the intangibility of services and differences in size and activity types, researchers have attempted to produce a typology of different service activities. Four types have been suggested by one study (Howells & Tether 2004) (see Table 1.1) to help highlight such differences.

As we outline in Chapter 5, services are on the cusp of a major transition. The convergence of technologies, with embedded intelligence and pervasive sensing and monitoring, will lead to increased personalisation of services, their greater availability, and a fundamental change in the relationship between experts and customers.

1.3 Services supply chains

Although studies of service supply chains remain limited, a literature review carried out for this project by Professor Jeremy Howells (with the help of Professor Paul Cousins) identified some important characteristics.

Service firms tend to develop innovations in more external, interdependent, and complementary ways than manufacturing firms. A recent study (Howells & Tether 2004) sought to outline the more 'outward-looking' nature of services innovation and the way service firms interact with other external actors (in particular customers) compared to the more 'inward-looking' nature of manufacturing innovation, which is more often associated with harnessing in-house activities and knowledge resources. Other studies (Tether 2005) tend to support the view of service innovation as more oriented towards the external sourcing of knowledge, inter-organisational collaboration, and customer interaction and networking.

Supply chains (backward links) and customer demand-driven chains (forward links) can form important sources of, and conduits for, new innovative practices. This is because in many cases innovations are actually co-produced by the service provider and consumer (see Section 1.2). It is perhaps more appropriate then, to think of services as entailing close, interdependent 'supply and demand chains'—inter-related networks of suppliers and users, involving complex engagement patterns between different sets of actors, often within wider collaborative teams or networks.

In some services, such as professional services, there is no transfer of tangible goods or components (Ellram *et al.* 2004), making measurement difficult. In other services, nothing can be physically stocked in the supply chain (ie there is no physical inventory) as the service is produced and consumed simultaneously, meaning that effective stocking is only created by the presence of labour to create supply capacity.

Nonetheless, service firms find it difficult to plan for and manage rapid changes in demand through the supply chain because of these inventory/capacity problems (Akkermans & Vos 2003) and hence suffer from 'demand amplification'[3] effects along the chain.

Building effective ICT, online, or web-based networks to support increasingly international supply chains has been an important characteristic of the development of service supply chains over recent years (Youngdahl & Loomba 2000).

However, service firms remain poor at demand integration and demand chain management (DCM; associated with gaining rapid (often real-time) demand information, managing inventory or stock to meet this demand and then planning,

3 'Demand amplification' is defined as the phenomenon in which demand becomes increasingly amplified and distorted at each stage up through the supply chain. As such, the actual variance and magnitude of the *orders* at each stage in the chain is increasingly higher than the variance and magnitude of the *sales* and this amplification propagates itself upstream within the supply chain.

scheduling, and executing this through the supply chain; see Frohlich & Westbrook 2002), no doubt in large part because of the issues associated with the nature of the service supply chain and its management outlined above.

Despite the apparent opportunities offered by co-production (a characteristic of many services) and the centrality of customer inputs in many innovative activities (Slater & Narver 1998), service firms have been slow to gain the benefits of reduced development time and improved performance for new services (Alam & Perry 2002) that can be afforded by closer customer involvement.

1.3.1 Blurring of boundaries between manufacturing and services

Studies of innovation in services have been complicated because the dichotomy between manufacturing and services is a crude and imprecise one, especially as previously in-house activities (eg accountancy) are outsourced or offshored and as 'servicisation' proceeds.

This has been primarily brought about by manufacturers seeking to capture greater value added from their knowledge of their products by adding a 'service wrapper' (a process known as 'encapsulation') and by service firms working more closely with their supply chains to respond more quickly to changing customer needs (eg European Commission 2007; BERR/DIUS 2008).

Thus, many manufacturing businesses have added services to their offerings by exploiting their own products. One of the most extreme cases is the oft-cited example of Rolls-Royce, which has effectively migrated to a different business model based on providing a service: the firm has moved from simply selling engines and spare parts to selling or leasing propulsion services ('power by the hour'). This is because often the value of after-market support services on a product through its lifespan exceeds original sales many times over (Lord Sainsbury of Turville 2007).

The relative fluidity of business models and sectors is in stark contrast to the rigidity that characterises the statistics often used to describe the firms and their activities (see Box 1.2 and Annex 3). The situation was described in an *Economist* article on 10 January 2009 (*Coming in from the cold*): 'In practice, there is no clear line between what counts as services and what has been made …. The distinction owes more to government statisticians than anything else.' Indeed, as a recent DTI report stated, 'it is preferable to look at service *activities* as opposed to service *sectors*' (DTI 2007 p5, emphasis added), but in practice this is difficult to do as most statistics are based on sectors as defined by the standard industrial classification.[4]

The technical inadequacies of the official statistics outlined in Box 1.2 have posed significant methodological complications for this and other studies, the implications of which are discussed later (see Section 6.2.4).

1.4 The growth of the services sector

Whatever the detailed problems of measurement, figures from the Office for National Statistics show the growing dominance of services over the past 30 years,[5] both in terms of contribution to UK GVA and proportion of UK workforce employed (Figures 1.1a and b). Figure 1.4 (see page 8) breaks this down by the sectors used in the 1992 ONS Standard Industrial Classification: the fastest rate of growth in the 30 year period 1978 to 2008 was in financial and business

Box 1.2 Defining services

All official statistics on employment by industrial category are produced by the Office for National Statistics (ONS). To seek to match the changing nature of the industrial sector, ONS (and its predecessor bodies) changed the Standard Industrial Classification (SIC) in 1958, 1968, 1980, 1992, 1997 and 2003; the last two were minor in scope. A new and substantial revision, published in 2007, expanded the detail in many areas (Hughes 2008). Indeed, ONS legitimated it by saying 'The revised classifications reflect the growing importance of service activities in the economy over the last fifteen years, mainly due to the developments in ICT'.[6]

Changing classifications can be complex. We note that the ONS is constrained by the requirement to ensure that the UK SIC is consistent with NACE, the European Union's industrial classification system, and with the UN's International Standard Industrial Classification of All Economic Activity (ISIC).[7]

That said, the timescales for adjusting to new forms of economic reality are extended. Following consultations with the user community begun in 2002, SIC 2007 was brought into initial use in January 2008, but full implementation of the new SIC will not be complete across all ONS statistics until the end of 2011 when national and regional accounts will be based on it. Where statistics are produced by other government departments that make use of the SIC, the timetable for adoption of the 2007 scheme is the responsibility of individual departments—though we understand that the Department for Business, Innovation and Skills (BIS) is seeking to coordinate timetables for all non-ONS surveys. It is therefore not surprising that almost all of the statistics we have found are defined under the 1992 SIC, but this nevertheless seriously complicates analysis of activity in the services sector. Moreover, we received representations that even the latest classification does not match the contemporary reality of how economic activity arises from innovative activity. We recognise that it is difficult to capture new developments of this kind in their infancy but we are convinced that continuous efforts to do so are vital to our understanding of the economy and policy responses.

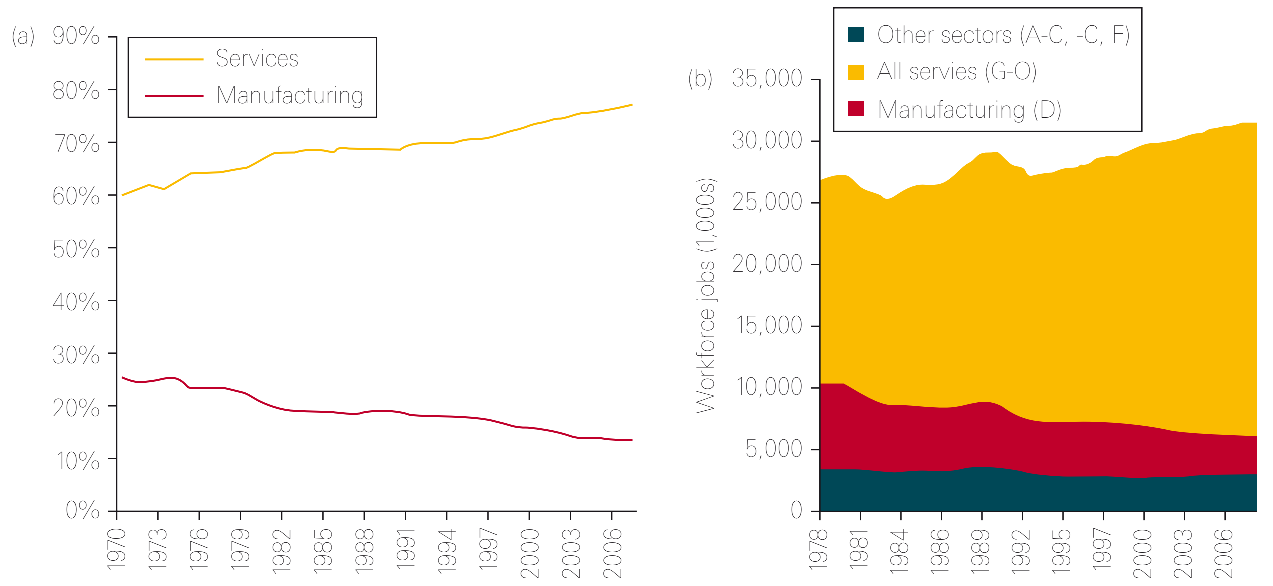
4 See Annex 3 for details of how the ONS classifies services activities; the full documentation on the 2007 and 2003 Standard Industrial Classification of Economic Activities is at http://www.statistics.gov.uk/statbase/Product.asp?vlnk=14012

5 See Bell (1973) or Castells (2000) for detailed examination of the changing nature of the economy.

6 http://www.ons.gov.uk/about-statistics/classifications/future-developments/operation-2007/index.html

7 That said, we recommend later that some additional breakdown of the service sector coding is desirable.

Figure 1.1. Growth of the service sector. (a) Proportion of UK GVA contributed by services and manufacturing, 1970–2007. (b) Employment in services, manufacturing, and other sectors 1978–2008. Source: Office for National Statistics.



services, which more than doubled in employed numbers (from 2.8 to 6.6 million) and contribution to UK GVA (from 15.5% to 33%). Large increases in employment also occurred in public administration and health and in the sector comprising employment in distribution, hotels, and restaurants.

Various consequences flow from the spiralling importance of the services sector within commerce. For example, investment in the sector has increased rapidly: the Library House UK Venture Backed Report (Library House 2007) claimed that services and retail has become the fastest growing sector for investors,[8] with 2005/06 growth in the value of investments rising by 91%.

But central and local government and the NHS also form an important part of the services sector. The vast majority of estimated government expenditure of £623bn (43% of GDP; HM Treasury 2008 Annex B) in 2008/09 is related to the delivery of services, including the redistribution of resources. It is therefore self-evident that innovation in the government sector to provide better services and better value for money is as crucial as in the commercial sector. Indeed the Westminster government's adoption of the Transformational Government Strategy (see Section 4.2) includes elements—notably the personalisation of services to individuals and families—that can only be achieved through the integration of STEM and wider innovation strategies (though only the T of STEM is mentioned in that strategy).

1.5 What do we mean by innovation?

'Innovation' is a difficult term to pin down. Taken literally, it can include almost any new development. Some commentators have limited it to what comes out of formal Research and Development (R&D). We think that is too restrictive: innovations can appear out of work sometimes done many years before—where the primary innovation is by connecting ideas or concepts from multiple sources.

8 At least until the financial crisis starting in Autumn 2007.

We therefore prefer the (still rather general) description of innovation as 'the successful exploitation of ideas'. We are aware, however, that in submitting evidence to this project respondents may have interpreted 'innovation' in different ways, and therefore use the term in a broad sense throughout this report. Some particular facets of developing innovation models are given in Box 1.3.

Innovation does not occur in isolation: to use Lord Sainsbury's term, there is an 'innovation ecosystem'. He described it as inter-linked activities including 'industrial research; publicly-funded basic research; user-driven research; knowledge transfer; institutions governing intellectual property and standards; supply of venture capital; education and training of scientists and engineers; innovation policies of government departments; science and innovation policies of Regional Development Agencies; and international scientific and technological collaboration' (Lord Sainsbury of Turville 2007, p4). Given our particular objectives (see below), we have sought to concentrate on one particular element of this ecosystem while recognising that success comes from many different contributions: science, however—in the widest sense—seems to be a necessary though not sufficient requirement for many key innovations, even if the lag between the science and its exploitation may be considerable.

1.6 The nature of services innovation

Notwithstanding the blurring of the boundaries between manufacturing and services (see Section 1.3.1), it is clear that the nature of service innovation differs to manufacturing in many regards.

Service providers tend to focus on business model innovation with technological innovation usually being left to suppliers of technical infrastructure upon which services are delivered. It is more difficult to develop new services 'offline' than it is to develop new products. New services are typically developed much closer to existing operations, making prototyping and evaluation more difficult. Services evolve through incremental improvement and gradual changes in use. Bruce Tether (Tether 2005) likens service innovation to the software development

Box 1.3 Innovation models in services—latest academic/practitioner thinking

Current academic thinking describes innovation in services as highly distributed (in some areas), 'open', and networked. There are many competing theoretical frameworks with no universal model or consensus (partly because of a lack of relevant data due to definitional issues and the simultaneous production and consumption of many services). Although innovation models have grown ever more sophisticated, most are still reactions to, or iterations/combinations of, earlier models.

Recent models have:

- recognised the distributed nature of innovation processes and the roles played by multiple actors (eg suppliers, customers, users, regulators, competitors);
- emphasised the importance of incorporating suppliers, users or demanding customers within the innovation processes of the firm;
- recognised the role of consumption patterns in shaping service offerings;
- demonstrated an increasingly strategic approach to innovation at the firm level;
- integrated manufacturing and services perspectives, as they become increasingly intertwined in practice.

However, most current models still live in the shadow of the linear model of innovation and 'national systems of innovation'. There remains a strong focus on production and process in service innovation, while outcomes or effects of innovation (eg impacts of innovation on users) have been largely neglected. There are some signs, though, that this is changing, with a growing focus—both in theory and in practice—on 'user-centricity' in services of innovation models.

The next generation of services innovation models are likely to centre on the development of new business models based on the convergence of transformative technologies (innovation technology).

process in describing development as often being in 'perpetual beta'. Gann and co-authors (Dodgson *et al.* 2008) have argued that one similarity between new manufacturing and new services is that 'innovation technology' is being "used to make customers on the one hand and scientific researchers on the other more central in decisions about new products and services". (The convergence of innovation technologies is discussed in more detail in Section 5.5.)

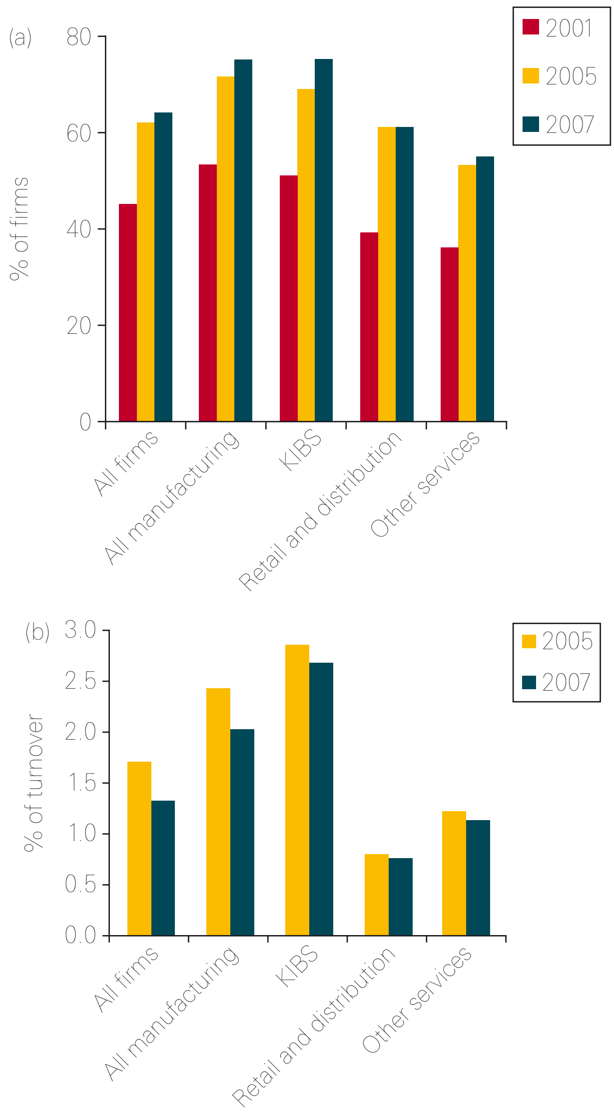
A number of recent policy studies have looked at innovation in the services sector, and to complement these, the Royal Society commissioned two academic researchers[9] to review the relevant academic literature and analyse available case studies.

A major conclusion from many of the reports and from our literature review and case study analysis was that there is poor understanding of services innovation and how to measure it effectively (CST 2003, 2006; NESTA 2006, 2007; CBI/QinetiQ 2008; Lord Sainsbury of Turville 2007; NESTA 2008a). This is due to a number of factors, including the diversity and relatively recent expansion of the sector, the intangible and sometimes ephemeral nature of services (often with simultaneous production and consumption—see Section 1.2), low academic interest in the topic, no common language for discussing innovation in services, and a tendency for policymakers to stick with established systems and metrics.

The reports characterise innovation in services as varying widely in extent and form between different sectors, and generally being driven by suppliers, customers, internal needs or systematic technological changes (NESTA 2008a). The role and power of consumers/users in the innovation process was particularly highlighted, partly enabled by rapid and transformational developments in information technology in recent years (BERR/DIUS 2008).

These characteristics mean that much innovation in services is not captured in the traditional metrics (eg spending on R&D and patents awarded), leading to its description as 'hidden

Figure 1.2. Innovation activity by sector and year. (a) Percent of all firms in each sector that are 'innovation active'. (b) Percent of total turnover spent on innovation-related activities in innovation active firms. KIBS = knowledge intensive business services. Source: UK Innovation Surveys 2001, 2005, and 2007.



9 Dr Sally Gee from Manchester Business School and Dr Alex Frenzel from Imperial College Business School.

innovation' (NESTA 2006). NESTA argues that this hidden innovation is vital to the future development of the UK, as it often represents the innovation that most directly contributes to the real practice and performance of a sector (NESTA 2007). NESTA identified four types of hidden innovation (not specifically relating to services). These overlap to some extent with a typology of services innovation developed in a different report (CBI/QinetiQ 2008), which described innovation as technology-driven, design-led, brand or marketing based, process or organisational, or business-model based.

When attempts are made to include these forms of innovation in innovation metrics, innovation activity in services is only at a slightly lower level than in manufacturing: for example, the UK Innovation Survey 2007 (see Annex 1—Glossary) found that around 60% of all services firms were 'innovation active'[10] in the years 2004–2006, compared with 75% of manufacturing firms (Figure 1.2a). Different sectors within services have different patterns of innovation expenditure, with knowledge intensive business services (KIBS)[11] firms spending a higher proportion of turnover on innovation-related activity than manufacturing firms, but retail & distribution and other services firms much less (Figure 1.2b).

There is also a split between KIBS, who resemble manufacturing firms, and other services firms in terms of the types of innovation activities in which they are engaged. The most common innovation-related activities for firms in all sectors is 'acquisition of advanced machinery, equipment and software' (AMES), followed by innovation-related marketing (Figure 1.3a). However, manufacturing and KIBS firms are much more likely to be engaged in internal R&D and innovation-related design than other services firms, and KIBS firms are more likely to engage in innovation-related training. Few firms in any sectors engage in the acquisition of external knowledge (AEK) or external R&D. The pattern is broadly similar in terms of how innovation active firms allocate their innovation budget, except that 'other services' firms spend a much greater proportion of their budget on AMES than firms in other sectors, and retail & distribution firms spend more on marketing (Figure 1.3b).

As well as identifying the need for further investigation into the nature of services' innovation, the various reports made a number of other, more specific recommendations for policy measures that would facilitate innovation in these sectors. These included improving demand-side pull for service innovation, for example via public procurement (CBI/QinetiQ 2008), ensuring markets are as open and flexible as possible (BERR/DIUS 2008), recognising the importance of ICT (BERR/DIUS 2008), and improving access to finance for innovative, high growth service businesses (BERR/DIUS 2008; CBI/QinetiQ 2008).

1.6.1 Open Innovation

We have been struck by the development of 'open innovation' models (eg Chesbrough 2003; Dodgson *et al.* 2008) and approaches by such major organisations as BAE Systems and Rolls-Royce. These models suggest that, to accelerate innovation, organisations should look outwards for new knowledge (eg collaborating or buying/licensing new processes or inventions from other companies), in addition to inwards (eg through their own research).

In these cases, service firms respond to science and technology that they see being developed elsewhere, for example in other companies, universities, or overseas. They promote collaborations and coalitions with others, such as suppliers, customers, academics, to solve their problems in innovative, competitive ways. Siemens is a good example of just such an approach.

It has been claimed by some that moves to more open or 'distributed' innovation models may result in declining volumes of fundamental research undertaken by companies and may ultimately impact on the existence of large in-house R&D teams, which have the disadvantages of high fixed costs and 'company think'.

But it should not be assumed that open innovation displaces the need for in-house R&D teams. If a company is to appropriate the benefits of ideas generated externally, it still needs many of the skills associated with traditional R&D in order to incorporate the benefits for itself. Open innovation changes the emphasis of R&D teams (less invention, more assessment and development of ideas in the firm context) but does not make them redundant. Cohen and Levinthal's (1990) paper on 'absorptive capacity' describes how firms with their own internal R&D functions are better able to recognise the value of external information and use it in their innovation processes.

While services firms do rely extensively on collaboration for developing innovations (see Section 1.3), data from the UK Innovation Survey show that for 2005–2007, compared with 2001–2005, external collaborations for innovation in the UK have declined, particularly in services firms (see Figure 2.7).

1.7 What do we mean by STEM?

'STEM' (science, technology, engineering and mathematics) is an imprecise concept, drawing together many distinct elements. It is often used to mean the 'public science base'—itself an entity that is hard to define. In this study, however, we use the term more broadly, to include STEM activities or knowledge throughout the economy and society. For example, we consider the skills of STEM-trained employees, cases of companies purchasing and deploying new technology and STEM-based internal research and development. Nonetheless, much of this report focuses on activities of the public science base, since this is arguably the area which government policy can most directly influence, given its reliance on public funding.

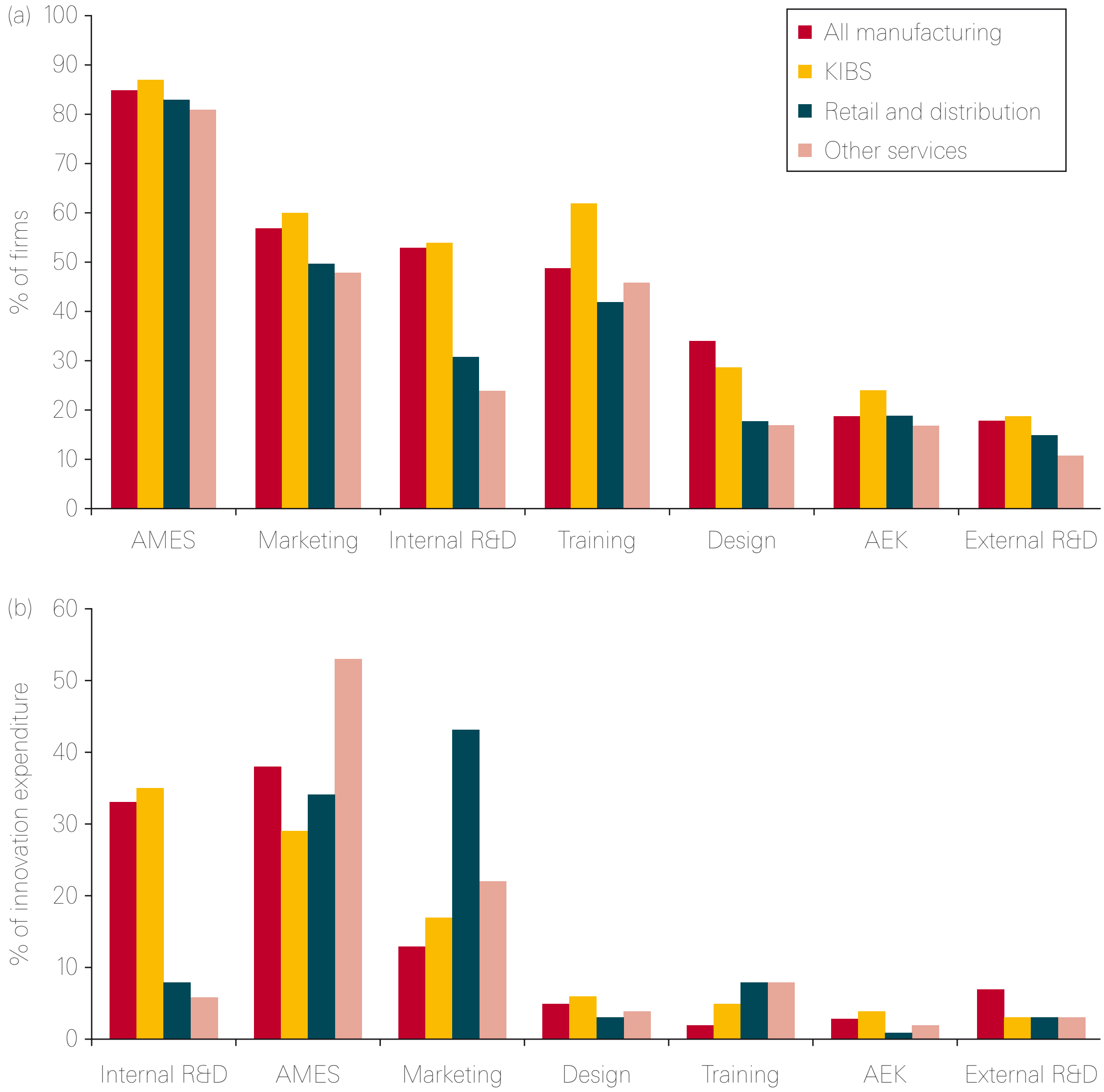
Although 'STEM' has strong disciplinary connotations we do not set out here a precise definition of STEM in terms of academic disciplines.[12] Indeed, we note that effective innovation often involves transgressing disciplinary boundaries and we recognise the importance of the interplay between STEM and other subjects (eg social sciences, including economics) in innovation processes.

10 Firms that introduced at least one product (good or service), process, or wider (managerial or organisation) innovation during the 3 years reference period, or failing this had engaged in various innovation activities (such as intramural R&D, acquiring innovative machinery and equipment, engaging in training related to innovation, etc.) and/or had incomplete innovation projects during the reference period.

11 Defined as SIC(92) 64.2, 65 to 67, 72 to 73, 74.1 to 74.4.

12 NOTE: In the later analysis of graduate destinations (see Section 2.3) and Knowledge Transfer Partnerships (see Section 2.5), the data is organised in terms of academic disciplines. In these instances, we do not include medicine, veterinary, or agriculture-related subjects as 'core STEM'.

Figure 1.3. Types of innovation activity engaged in by firms in different sectors. (a) Percent of innovation-active firms engaging in each innovation activity. (b) Percent of innovation expenditure allocated to each type of innovation activity. AMES = acquisition of advanced machinery, equipment and hardware; AEK = acquisition of external knowledge; KIBS = knowledge intensive business services. Source: UK Innovation Survey 2007.



For reasons of practical necessity this study is limited to areas where the contribution of STEM to innovation is less well-known or indeed unexpected. For example, the report does not address the well-documented impact of biomedical research in healthcare and the development of patient services.

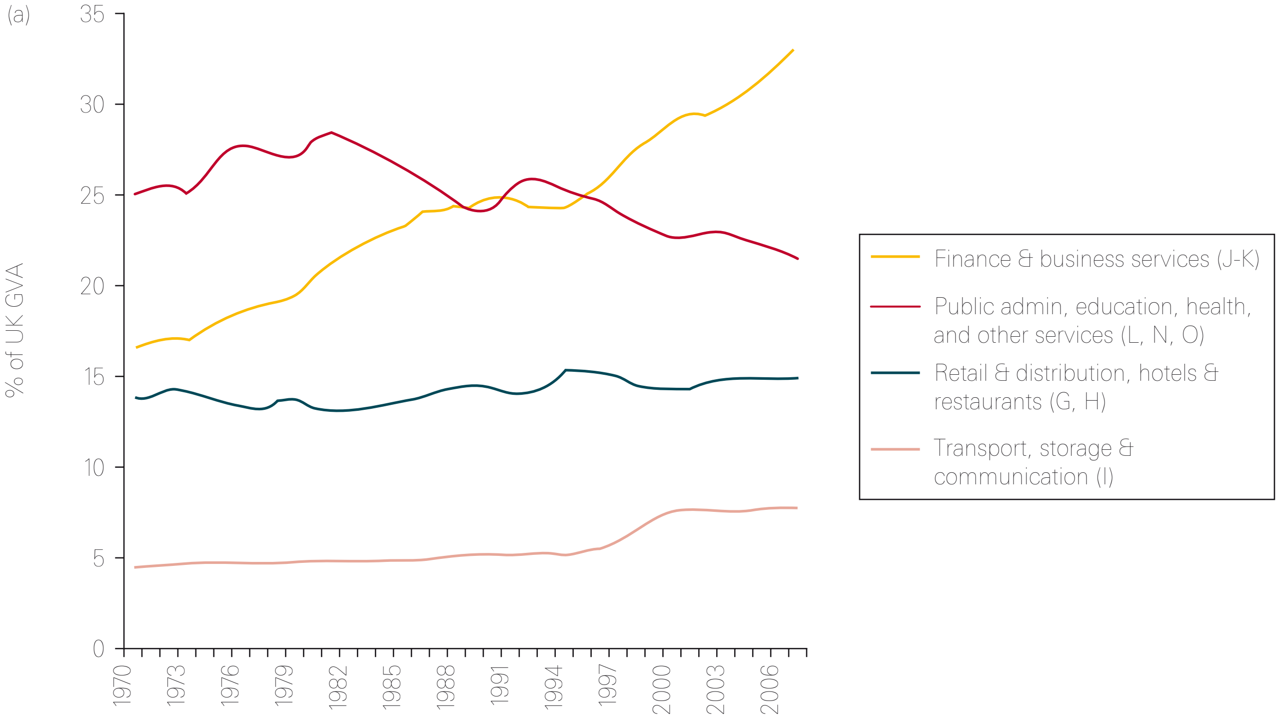
Seen from a funding perspective, there is a distinct UK science base. In reality, however, science is a highly international activity. Many British universities collaborate with counterparts in other countries. Many of them also receive research grants and contracts from multi-national organisations such as the European Union or from non-UK public or private sources. Innovation often arises from the exploitation of ideas whose origins lie in international collaborations. But any idea that we could simply reduce our commitment to science to monitoring work done outside the UK and 'pick up' ideas from science carried out elsewhere is nonsensical: exploitation requires individuals who are familiar with the 'state of the art' in a particular field, who understand emerging trends and developments and who can envisage what might be possible. That ability only comes from being actively involved in new developments. It is also universally accepted that British science has been particularly successful in generating knowledge and sparking new ideas. Where we can still do better is in the joining up of ideas and of those who have them with commercial exploitation.

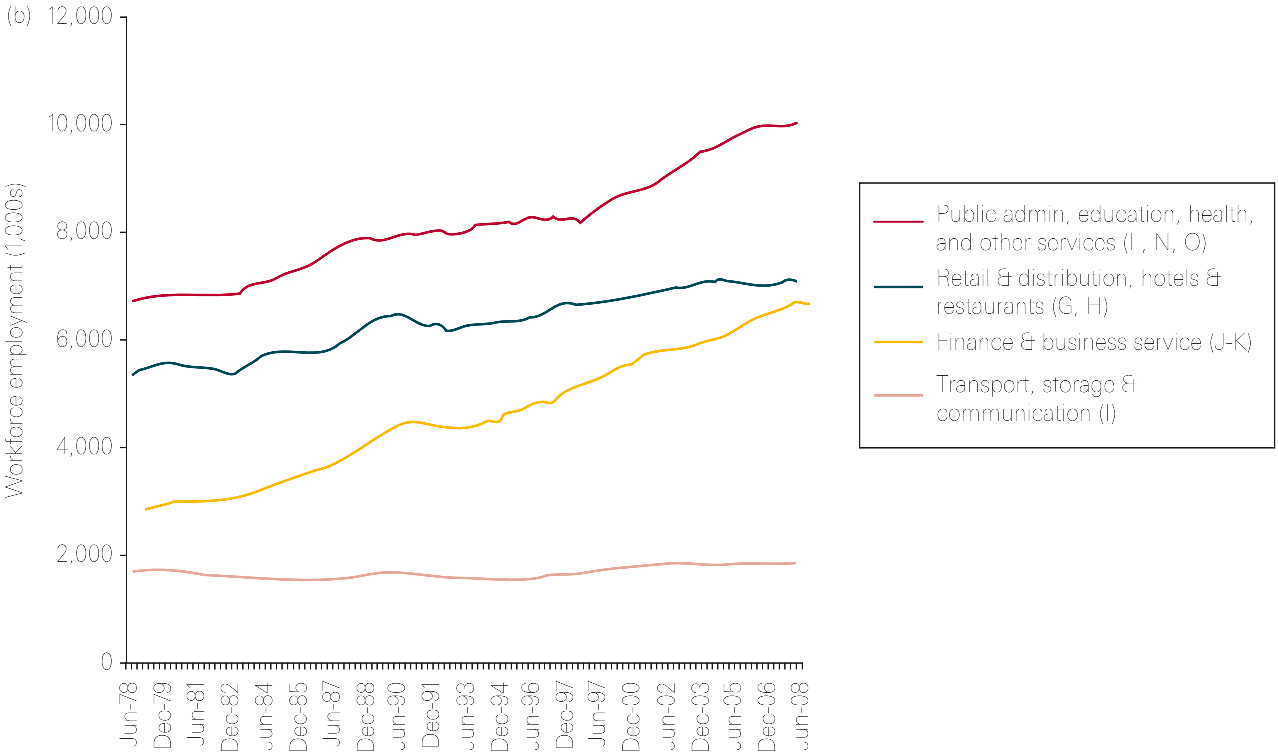
In recent months there has been some reaction in universities to the Government's wish to foster innovation by encouraging university/business relationships. The Vice-Chancellor of Cambridge University, for instance, argued that 'As institutions charged with education, research and training, our purpose is not to be construed as that of handmaidens of industry, implementers of the skills agenda, or indeed engines for promoting social justice' (Richards 2008). In this report, we are wholly supportive of the autonomy of universities, but we also believe that there is great benefit in fostering better interactions between universities, with other bodies in the science base and with business. We see no fundamental conflict between these two positions since different individuals, departments and universities will choose to specialise in different areas, some working closely with business, others focusing primarily on 'blue skies' research. Two fundamental conditions need to be satisfied if we are to be successful. The first is that enough high quality work is being conducted across the whole spectrum. The second is that the 'navigation pathways' are sufficiently clear for those in different sectors to find out what others are doing or need and to find partners where desired.

1.7.1 Previous work on STEM and services innovation

Although few studies to date have explicitly focussed on the role of STEM in services innovation (except for CST 2003), a number have discussed the role of the research base in services. The conclusion from these reports is that there are few and/or weak links between services firms and the research base, in comparison with manufacturing (CST 2003, 2006; BERR/DIUS 2008), and indeed that 'the innovation that matters most to services sectors is rarely science-based' (NESTA 2007, p13). Similarly, our literature review and case study analysis found few examples of interactions between universities and services firms, although there were some cases of multi-national firms initiating collaborations with universities to develop new research streams and influence their teaching curricula, for example by developing courses in 'service science' (see Section 6.6). As we show in later chapters, these earlier analyses are at best partial.

Figure 1.4. The growth of different sectors of the services sector. (a) Contribution of different service sectors to UK GVA, 1970–2007. (b) Workforce employment in different service sectors, 1978–2008. Source: Office for National Statistics.





1.8 Conduct of this study

1.8.1 Rationale and objective

This report is the product of a year-long study by a Royal Society Working Group focused on the role of STEM in enhancing innovation in the services sectors. Our simple objective is to highlight where science—in the widest sense—already contributes well, and where and how new policies might enhance the situation.

1.8.2 Methodology

Inevitably, the scope of such a study needed to be constrained to make it achievable. Given the scale of the services sector, it would have been impossible to have reached any conclusions that were demonstrably and statistically representative of the entire sector. We considered simply restricting ourselves to one or two (assumed typical) market sectors. But that proved unsustainable because we found evidence of rapid mutation in the membership of sectors plus some commonalities and inter-linkages between the different market sectors. We concluded that we had to be illustrative rather than statistically definitive, while carefully using quantitative data where available and reliable. In practice, and because of their contribution to the UK economy, our main focus is on what has happened in the financial services, business services and the retail sectors. Given its importance (making up 43% of GDP), we also set out to know more about science's contribution to innovation in the public sector.

The study was carried out in six phases set out below:

Phase 1 Definition of scope, working group membership and issues to be addressed

Phase 2 Data and literature analysis. A literature review and case study analysis was undertaken by consultants from Manchester Business School and Imperial College Business School. We commissioned consultants from Imperial College Business School to analyse data from the UK Innovation Survey 2007 and to undertake a secondary analysis of data from a survey of businesses collaborating with universities. There was further in-house analysis of data from the Higher Education Statistics Authority (HESA) on the destinations of university leavers, the Technology Strategy Board's Knowledge Transfer Partnerships scheme and some economic data from the Office for National Statistics.

Phase 3 Call for evidence, based on a set of questions and explanatory material, sent directly to approximately 400 organisations, and promoted and published more widely. We received 68 responses. All of the non-confidential responses are on the Royal Society web site at www.royalsociety.org/hiddenwealth

Phase 4 Structured interviews with 44 key individuals in business and public sector organisations. This was based on an *aide memoire* sent to each, itself derived from the previous stages and ongoing discussions. The work was carried out for us by SQW Consulting, who produced confidential notes of each discussion and a final report whose conclusions were debated with SQW and incorporated wherever appropriate in this report.

Phase 5 Two half-day workshops—one with representatives from services organisations and another with academics working in services-related or innovation research settings.

Phase 6 All the evidence was assimilated within the Royal Society and discussed with the Working Group, the members of which made numerous comments and suggestions. The final report went through the Society's formal quality assurance process before publication.

In addition, numerous conversations were held with individuals and groups in business, government and academia throughout the whole process. We are grateful to all those who helped in this way, and list those who were prepared to be identified in Annex 2.

The conclusions in the report are based on the evidence gathered above, published literature and the expert knowledge of the working group. The Council of the Royal Society has endorsed its findings.

2 How STEM contributes to innovation in services

Summary

- Developments in computing and communications technology have underpinned huge transformations in the delivery and consumption of many services over the past two decades. STEM is 'embedded' in most of the technology and infrastructure used by services organisations, and will continue to be a major enabler of innovation in services;
- The services sector is the destination for the vast majority of university graduates in core STEM subjects, and STEM trained personnel are highly valued in services organisations—particularly for their 'generic' skills such as numeracy and analytical abilities. However, there is some concern about the quality and quantity of STEM graduates, and particularly the shortage of graduates with 'multi-disciplinary' skills (see Section 6.6);
- Internal STEM-based research is very significant for a number of services organisations, even though formal R&D is less common than in manufacturing. We came across several examples of fundamental research and development taking place inside services firms, often with very substantial STEM involvement;
- Engagement with external organisations is another way STEM contributes to services innovation. Although direct engagement with the research base is uncommon, it is of fundamental importance to some services organisations' innovation processes. However, a number of indicators suggest that services organisations are finding it harder to engage with the research base, and collaborations appear to be decreasing in frequency.

2.1 Introduction

In this section we outline the variety of ways in which science, technology, engineering and mathematics (STEM) contribute to innovation in services. This is not intended to be an exhaustive list of every possible contribution, but rather a description of some of the main mechanisms by which STEM plays a role.

We draw upon a variety of sources to inform our observations. These include published and unpublished surveys of graduates, businesses, industrial collaborators with universities, and Higher Education Institutions (HEIs) themselves, as well as respondents to our calls for evidence and interviews with key individuals in businesses and public sector organisations (see Section 1.8).

Based on this evidence, we have identified four main ways in which STEM contributes to innovation in services. These fall into two broad categories: STEM embedded in pervasive infrastructure, bought-in technology or within organisations (via STEM-trained employees and internal R&D functions); and STEM accessed from external sources, including the public research base. We now discuss these in turn.

2.2 Pervasive infrastructure and bought-in technology

The 'digital revolution' over the past two decades has fundamentally changed the way many services are delivered and consumed (through the enablement of disruptive business models), as well as the internal processes of firms themselves. Computing, communications, IT, the internet, the worldwide web, massive distributed databases, large scale computer modelling and deep numerate analysis are fundamental STEM underpinnings to many areas of service innovation.

These have been the underlying enablers that have driven an unprecedented level of change and innovation in almost all kinds of services over the past 10–20 years. This is a baseline fact which is not well appreciated by many stakeholders and should be widely recognised, promoted, and included in research and education agendas, because these core IT and numeracy capabilities will continue to be central to future cycles of service innovation. Some examples include: global industries delivering communication, entertainment and other services via mobile phones and hand held devices (eg Box 2.1); financial services from personal ATM services and online banking through to the most obscure and complex professional dealing and trading services; healthcare services in hospitals and doctors' surgeries; widespread and sophisticated closed-circuit television surveillance.

These developments are not just historical: there are current and future technological advances which have the potential to change the nature of services in similarly profound ways (discussed in more detail in Chapter 5).

An indirect measure of the importance of technology for innovation in services comes from the UK Innovation Survey 2007 (see Section 1.6 and Annex 1—Glossary). This survey was sent to 28,000 UK enterprises with 10 or more employees and had a 53% response rate, so represents a very substantial sample of UK companies. It shows that:

- More than 80% of innovation-active services firms (which account for around 60% of all services firms) are engaged in innovation-related acquisition of advanced machinery, equipment or software (AMES; Figure 1.3a). These all require STEM input and expertise in their development, which can therefore be considered as 'embedded' within the technology. In addition to the STEM involved in the development of such technology, they often require a high level of STEM expertise in the user;
- AMES is a major component of innovation-related expenditure in such firms, ranging from 30% to over 50% of firms' innovation budgets, even in sectors such as retail and distribution which are not typically thought of as 'high technology' (Figure 1.3b) (although it should be noted that the innovation budgets, as a proportion of turnover,

Box 2.1 Mobile banking—Monitise

Monitise is a UK organisation with 130 staff, three-quarters of whom are engineers or telecoms experts. Formed in 2004 and listed on the Alternative Investment Market in London in 2007, Monitise has developed the world's first mobile banking platform which allows consumers to perform banking transactions using a single consistent interface, regardless of their choice of mobile operator or bank.

Situated between the very large banking and telecoms industries, Monitise has used existing global standards and partnerships to be accepted by them. A joint venture with the LINK network and use of familiar ATM interfaces has facilitated the process. The innovation has largely been in-house, due to the need to keep their developments and plans confidential while the intellectual property rights were being secured. At October 2008, some 250,000 users already existed and growth to over a million was projected for 2009.

This example also illustrates the importance of standards to efficient innovation in the service sector, particularly where a number of different systems are being brought together to create an interlinked service. Monitise said that, without these standards, growth of their mobile banking technology would be constrained by the difficulties in agreeing terms on introduction of standardised systems between handset providers and mobile networks. STEM expertise is essential to allow continued contribution to the development of global technical standards, with all the economic benefits that follow.

of retail and distribution firms tend to be much smaller than those of 'knowledge intensive' services firms).

Some examples of important recent STEM-based technological advances from responses to our call for evidence and interviews conducted for the study include:

- the use of satellite navigation systems, particularly when combined with mobile phones or other transmission technology, to allow tracking of vehicles, people or goods in real time (eg 'pay as you drive' insurance, tracking of delivery vehicles to plan efficient routes);
- enhanced functionality of mobile devices, and especially the integration of phone, satellite navigation, near field communications, and mobile internet access, allowing a whole raft of new services to be provided to people on the move (eg mobile banking; Box 2.1), location-based information provision);
- high precision Real Time Kinematic satellite navigation for high resolution mapping to centimetric accuracy;
- the reduced size and cost of radio-frequency identification (RFID) devices, allowing products, paperwork, etc. to be tracked through complex systems;
- the increased availability and reduced costs of powerful 3D computer-aided design, computational fluid mechanics, and finite element analysis software, enabling even small services firms to carry out complex modelling of new products or services;
- developments in Geographical Information Systems (GIS), databases and online delivery platforms enabling added value to be derived by integrating information from multiple sources (eg Box 2.2);
- visualisation and 'virtual prototyping' technology, allowing services to be piloted 'off-line' (services have been referred to as being in 'perpetual beta' due to the limited possibility for off-line testing; see Section 1.6 and Chapter 5);
- the development of sophisticated database software enabling storage, data mining and analysis on a scale not previously possible (eg Box 2.2);
- the availability of 'grid' computing and other developments in computer hardware, allowing the rapid analysis of much larger datasets than previously possible (eg financial services firms running models with 450 million data points);
- social networks/virtual worlds, allowing firms to provide services in innovative ways attractive to large numbers of people.

Many technologies that have had significant impacts on services innovation have their roots in fundamental, 'blue skies' research. For example, in its evidence the Institute of Physics highlighted the development of fibre optics, which has its roots in fundamental physics research from the 1800s, and more recently, from research into photonics. Fibre optics has resulted in the creation of broadband internet connections and rapid world-wide communication of information, which have enabled the development of online innovations that have revolutionised the services sector, such as virtual interfaces, online healthcare monitoring, and remote networking.

Fundamental physics research has also made an important contribution to innovations in medical technology services, particularly in medical imaging techniques. Nearly all commonly used medical imaging techniques such as X-rays, magnetic resonance imaging (MRI), electroencephalography (EEG), positron emission tomography (PET) scanners, ultrasound, infra-red, terahertz, and optical probes, are underpinned by discoveries in the physical sciences. Furthermore, many treatment techniques—such as those involving lasers (eg laser eye surgery)—also owe their existence to fundamental physics research. (See Box 5.1 for an example of the application of cutting edge biological sciences research in services.)

From these examples, it is clear that 'blue skies' research plays an important role in services sector innovation, primarily as an enabler or a prerequisite for innovation to develop. As such, we believe that it is important that future innovation policy does not neglect the likely future impact of blue skies research on innovation in services, even if—by its very nature—it is impossible to forecast when, where and how these benefits will accrue.

STEM has also enabled radical, paradigm-altering changes in business models. The oft-cited example of easyJet (Box 2.3) shows how technology has helped to support a disruptive business model, which subsequently became the industry standard.

Box 2.2 Databases—Landmark Information Group

Landmark Information Group was formed in 1995, predicated upon the concept that developments in Geographical Information Systems (GIS) and Science[13] would enable added value to be extracted by bringing together information from a myriad of sources to provide novel solutions to intractable environmental risk problems. The data sources include maps, aerial and satellite images.

In essence, Landmark supplies information services to customers in various sectors. Since 1995, the firm has spent about £20 million on establishing one of the largest geographical information databases in Europe built around a series of partnerships with statutory or non-statutory bodies. The data sets included are Ordnance Survey digital maps, some 500,000 historical OS maps dating back to 1850 and digitised under a joint venture with Ordnance Survey, geological data from the British Geological Survey, flood and other environmental data such as landfills, pollution incidents, water abstraction points, sites of Special Scientific Interest, and IPPC and APC licences from the Environmental Agency, mining and subsidence data from the Coal Authority, and the contents of Kelly's Directories (historical trade directories from the 19th and 20th centuries). Many transformations of the data were required to create an integrated database where the information may be queried in combination: for example, all the historical OS maps had to be converted from a series of (old) county-based map projections, details of which had to be discovered through detailed research, to the National Grid. This in turn then had to be made compatible with GPS coordinates.

From this database, Landmark developed a range of standard products including recent and historical planning decisions, site searches to identify past uses of the land which might contaminate it, areas prone to flooding, the location of utility companies' pipes or cables underground, a 5 m resolution elevation matrix of Britain derived from radar sensing and much else. By bringing together the data in a coherent form, other data sets (eg land use) have been derived.

The full understanding of environmental risk requires more than the 'mechanical' overlay or integration of multiple data sets. The quality and other characteristics of each of the data sets plus the appropriateness of each for the new purpose, allied to the algorithms used to carry out the analyses ensure that—beyond the most trivial of examples—considerable STEM skills and knowledge are required to carry out all such work safely and effectively.

Box 2.3 easyJet

Incorporated in 1995, easyJet launched its first flight in November of that year based upon telephone bookings and two leased aircraft. Its web site was launched in April 1997 as an information source, but the first booking was taken by this method a year later. By October 1999—18 months after the facility was made available—easyJet sold its one millionth ticket online and by September 2000 this had reached 4 million sales, with 85% of tickets being sold through the web channel. By November 2008, easyJet had grown from having two leased aircraft 13 years earlier to owning 167 aircraft and carrying 45 million passengers a year.

Central to the success of Sir Stelios Haji-Ioannu and his colleagues has been the use of the web and the underlying internet. This has permitted the implementation of time-dependent pricing (where prices vary by demand and by the period between booking and the flight), a business model evolved during Haji-Ioannu's studies at Cass Business School. It has also permitted tailoring of options (eg boarding priority, baggage) to meet the individual customer's wishes, while at the same time minimising various costs (eg ticketing and distribution) to the airline and maximising the utilisation of each aircraft which facilitates its competitive position. Some 95% of all flights are now sold online, making the airline one of Europe's largest internet retailers. All administration and documentation is now based on secure servers, accessible globally. This exploitation of web technology and underpinning databases has continued with the launch of the easyJet desk top gadget which enables customers to personalise flight information and booking services. The airline's customers can also use the web to offset the carbon emissions of their flights by investing in United Nations-certified projects.

The easyJet web-based model is now regarded as the industry benchmark, though it was highly innovative when launched. It is an excellent example of how STEM has enabled mass customisation to flourish and, in the process, create a highly successful new enterprise.

---

13 Geographical Information Systems originated—in their present form—in the late 1960s as a means for linking together and analysing data relating to different areas of the earth which are often derived from different sources and to different specifications. With initial work done by geographers, foresters, town planners and landscape architects, the advent of much improved computing facilities led to important developments by computer scientists and mathematicians. A distinct geographical information science, drawing upon other sciences but with some distinctive properties, began to emerge from the 1990s. While the UK pioneered a number of developments in the early phases, reductions in financial support by government led to the bulk of commercial developments in the USA of what is now a $20bn global industry.

2.3 STEM-trained employees

Another major contribution of STEM to services innovation is via the recruitment of STEM-trained personnel—representing STEM knowledge embedded within an organisation. We examine this in several ways: by looking at the destinations of university leavers, the findings of the UK Innovation Survey, and the evidence from people we interviewed.

2.3.1 Destinations of university leavers

We used data from the 'First Destination Supplement' (covering 1994/95 to 2001/02) and 'Destinations of Leavers from Higher Education' (covering 2002/03 to 2006/07) surveys, carried out by the Higher Education Statistics Authority (HESA). These data sets record the occupation of university leavers four to eight months after obtaining their qualification. While this short interval between graduation and the survey date questions whether the data are an accurate reflection of the longer-term careers of graduates, this is the only substantial dataset available, and we believe that it has the potential to reveal some interesting findings. Moreover, a smaller longitudinal survey carried out by HESA showed good correlation between destinations 6 months and 3.5 years after graduation (HESA 2007). However, we recognise that these findings should be interpreted with caution.

We restricted our analysis to UK domiciled leavers who were in full-time paid employment at the survey date, and who had studied for full-time first degrees, Masters, or Doctorates. HESA allocate degrees into 19 broad subject areas, of which we have defined five as 'core STEM' (biological, physical, computing and mathematical sciences, and engineering & technology), and four as 'quasi-STEM' (medicine & dentistry, subjects allied to medicine, veterinary science, and agriculture & related subjects).

A broad analysis of the data showed that:

- 82% of leavers with a 'core STEM' first degree who were in full-time employment 6 months after graduating were working in the services sector (as were 90% of leavers with a non-STEM first degree) (Figure 2.1);
- breaking this down by subject, 90% of first degree graduates in mathematical, biological, and computer sciences, 80% of graduates in physical sciences, and 60% of graduates in engineering and technology who were in full-time employment were working in the services sector;
- the proportion of core STEM graduates going into service sectors has been steadily rising (at about 1% a year) for the last 15 years.

The below figures are affected by the relative size of the services sector, compared with other sectors of the economy: since services account for 80% of all jobs in the economy, it is not surprising that most graduates in all subjects end up working in that sector. To gauge the degree to which different sectors differentially select for STEM graduates, we looked at what proportion of all graduates entering a particular sector had STEM first degrees. This showed that:

- manufacturing is more selective for core STEM graduates than services, with 35% of its graduate intake having a first degree in a core STEM subject, compared with 21% in services (Figure 2.2a);
- the manufacturing sector is particularly selective for graduates in engineering and technology subjects and physical sciences (who make up 15% and 6% of graduate intake, respectively, compared with 3% and 4% in services); the proportion with first degrees in Biological

Figure 2.1. Proportion of leavers with a first degree in a core STEM subject in full-time employment in each sector six months after graduating (2006/07 data). Leavers entering 'Private households with employed persons' (P) and 'International organisations and *bodies' (Q) are excluded, as these represented <0.05% of core STEM graduates. Letters and numbers in brackets refer to SIC 1992 codes, and 'x' means 'excluding'. Source: HESA 'Destinations of Leavers from Higher Education'.*

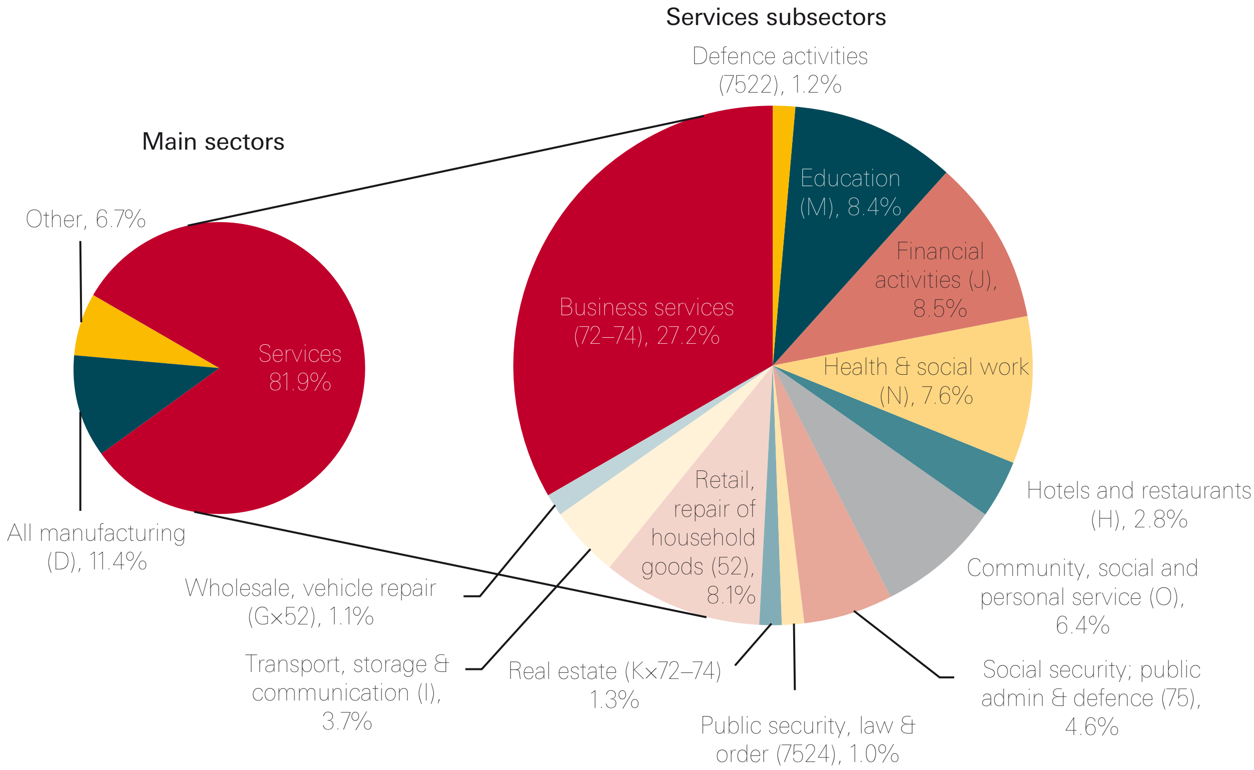
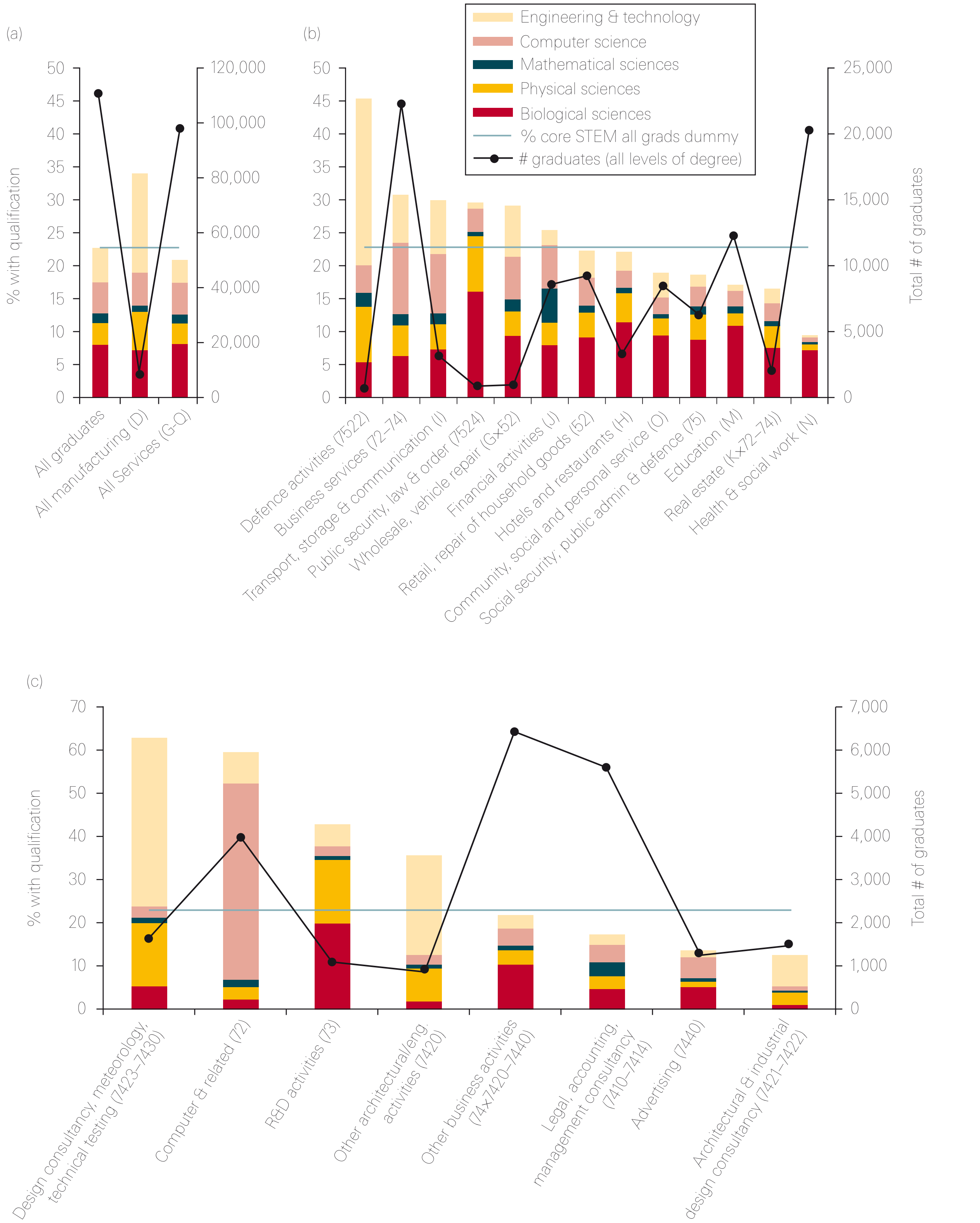


Figure 2.2. Proportion of leavers in 2006/07 entering full-time employment in (a) manufacturing or services, (b) different service sectors, or (c) business services, who had studied for a first degree in a 'core STEM' subject. Restricted to full-time UK domiciled students entering full-time employment.

The black line with round markers shows the total number of leavers (with first degrees, Masters or Doctorates) entering full-time employment in each sector (right axis). The horizontal red line shows the proportion of all leavers entering full-time employment with a first degree in a core STEM subject. Source: HESA 'Destinations of Leavers from Higher Education'.



Sciences are roughly similar between manufacturing and services (7% vs 8%, respectively) (Figure 2.2b);

- services subsectors such as 'defence activities', 'business services', 'transport, storage and communication', 'public security, law and order', and 'wholesale and vehicle repair' had a relatively high proportion graduates with core STEM first degrees (>29%), and subsectors such as 'health and social work',[14] 'real estate' and 'education' had relatively few (<18%; Figure 2.2b).

14 Note that the majority of graduates entering the 'health and social work' sector (66%) studied medicine, dentistry, or subjects allied to medicine, which are not counted as 'core STEM' in this report.

Businesses services is the largest single component of the services sector in terms of graduate destinations, accounting for 22% of all graduates employed in the services sector (33% of 'core STEM' and 24% of non-STEM graduates). It is a very diverse area, and the subsectors within business services can be roughly divided into STEM-related and non-STEM-related businesses. Subsectors such as design consultancy, computer and related activities, and research and development tend to take a high proportion of core STEM graduates, whereas the non-STEM-related subsectors such as business and management consultancy, law, accounting and advertising have a relatively low proportion (Figure 2.2c).

The picture is similar when looking just at graduates with higher degrees: the services sector is the destination for the majority, accounting for 83% of core STEM Masters and Doctorate-level graduates entering full-time employment. A slightly higher proportion of graduates entering the manufacturing sector have a Masters or Doctorate in a core STEM subject (2.8% and 2.6%, respectively) than graduates entering services (2.4% and 1.4%), but the pattern varies significantly between different services subsectors. Certain sectors (eg 'public security, law and order', 'defence activities', 'business services', and 'social security, public administration and other defence activities') have a relatively high proportion of graduates with Masters or Doctorates in various core STEM disciplines, whereas other sectors (eg 'retail', 'hotels and restaurants', and 'real estate') tend to have low proportions.

2.3.2 STEM graduates in financial services

There has been much comment in recent months about the numbers of physicists and engineers working in the financial services sector, in light of current economic events. It is therefore quite striking to note that in the data presented here, only 8.5% of leavers with a first degree in a core STEM subject were working in the 'Financial activities' sector (Figure 2.1), and as a proportion of all graduates entering financial activities, core STEM graduates were barely over-represented (Figure 2.2a). Considering just physical sciences and engineering and technology, the same picture holds: 8.6% and 5% (respectively) of first degree leavers entered financial services, and just 2.9%/2.4% of leavers with doctorate degrees. In both cases the proportion of leavers entering financial activities has actually fallen slightly over the last 5 years. Perhaps unsurprisingly, a much higher proportion of leavers with degrees in mathematics were working in financial services six months after graduating (29% of first degree graduates and 19% of graduates with PhDs), although these represent much smaller numbers of individuals than other STEM disciplines. A follow-up study of a sample of graduates 3.5 years after leaving university (HESA 2007, tables 1.9 and 1.10) shows similar results: 4%/5% of physical sciences/engineering and technology first degree graduates were working in 'Financial intermediation' (and 18% of mathematical sciences graduates), and less than 1% of postgraduates in these subjects (no data were available for postgraduates in mathematical sciences as the base population was under 52 individuals).

These findings are puzzling as they conflict with views expressed by senior academics from a number of universities that up to 50% of students on some STEM courses were entering financial services (see Section 3.2). Possible explanations for the discrepancy include differences between universities in graduate destinations, and that graduates may be business or finance professionals while working for companies not classified in the 'financial activities' sector. Nevertheless, it seems that the situation is more complex than commonly believed, and more data would be useful to gain a clearer understanding.

2.3.3 STEM graduates and innovation

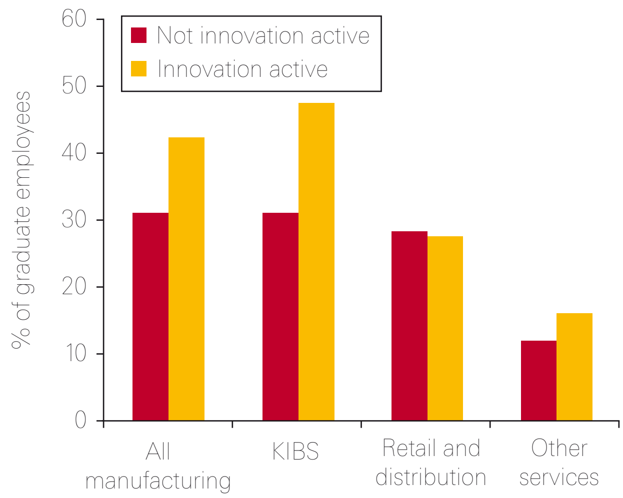
The above analyses illustrate the economic sectors within which STEM graduates find work, but do not provide any information about their importance for *innovation*. Some indirect evidence regarding this can be gleaned from the UK Innovation Survey:

- almost 50% of graduate employees in innovation-active knowledge-intensive business services (KIBS) firms had science or engineering degrees, compared to just 30% in non-innovation-active KIBS firms (Figure 2.3)—a similar pattern to that seen in manufacturing, but not in retail and distribution or other services firms;
- the proportion of science and engineering graduates on the workforce of KIBS firms increased by ~30% between 2001 and 2007.

This suggests that there may be some link between the proportion of science and engineering graduates and innovation activity, but does not indicate what roles those graduates are playing within firms, or what the firms themselves are doing. For this, we draw on the evidence we gathered during our project. Both the respondents to our Call for Evidence and the individuals we interviewed highlighted that:

- STEM-trained employees are of fundamental importance to many services firms (eg Box 2.4), and play a variety of roles within them;
- most frequently, employers value the numeracy, IT, analytical, and problem solving skills of STEM-trained graduates ('generic' STEM skills; see Box 2.5);

Figure 2.3. Workforce composition and innovation activity. Bars show the proportion of graduate employees with a science or engineering degree in innovation active/non-innovation active firms, by sector. Source: UK Innovation Survey 2007.



Box 2.4 Innovation in actuarial services

Actuaries provide commercial, financial and prudential advice on the management of assets and liabilities—especially where long term management and planning are critical factors. The problems actuaries address typically involve analysing future financial events, especially when the amount of a future payment, or the timing of when it is paid, is uncertain. Much of actuaries' work might be thought of as 'risk management': assessing how likely an event may be and the costs associated with it.

The UK actuarial profession has some 9,000 fully qualified Fellows and is expanding at about 500 each year. Entrants are now all graduates and drawn mainly from the following first degree backgrounds: Mathematics, Actuarial Science, Economics, Finance, Computer Science, Physics and other sciences.

By statute, actuaries must be consulted on many of the decisions made by pension schemes and insurance companies. Given this and its other roles, the UK actuarial profession has an important role in the UK economy, albeit a role that is largely hidden to many observers.

Actuarial work requires and demonstrates constant innovation. The stochastic modelling methods used to calculate life expectancies are constantly being developed. In particular, this includes new ways of modelling low probability but high impact events—crucial for the measurement of catastrophe risk (see Box 2.8 on the insurance industry). Increasingly, the actuarial profession is taking a wider view by describing and controlling the risks of firms as a whole, an area known as Enterprise Risk Management.

- for a subset of services firms, the deep, subject-specific STEM skills ('specific' STEM skills) of employees are of crucial importance;
- these skills are most commonly valued by 'type 1' services firms (see Section 1.2), whose outputs are fundamentally STEM-related, but a significant minority of 'type 2' firms also value specific STEM skills; in particular, insurance companies (eg Box 2.8);
- STEM-trained employees play a role in several different parts of firms' innovation processes. In many organisations (especially banks and insurance companies, but also a wide variety of other firms) they are involved in quantitative analysis and building mathematical models, on which new products or marketing strategies are based; however, STEM-trained employees are also valued in project-management roles, horizon-scanning, technical departments, operations, support/maintenance, etc.

There were mixed opinions regarding the skills of STEM-qualified recruits. Most employers seemed reasonably satisfied with the quality of graduate recruits, although they recognised that a lot of in-house training was required. However, some specific complaints were:

- that graduates were trained to pass exams and solve problems structured in familiar terms, but were not good at developing strategies for solving problems they had not encountered before;
- graduates (mainly engineering) had an inadequate understanding of the 'big picture' and essential cornerstones of their disciplines;
- written English was sometimes thought to be of a low standard;
- a number of firms felt that there would be benefits to employers and graduates if placements in service

Box 2.5 STEM skills and data mining: dunnhumby and Tesco

dunnhumby was created by its eponymous founders in 1989. It has grown to 850 employees (some 500 of whom are in the UK), with a turnover of £150m. Tesco now owns 85% of dunnhumby but the firm also provides similar services to major retailers in 20 countries outside of the UK. The main service dunnhumby provides is based on the data mining of information from sales, loyalty card use and other data to enable retailers to understand customers and their needs, wants and preferences. This is achieved through enabling retailers to provide the stock that customers are likely to want at a time they want it, and by facilitating effective interactions with customers via promotions, vouchers, reminders and offers tailored to their particular needs.

The scale of the data mining, analysis and exploitation is huge: Tesco, for example, has 13 million regular customers, and the patterns of their purchasing are created from their shopping records, price consciousness and behaviours in response to offers, etc. Some 25,000 Tesco products are individually categorised to help build up a 'Lifestyle DNA profile' of each customer. From such analyses, each individual shopper is grouped together and vouchers printed for discounts on goods they have purchased in the past or goods which other shoppers with similar characteristics have also purchased. This results in a mailing to all 13 million Tesco Club Card customers four times a year with a summary of their rewards and vouchers tailored to encourage them to return and try new goods; some 7 million different variations of product offerings are made in each mailing. Customer take-up is between 20 and 50%, in contrast to the norm of about 2% in most direct marketing. The ranges of goods in store are also adjusted in response to the habits of those who shop there, and the characteristics of new stores are planned on the basis of knowledge of people living nearby (including use of Population Census and other externally provided data).

Of the 850 dunnhumby staff, some 150 are graduate analysts working with the SAS statistics package, and a few are PhD statisticians.

industries for both STEM and non-STEM students were increased (see Recommendation 20 and Section 6.6);

- there was some concern that the recent increase in students on STEM-based courses is driven by an increase in numbers of overseas students, and that these students would return home after graduation leading to a shortfall in the numbers of UK-based STEM graduates;
- there were some comments about undergraduate courses in UK universities being too narrowly disciplinary-focussed, with few courses producing students with good multi-disciplinary skills and knowledge. Some firms mentioned that they preferentially recruit from other European universities, which have more relevant courses and produce more rounded graduates.

We make recommendations to address the issue of skills of STEM qualified recruits in Section 6.6.

2.4 Internal research and development

The significance of internal STEM activities was highlighted in almost all business responses to the call for evidence. Some of these may take the form of traditional R&D (eg Box 2.6)—and indeed, KIBS firms spend slightly more on internal R&D than manufacturing firms (Figure 1.3)—but frequently internal STEM activities take place in a more distributed manner that bears little resemblance to traditional R&D, and would not be counted as such in usual metrics (see Section 1.6.1 for discussion of the impact of this transition on internal R&D functions).

Some examples of internal STEM activities include:

- Accenture Technology Labs, where R&D is undertaken to develop electronic identity documents integrating fingerprints, iris, and facial recognition technologies. The team comprises a research group, consisting of staff with PhD level qualifications specialising in different areas, and a development group with staff who are IT consultants with computer science degrees;
- Monitise, who used extensive internal R&D to develop mobile payments technology, integrating near-field communications, mobile telephony, and banking standards (see Box 2.1);
- Risk Management Solutions, which has a team of more than fifty doctorate-level scientists conducting in-house research into quantification of catastrophic risk (eg evaluating the frequency, severity and cost of floods, windstorms, and earthquakes). They say that their innovation is driven almost entirely by industrial scientific research, as there is very little relevant research conducted in academia;
- Another firm is involved in financial risk modelling, and the geographical analysis of insurance assets in order to manage risk, accumulation and exposure. This firm applied financial risk modelling to the general insurance sector (rather than just life insurance), which they say led to a significant rise in models, applications and commercial innovations in that area.

2.5 Collaboration with external organisations

Another way STEM can contribute to services innovation is through engagement with external organisations, such as suppliers, consultants or the public research base—very often on a collaborative basis. The UK Innovation Survey shows that:

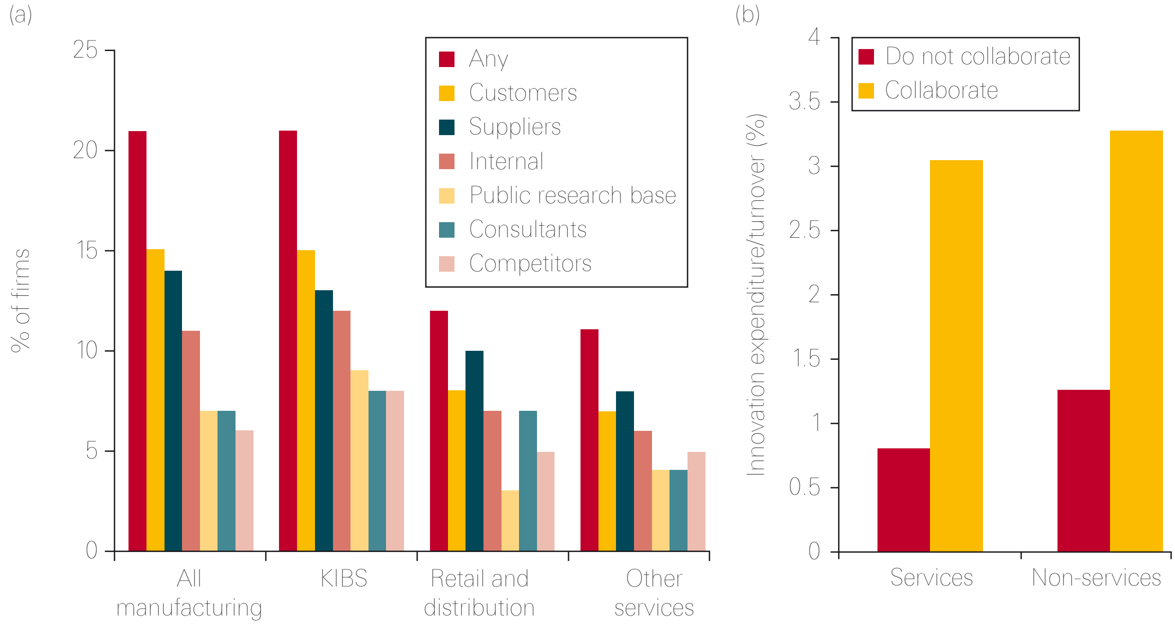
- Approximately 20% of innovative KIBS firms co-operated with another organisation for innovation (the same percentage as manufacturing firms), and around 10% of other services firms (Figure 2.4a; UK Innovation Survey);
- customers, suppliers, or other businesses within the group were most common partners in all sectors;
- universities and government laboratories (the public research base) were the least common partners for Retail & Distribution and Other Services firms (<5% of firms), although slightly more common amongst KIBS firms (9% of firms);
- those firms that did collaborate with the public research base were far more likely to conduct all forms of innovation, and spent a greater proportion of their turnover on innovation-related activity (Figure 2.4b). In particular, collaborating firms allocated more of their innovation expenditure to internal R&D, whereas non-collaborating firms allocated most to AMES and innovation-related marketing.

While giving a broad picture of innovation-related collaboration, the above data do not address the role of science and technology specifically: collaborations—even those with the public research base—may have related to other functions, such as business or management studies. The respondents to our call for evidence highlighted that intermediaries, such as consultants, do have an important role in the provision of STEM expertise: for example, the Royal Bank of Scotland said that 'technology led developments are mostly derived from other commercial organisations, suppliers/partners'. The University

Box 2.6 Unilever

Unilever, like Rolls-Royce (see Section 1.3.1) has developed service aspects to its business model. This multi-national has a major internal research programme, and also works with academics in the UK, the USA, Italy, India and elsewhere. The products and services that arise from this research are generated by individuals with skills in maths, computing, statistics, economics, psychology and behavioural science. One web-based tool that Unilever developed provides information and services to people in rural India covering education, employment, agriculture, health e-governance, personal care and entertainment. It is designed to personalise information, doing this through adaptive algorithms which adjust to previous responses. Coupons are produced for Unilever goods whose price and products reflect what has been found in the online session. Unlike elsewhere, however, it is designed to work under testing conditions—such as assuming there is only a three minute slot for internet connectivity. Another system built by Unilever and then spun out as a separate company is designed to help individuals manage their weight and improve their health. It integrates best practice in nutrition, activity and motivation using patented coaching techniques. Built on what is known about the psychology of behavioural change it provides personalised advice.

Figure 2.4. Collaborations for innovation. (a) Proportion of firms collaborating for innovation with different partners. 'Internal' refers to collaboration with other businesses within a firm's enterprise group. 'Consultants' includes commercial labs and private R&D institutes. 'Public research base' includes collaborations with HEIs and government or public research institutes. (b) Median innovation expenditure (as a percentage of turnover) of firms who do or do not collaborate with the public research base for innovation.



of Leicester also commented on the role of consultants in diffusing knowledge or innovation with the services sector, and noted that this is often a slow process involving high cost.

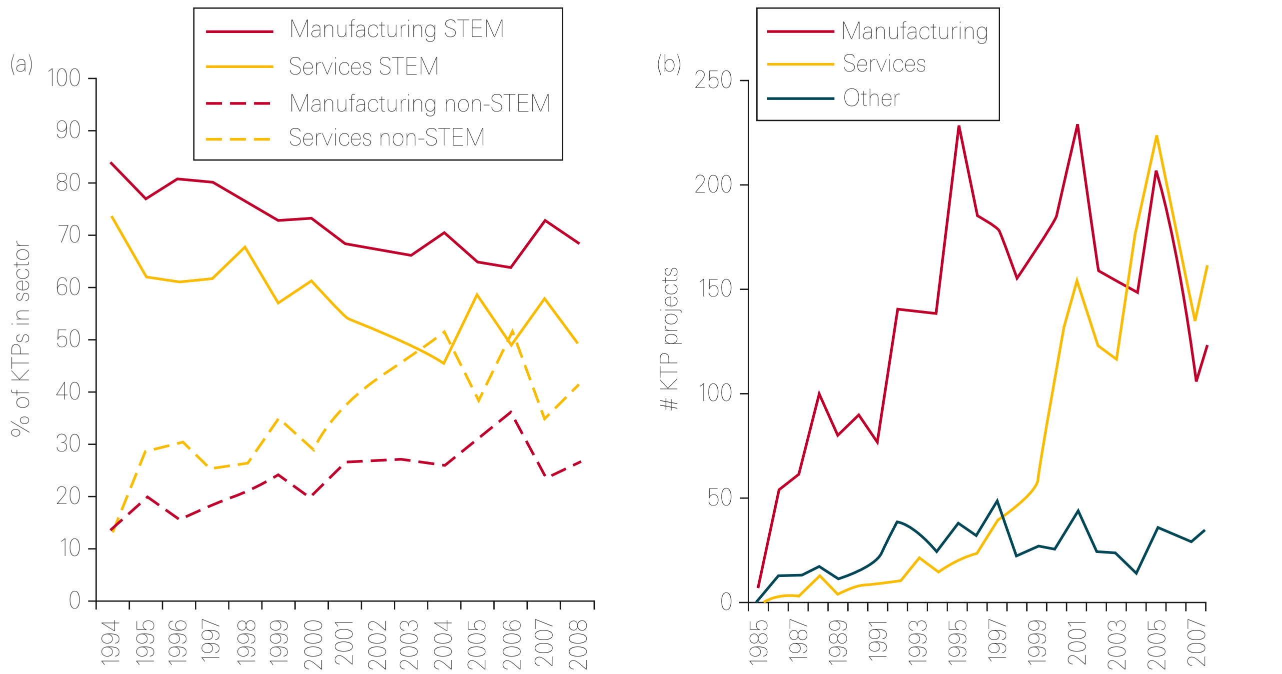
To delve into the nature of collaborations with the public research base in a little more depth, we have analysed patterns in Knowledge Transfer Partnerships (KTPs)[15] and the findings of a survey (a commissioned reanalysis of Bruneel *et al.* 2009) of industrial collaborators on grants from the Engineering and Physical Sciences Research Council (by definition, involved in science-related projects). These show that:

- the proportion of KTPs with services firms has increased rapidly, from ~20% during the late 1980s and early 1990s, to ~50% in recent years (Figure 2.5a) (although note if the relative sizes of the services and manufacturing sectors are taken into account, services firms are still substantially under-represented as KTP partners);
- of KTPs with service firms, ~50% are with STEM academic departments, compared with 65% of manufacturing KTPs; in both manufacturing and services firms, the proportion of KTPs with STEM departments has been falling since 1994, while the proportion with non-STEM departments has been rising (Figure 2.5b);
- the majority of KTPs with STEM departments (48%) are with computer science departments, followed by engineering departments (22%); only 10% were with biology, chemistry, maths and physics departments combined (Figure 2.6);
- in contrast, engineering and mechanical engineering departments were the commonest partners for manufacturing KTPs (56% of all partnerships with STEM departments); just 14% were with computer science departments, and 10% with biology, chemistry, maths and physics;
- of services partnerships with non-STEM academic departments, 66% were with management/marketing/business studies, and 10% with design; in manufacturing, the picture was 53% and 27%, respectively;
- of the responders to the survey of collaborators on EPSRC grants, 37% were from business services firms; these made up the largest single sector in the sample (34% of responders were in the manufacturing sector);
- 65% of business services firms were involved in joint research with the HEI, and 64% had student placements; 47% were involved in contract research. Access to state of the art science and technology was the most commonly cited reason for interacting, by 55% of firms, followed by access to problem solving, a research network, and R&D facilities;
- the creation of long term links with universities was the benefit of collaborating most frequently identified, followed by recruitment.

These data show that, although only a small proportion of services firms directly engage with the public research base, a significant fraction of those that do are involved with STEM departments or projects—although this proportion is falling in both services and manufacturing. The KTP data indicate that services companies are most interested in IT and management/business studies, whereas manufacturing firms are most interested in various engineering disciplines. For both services

15 A Knowledge Transfer Partnership is a three-way project between a graduate, an organisation (eg business, public sector body or not-for-profit organisation—the 'knowledge base partner'), and a higher or further education institution or research organisation (the 'knowledge base'). The project is designed to draw on the expertise in the knowledge base to help solve problems relevant to the knowledge base partner, via employment of a recently graduated 'KTP associate' and close involvement from academics. KTPs are part-funded by a government grant and partly by the knowledge base partner (for example, an SME would be expected to cover one third of the cost, amounting to roughly £20,000 per year on average). See http://www.ktponline.org.uk for more information.

Figure 2.5. Knowledge transfer partnerships (KTPs) trends over time. (a) Trends in the number of KTPs with companies in different sectors, 1985–2008. (b) Proportion of KTPs in each sector with STEM or non-STEM academic departments, 1994–2008. (Data are only shown from 1994, as previously there were too few KTPs with services firms for robust analysis.) Source: KTP online (http://www.ktponline.org.uk/dbsearch.aspx).



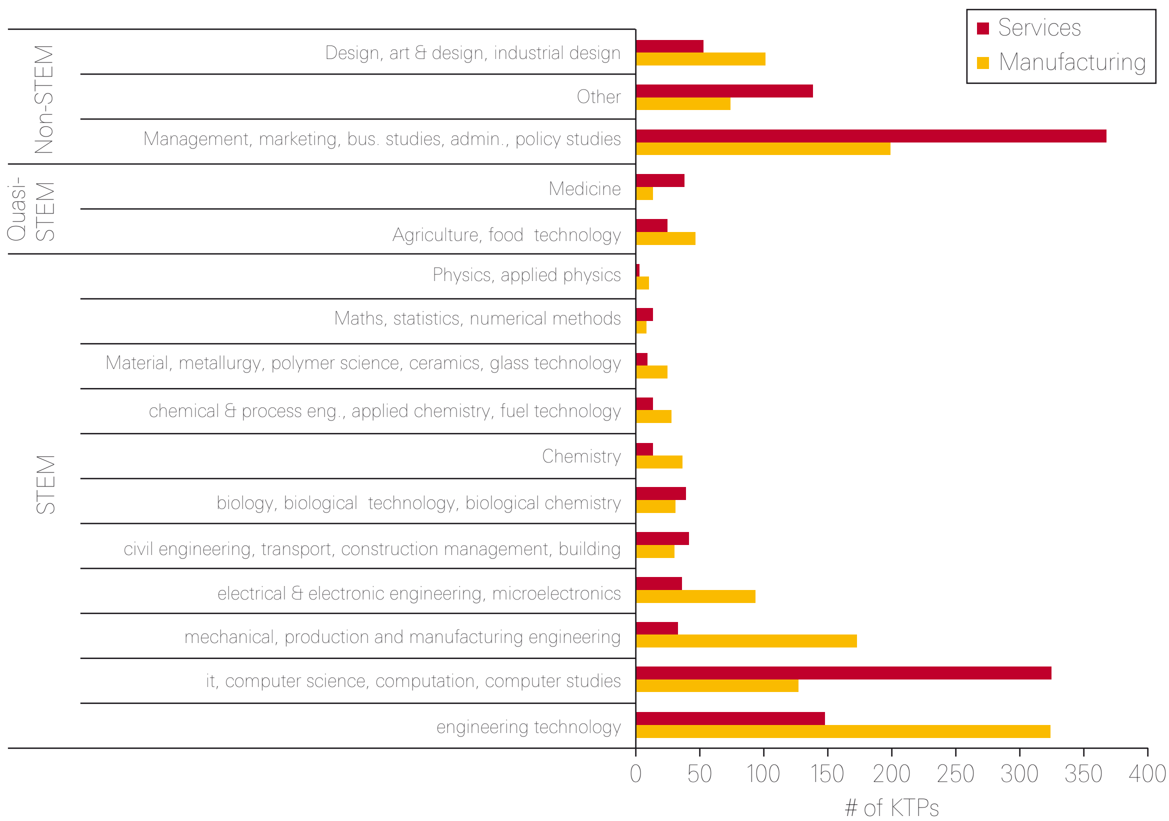
and manufacturing firms, only a small proportion of KTPs were with the 'pure' STEM departments such as biology, chemistry, maths, and physics.

We make recommendations regarding enhancing knowledge exchange in Section 6.7.

To get an idea of the nature of these collaborations with the public research base, we turn to examples from our interviews and call for evidence. These include:

- university courses, such as a Masters in Financial Computing at University College London, sponsored by

Figure 2.6. Number of KTPs with different academic departments by sector, 2001–2008. Source: KTP online (http://www.ktponline.org.uk/dbsearch.aspx).



services firms (in this case, a network of Chief Information Officers from leading banks) and developed in collaboration with universities;

- collaborations between a large market and social research organisation and several universities (mainly social science departments) to formulate questions for major surveys;
- The Oxford Man Institute of Quantitative Finance (see Box 6.4), funded by the Man Group. Man Group has co-located its corporate research laboratory with the Institute;
- The Willis Research Network supported by the Willis Group (a global risk management and insurance intermediary), which has funded research posts at 16 universities worldwide to support open academic research into areas of interest to Willis, such as risk modelling and Geographical Information Systems (see Box 2.8c);
- a collaboration between the FX (foreign exchange) Quantitative Strategy division of HSBC Bank and physics and mathematics departments at a top-ranking university, to undertake academic research to try to understand the dynamics of complex systems in terms of risk and randomness, in order to help the bank manage inter-market risks;
- Roke Manor Research, a specialist research and development business which develops solutions to challenging technical problems for clients in telecoms, transport, and defence sectors; the company has links with 32 universities, mainly for conducting early basic research, although it is now planning to build deeper linkages with fewer universities as it has encountered cultural problems in several of its collaborative research projects to date;
- Collaborative research to develop and integrate technology to sense chemicals in the environment (see Box 2.7).

2.5.1 Trends over time

There are some indications that collaborations between businesses and the public research base are declining—from a low starting level—and facing more difficulties than previously. There was a marked fall in the proportion of services firms collaborating for innovation with external organisations between the 2005 and 2007 UK Innovation Surveys, and the largest percentage fall was in the proportion of firms collaborating with the public research base (Figure 2.7). There was a similar trend in the 'panel analysis' of the 7,000 organisations who responded to the 2005 and 2007 surveys (DIUS 2008b; note that these data are not broken down by sector), suggesting that this is not likely to be a sampling issue. Data from the AIM IPGC survey of industrial collaborators on EPSRC grants (Bruneel *et al.* 2009; see Glossary) seem to back this up: a much greater proportion of responders to the 2008 survey identified barriers to collaboration compared with 2004, particularly in terms of the long term orientation of university research, unrealistic expectations of Technology Transfer Offices, difficulty in

Box 2.7 Sensing chemicals in the environment

(a) EA Technology

EA Technology delivers power asset management solutions to companies which supply, distribute and use energy. STEM skills are widespread throughout the company and more than 60% of its staff have a degree or higher qualifications in STEM.

The firm developed a 'CableSniffer'—a tool for identifying faults to low voltage electricity cables by detecting the gasses given off by the fault. The STEM work (mainly involving skills in chemistry) that underpinned the product was carried out in collaboration with the University of Manchester Institute of Science and Technology (UMIST, now part of the University of Manchester) through a post graduate training programme funded by the EPSRC, the DTI and EA Technology. The research work undertaken by a PhD student led to the development of a prototype which was subsequently brought to market by the company. The innovation arose because the company was aware of a gap in the market for an affordable solution for detecting faults in cables. Prior to the advent of the CableSniffer it was necessary to dig holes to look for faults—costing around £650 per hole. The firm's alternative costs significantly less because it only requires the drilling of a number of 8 mm diameter holes, the introduction of the CableSniffer to locate the source of the gasses and the digging of a single hole to repair the fault. The payback time is typically 2 to 3 weeks.

(b) BMT Group

BMT is a multi-disciplinary engineering, science and technology consultancy that employs around 1,000 people internationally. Since it was established in 1985, BMT has been involved in developing marine environment information systems for operational decision-support, many of which have involved significant STEM innovation.

BMT recently developed an autonomous 'robotic fish' to detect water pollution, in collaboration with scientists at the University of Essex as part of a £2.5 million EU-funded project. Each fish will be equipped with a variety of sensors to detect potentially hazardous chemical pollutants in the water, such as leaks from vessels or pipelines. The fish will be deployed in schools of five, using specially developed 'swarm intelligence technologies' to communicate ultrasonically with each other. Unlike previous developments, the fish will have artificial intelligence software and autonomous navigation systems, and will therefore operate without input from humans, simply returning to a 'charging hub' periodically to transmit (via WiFi) the information collected to a monitoring centre and recharge their batteries. When one fish detects pollutants, it would signal to other members of the school and instruct them to take detailed readings in the area. The data collected could be used to build a near 'real-time' 3D water pollution map, allowing operators quickly to identify and treat sources of pollution.

BMT is co-ordinating a project to release robotic fish developed and built by UK scientists into the coastal seas of Northern Spain to detect water pollution and other changes in environmental conditions. Reproduced by courtesy of UPPA.

Box 2.8 STEM, innovation and the insurance industry

Over the last twenty years the insurance industry's use of graduates, including those trained in STEM, has expanded greatly. Major players like Lloyd's have their own analytical capabilities ('embedded STEM') to inform their individual member companies of the probability and magnitude of certain kinds of risk. A central part of Lloyd's work is in stochastic modelling. Monte Carlo simulations of both insurance claims and returns on asset portfolios have given rise to a wide range of methods so as better to understand and manage risk. Overall, the increasing sophistication of catastrophe models has been key to appropriate pricing and capital setting.

Apart from exploiting employees' deep disciplinary skills and using Geographical Information Systems, however, the reinsurers and brokers in particular have developed a web of relationships with the research base. Four examples are set out below. The conclusion is obvious: STEM approaches, interactions with the STEM community and exploitation of high quality STEM-trained staff is now central to innovation in and the performance of this global success story for the UK economy.

(a) The Benfield UCL Hazard Research Centre

In existence since 1997, the Centre is hosted at University College London by the Departments of Earth Sciences and Space and Climate Physics. Sponsored by Benfield, a global reinsurance broker, it has more than 50 core staff, research students and affiliates. The Centre comprises three groups: Geological & Geotechnical Hazards, Climate Extremes & Seasonal Forecasting and Disaster Studies and Management.

One area where scientific discovery has led directly to service innovation is in Tropical Storm Risk research. Through a breakthrough in forecasting US hurricane activity published in *Nature*, and in collaboration with the Bank Leu, various new online products have been produced, including the 'Tropical Storm Tracker', which forecasts wind probabilities and wind fields. (The tool won the British Insurance Award for London Market Innovation of the Year in 2004).

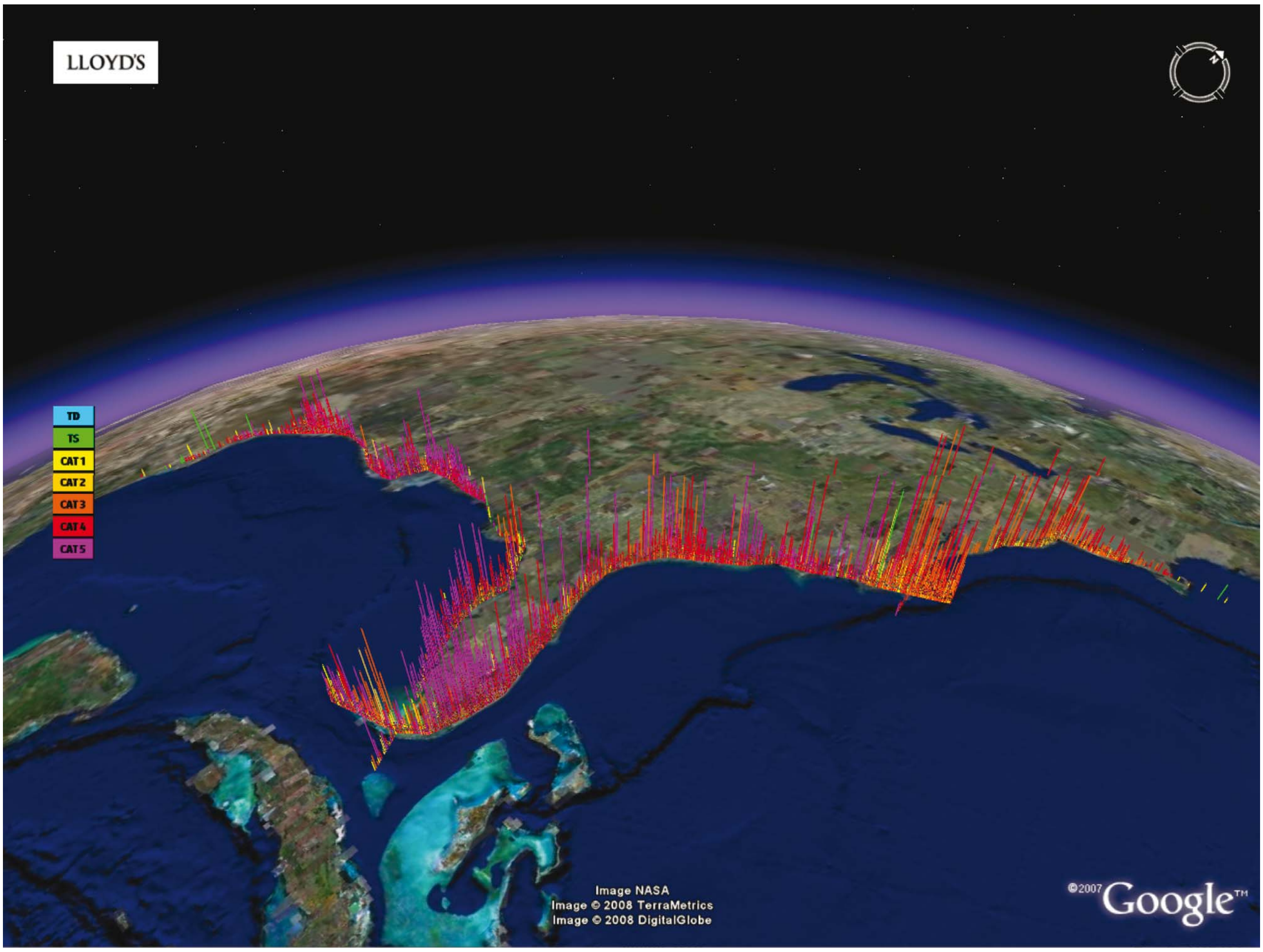
(b) Guy Carpenter

This re-insurer identified several links between STEM and service sectors in its domain:

- the development/improvement of internal stochastic simulation modelling software for modelling insurance loss activity and the impact of different reinsurance purchases;
- the development of models (based on network theory) to look at exposure to possible life/injury/disability insurance losses due to concentrations of people at events (eg conferences);
- the application of similar approaches to liability insurance and man-made insured catastrophic events.

STEM contributes to meeting these ends at or just before a sale—the successful arrangement of a reinsurance contract for an insurer or reinsurer—and primarily within the analytical services area of the organisation. This area employs actuaries/statisticians, catastrophe modellers, geophysical scientists, and finance specialists including accountants. Over the past 5 to 10 years the need for well-presented analysis of the insurance data provided has increased; in some transactions it is a key driver of the price for the transaction and the STEM graduates have become increasingly client-facing.

Projected losses to Lloyd members due to hurricanes of different categories in the south eastern USA. Reproduced by courtesy of Lloyd's of London.



(c) The Willis Research Network

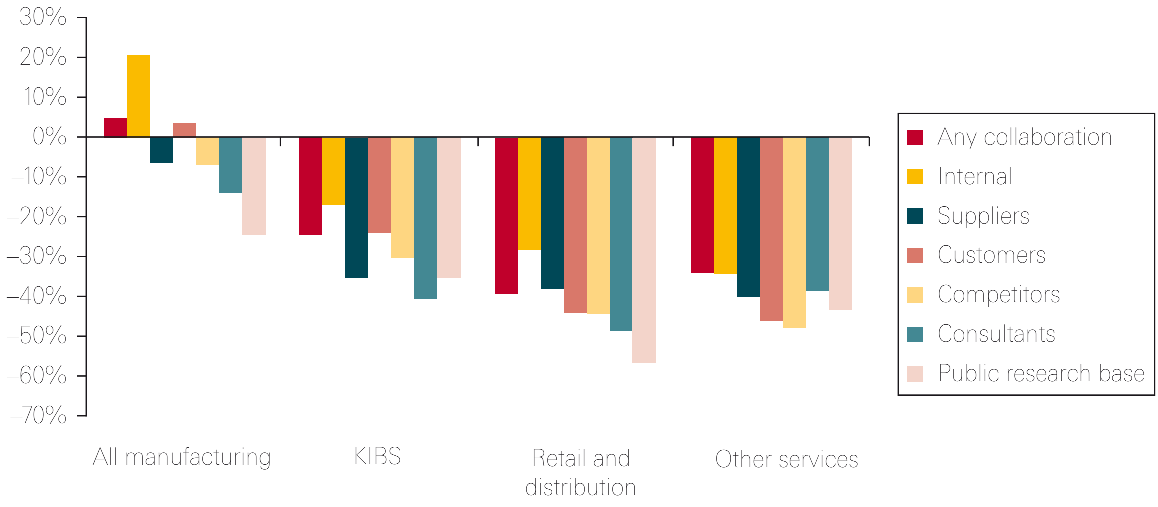
Willis Re is part of the 20,000 employee global Willis Group and has 1,500 employees. Its work falls into three categories. The first is Catastrophe Risk Modelling (CRM)—evaluating the frequency, severity and cost of floods, windstorms, earthquakes, etc. The second is the evolving use of Geographical Information Systems (GIS)—linked to CRM but also a distinct innovation in its own right (ie the geographical analysis of insurance assets to manage risk, accumulation and exposure) and Financial Risk Modelling (the development of actuarial techniques to apply to the general, rather than life, insurance sector). This has led to a significant rise in models, applications and commercial innovation in this area. The Willis Director responsible for this area argues that the influence of STEM personnel and skills has impact through the value chain and that STEM-related activities represent at least 75% of innovation within the firm.

One way this has been taken forward is by building a large and highly active network of academics and insurance professionals through the funding of research posts at 16 universities worldwide (and growing); eight of these are in the UK, with the others being in Australia, Italy, Japan, Singapore and the USA. A distinctive characteristic is that it supports open academic research and publishing as well as the development of new risk models and applications, and an active programme of meetings and collaboration. The ethos is to provide an open forum for the development of the science, and the Willis Research Network actively works with insurers, reinsurers, catastrophe modelling companies, government research institutions and non-governmental organisations. Willis also co-funds projects with the Research Councils and additional project-based funded research projects. One consequence of this relationship is that the network has helped to shape university research agendas by helping to make them more practical and relevant to insurance markets, stimulating genuinely useful cross-disciplinary working and raising new and intellectually promising research questions. The commercial input has helped to shape selected Masters courses in relevant subjects.

(d) The Lighthill Risk Network

This network aims to facilitate and enhance knowledge transfer into business, (initially the insurance sector) from academic, government, professional and commercial experts at the leading edge of risk-related research. It is not-for-profit and dedicated to establishing and fostering links that create value between all of its members; those members include professional bodies, businesses, research councils, regulators and government bodies. The network is managed by individuals from the insurance, science and engineering communities. Knowledge is exchanged between members and experts by various means including a research network of individual experts, expert panels tackling specific issues, and provision of news, data and information services. The Lighthill Risk Network is an open network and provides its members with connections to other networks involved in risk (eg the Institute of Actuaries' Quantitative Finance Initiative).

Figure 2.7. Change in collaborations for innovation over time. Bars show the difference between the proportion of firms collaborating with the specific partner in 2005 and 2007, as a percentage of the 2005 figure. Source: UK Innovation Surveys 2005 and 2007.



finding the appropriate partner, university researchers seeking immediate dissemination, and concerns over intellectual property rights (all rose by over 50%; Figure 2.8). Similarly, there was a marked decrease in the proportion of organisations using university outputs in over 40% of their innovation projects, especially in the use of problem solving (both at early stages and close to market), consultancy and advice, and real time feedback throughout innovation projects (Figure 2.9). Note that all the respondents to this survey (646 organisations) had actively collaborated with HEIs, so this apparent increase in perception of barriers is very concerning.

2.6 Conclusions

The data and evidence discussed above clearly show that STEM contributes in many important ways to innovation in services.

First, there has been a fundamental shift in the way many services are delivered and consumed over the past two decades, with greater personalisation, interconnection, and 24 hour availability. To a large extent, this transformation has been underpinned by fundamental STEM developments in computing and communications technology. STEM can therefore be considered as 'embedded' in the technology and infrastructure used by many services organisations, even for businesses with little apparent connection or interest in science and technology. We believe embedded STEM will continue to be a major enabler of innovation in services.

Second, STEM-trained personnel are highly valued by services firms in many different sectors. The vast majority of university graduates in core STEM subjects end up working in the services sector, with some subsectors largely composed of

Figure 2.8. Barriers to collaboration with universities. Bars show the percentage of respondents (services and non-services) in the 2004 and 2008 surveys stating that they 'agree' or 'strongly agree' that a particular issue was a barrier to interacting with universities. Source: AIM IPGC Survey of EPSRC Industrial Collaborators.

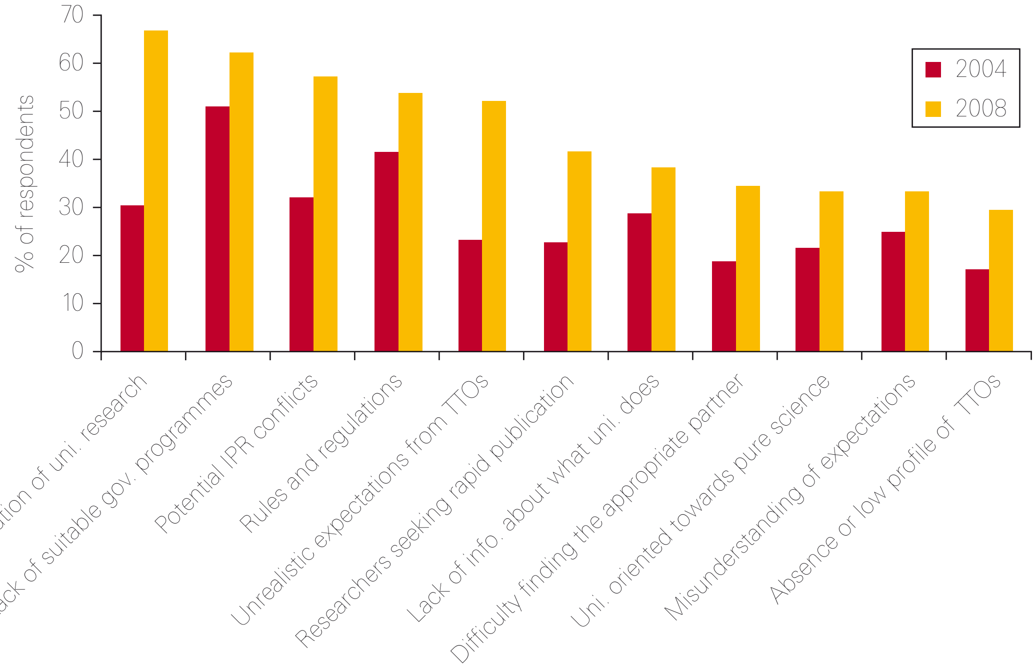
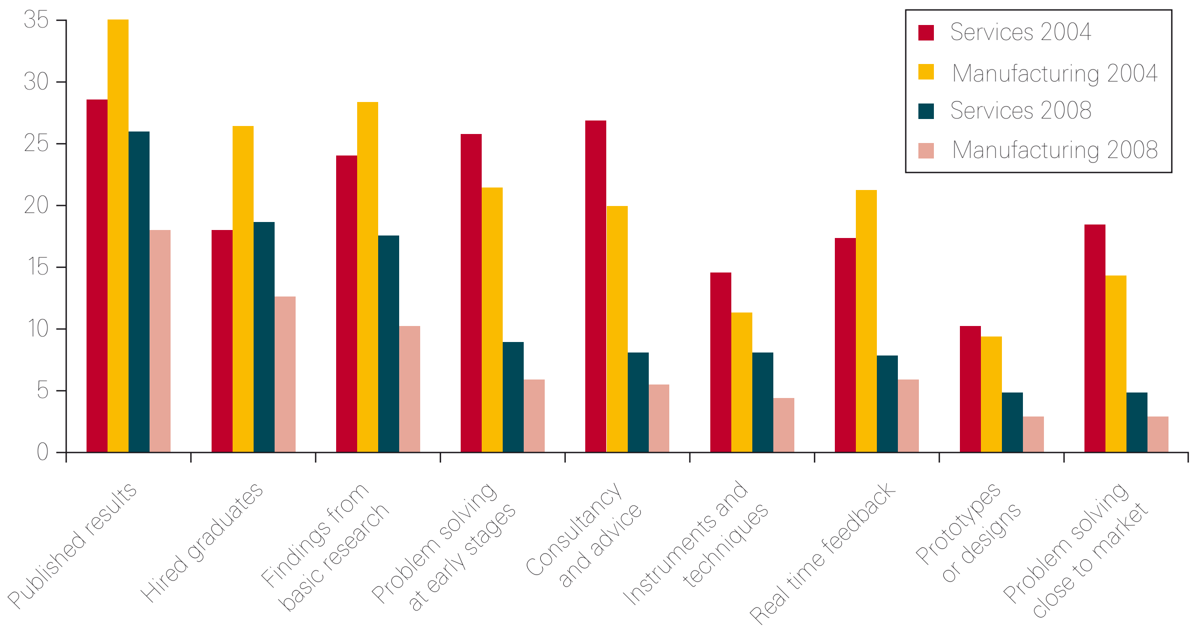


Figure 2.9. University outputs used in innovation projects. Bars show the percentage of respondents stating that each output was used in more than 40% of their business units' innovation projects. Source: AIM IPGC Survey of EPSRC Industrial Collaborators.



STEM graduates. Most frequently, it is the 'generic' skills, such as numeracy and analytical abilities, of STEM trained employees that are considered of most importance, but a significant minority of services organisations also require deep disciplinary knowledge. Employees represent another way in which STEM can be 'embedded' within organisations. However, employers we consulted expressed mixed opinions about the quality of STEM graduates, with complaints regarding their skills (particularly lack of multi-disciplinary skills) and problem-solving abilities.

Third, although traditional internal R&D is less common in many services firms than it is in the manufacturing sector, internal STEM-based research is nevertheless very significant for a lot of services organisations, even if it takes place in a more distributed manner. The significance of internal STEM activities was highlighted by almost all business responses to the call for evidence, and we were told about many examples of fundamental research and development taking place inside services firms, often with very substantial STEM involvement.

Fourth, and finally, engagement with external organisations provides another route for STEM to contribute to services innovation. STEM expertise is often provided via intermediaries, such as consultants, but for some firms direct engagement with the public research base is of fundamental importance to their innovation processes. This may take the form of participation in Knowledge Transfer Partnerships (which have become much more common in recent years in services organisations) or Networks, or via collaborative research. Worryingly, however, there appears to be a trend for decreasing collaboration with the public research base amongst services, an increasing perception of barriers to collaboration, and a decline in the use of outputs from the research base in firms' innovation projects.

3 Innovation in the banking sector

Summary

- Innovation has always been a characteristic of the banking sector and has led on many previous occasions to periods of boom with excessive risk-taking followed by crises, large or small;
- Britain has had a huge competitive advantage in financial services over an extended period, bringing substantial advantages to the UK economy. Developments in ICT and in financial modelling have fostered particularly rapid innovation in recent years, enabled by STEM-trained staff, notably computer scientists and mathematicians;
- These particular innovations have brought global as well as UK benefits, particularly through the wider availability of credit, and have helped trigger the growth of economies world-wide, notably in China, India, Brazil and Russia;
- However, vast imbalances in capital funds between countries, mispricing of risk and the collapse of the US sub-prime mortgage market triggered a global banking crisis in Autumn 2007. This has resulted in a sudden, massive and ongoing reduction in credit availability with dire consequences for governments, taxpayers, consumers, companies and banks world-wide. The financial crisis has led in turn to a near-global recession in 'the real economy';
- There is a wide diversity of opinions on the real causes of the crisis, but some commentators have attributed at least some blame to the inappropriate use of mathematical tools, whose properties and consequences were not properly understood by those responsible for managing their exploitation;
- This chapter considers some of the issues which underlie the failure of the banking sector, including the reliance on tools created by STEM practitioners working for banks and equivalent organisations, the low levels of understanding and oversight shown by some senior management and the regulatory and geopolitical framework which underpinned global financial systems;
- We have been very struck by how internalised research and development of mathematical models is within the banking sector—certainly by comparison with the insurance industry and the world of actuaries (where contacts with the research base are good and growing). This may be due to fierce competition and secrecy in a domain where first to market is more important than seeking to protect Intellectual Property Rights;
- We make four recommendations about the role of STEM in ensuring greater stability of the financial system of the future. These focus on improving the understanding of risk and system stability—within banks, regulators and university courses.

3.1 Introduction

Up to August 2007 the financial services sector—and banking in particular—would have been seen by many as an unqualified success story for Britain, especially for the London financial cluster,[16] but also for STEM.[17] Many innovative financial instruments were built upon sophisticated mathematics and produced by STEM graduates and PhDs for their employers.

Such innovation in banking is not new. As Ferguson (2008) has shown, there has always been innovation in this sector. Tufano (2003, p309) claimed that 'History shows that financial innovation has been a critical and persistent part of the economic landscape over the past few centuries … financial markets have continued to produce a multitude of new products, including many new forms of derivatives, alternative risk transfer products, exchange traded funds, and variants of tax-deductible equity. A longer view suggests that financial innovation … is an *ongoing* process whereby private parties experiment to try to differentiate their products and services, responding to both sudden and gradual changes in the economy … financial innovation is a regular ongoing part of a profit-maximizing economy.' Moreover, he presciently noted that 'there have been numerous periods throughout the past centuries in which innovation flourished, failures took place, and public and regulatory sentiment led to temporary anti-innovation feelings. … More recently, the failure of Enron has probably slowed the innovation of new forms of special purpose entities and off-balance sheet financing, although this chilling effect is unlikely to be permanent.' Lerner (2006) highlighted differences with manufacturing: 'The financial services industry has historically differed from the bulk of manufacturing industries with regard to the ability of innovators to appropriate their discoveries. Until recently, financial firms have been very limited in their ability to protect new ideas through patents … as a result, new product ideas have diffused rapidly across competitors.'

The nature and scale of innovation in banking, facilitated by the forces of globalisation, have ensured for at least two decades that banking was an area of major competitive global advantage for the UK. The Global Financial Centres Index of March 2009 (Yeandle *et al.* 2009) has London as the global leader, closely followed by New York with Singapore and Hong Kong following some way behind. Though financial services are heavily concentrated in London, Edinburgh became another major centre and Leeds, Manchester and

16 This includes the traditional centre in the City of London, the large scale development in investment banking and trading in Canary Wharf and the hedge funds and private equity located mainly in the West End of London.

17 The relationship between the science base and the financial services sector has previously been considered—in a different climate—in *Set and the City: financing wealth creation from science, engineering and technology* (ETB 2006).

The City of London, one of the three most successful financial centres in the world (and the most international). Its success relies upon STEM skills and tools. Reproduced by courtesy of City of London.

other UK cities all established burgeoning financial clusters (until the current financial crisis, at least). There has been much methodological dispute about the contribution of financial services to the UK economy but it is widely accepted that this lies somewhere between 7 and 13% of national income. Using the lower estimate, in 2003 (the last year with fully balanced estimates for national accounts) banking accounted for 4.4% of all GDP—ie it formed the bulk of the financial services sector. This proportion is sure to have risen in the subsequent period to 2007. In recent years, around 25% of the UK corporate tax take came from the financial sector, and approximately 12% of all UK income tax and national insurance.[18]

The global significance of the financial services in the UK is illustrated by the following 2006 figures pertaining to the period just before the financial crisis[19]:

- 34% ($1359bn) of the global foreign exchange turnover each day took place in London;
- 53% of the global foreign equity market and 70% of all eurobonds were traded in London;
- 20% of international bank lending was arranged in the UK (the largest single market globally);
- London is the world's leading market for international insurance. UK worldwide premium income reached £194bn in 2006;
- £3.8trn total funds were under management in the UK that year;
- £1.5bn in overseas earnings were generated by the shipping, trade and finance industry in London;
- £1686bn pension fund assets were under management (the third largest such set of assets in the world);
- 75% of Fortune 500 companies have offices and 254 foreign banks operate in London.

It is therefore obvious that financial services—and especially banking—have mattered greatly to the UK.

But the situation has now changed drastically, with an economic recession—triggered by the financial crisis—affecting most of the countries in the world and manifested most graphically by rapidly rising unemployment and bankruptcies. The failure or bankruptcy of organisations such as Lehman Brothers and Icelandic and German state banks has had world-wide consequences. At the time of writing, the taxpayer support of the UK banking system to buttress the capital base of British banks, foster liquidity and provide insurance against the failure of toxic loans runs into many tens of billions of pounds. Alongside this is the increased cost of social services in an era of lower corporate and individual tax take, plus the cost of stimulating the economy to foster recovery. The final cost of all this to the taxpayer will not be known for years, but the Chancellor estimated in the April 2009 Budget that government borrowing in 2009/10 will be some £175bn—five times higher than in 2007/08 (HM Treasury 2009a, Table 2.3). This will inevitably lead to substantial cuts in funding for UK public services or higher taxes (or both).

From a STEM perspective, innovation in the component parts of the financial services sector appears to have differed significantly. At the time of writing, some parts of banking[20] have been much the worst affected parts of the financial services sector and, given the importance of STEM inputs into it, we concentrate on it in this chapter and review whether STEM played a significant role in the current crisis as well as in the preceding boom. Some contributions of STEM to other parts of the financial services sector have already been described in Chapter 2.

18 Statement made by the Chancellor of the Exchequer to the Treasury Select Committee on 19 March 2009 (House of Commons Treasury Committee 2009b, Q2820).
19 See http://www.cityoflondon.gov.uk/

20 It should be noted that not all aspects of banking have been in recession. Foreign exchange, the fixed income bond markets, certain commodities (eg those traded through the London Metal Exchange), Islamic banking and certain other activities in the City of London have continued to prosper.

3.2 The role of STEM in financial innovation

Historically, national encouragement of the financial sector through investment and helpful statutory frameworks, plus the breakdown of barriers to capital flows, global competition and clusters of supporting skills have certainly fostered innovation in the financial services. But the development of STEM—and ICT in particular—has been central to its huge expansion to a globally integrated industry in the last 20 years. Jenkinson and colleagues (2008) have shown how much global financial business increased in the period up to 2007 (Table 3.1).

The most obvious impact of ICT has been in the growth of electronic transactions and the means of payment associated with them. The ability to move funds nearly instantaneously in response to opportunities large and small is a major innovation: this has enabled speculators to move massive amounts of currency around the globe as they seek to profit from minute differentials in pricing of financial instruments and currency. The need to exploit tiny windows of time is such that some data centres are now located physically adjacent to trading floors to minimise data transmission times. Much of the algorithmic and other trading seeks to exploit anomalies between prices and theoretical models between cash products and derivatives. Not all such trading is beneficial to society: Cowdery, for example, has controversially argued that only 5% of this is related to trade and other real economic transactions—the rest is simply financial speculation, which often plays havoc with national budgets, economic planning and allocation of resources (see Collins & Harrington 2008). Along the same lines, we note the extraordinary situation that interest rate swaps and other derivatives are estimated in 2007 to have exceeded global GDP by more than an order of magnitude (see Table 3.1).

But the impact of STEM is more fundamental still: Hamilton and colleagues (2007) have argued that 'The ability to assimilate data and to perform complex calculations has helped market practitioners to develop new financial products that decompose and repackage different components of financial risk. These new products can be matched more closely to the demands and risk preferences of both investors and borrowers and thus improve the completeness of financial markets. The innovation process has been underpinned by the widespread and ready electronic access to news and information on economic and financial developments and on market responses. That, in turn, has improved arbitrage and market pricing'. A crucial benefit of this modelling approach was thought to be that risk would be dispersed much more widely and hence reduce risk to any one institution though—as we have seen—it has led to the catastrophic raising of systemic risk.

Taking a broad view, we see two fairly distinct types of mathematical modelling being carried out. The first ('modelling products') is that which analyses data so as to produce financial products where risk is 'sliced and diced' to meet the needs and risk preferences of customers. In general this is carried out within individual banks, often in great secrecy. The second type of modelling ('modelling systems') is that of systemic risk, when data from many individual financial institutions—and other banking, national policy, geopolitical and other contributions—are considered in combination. Typically this is carried out by central banks and is exceptionally difficult. Regulators—some of which are part of central banks—often need to understand the nature and characteristics of the first set of models and also the policies of each and every bank.

In addition to all of the innovation in generating new financial instruments and transferring money globally in fractions of a second, STEM has contributed to the transformation of retail banking. The launch of the first electronic ATM by Barclays in North London in 1967 was perhaps the first manifestation. Later developments of First Direct by HSBC and of Egg (built on the infrastructure of Prudential), have been followed by every UK bank and most building societies. The result has been internet-based banking services and the widest ever choice of financial tools for the individual customer. These developments have been facilitated by early work on the web by scientists and much subsequent work by computer scientists and engineers (as well as by marketing specialists).

As a consequence of this immense innovation in the financial services and of globalisation, the availability of capital and credit to corporates and households has expanded hugely. In 2006, for instance, two-thirds of UK adults had a credit card, double the proportion in 1984. The menu of financial products has widened to meet diverse demands (eg the multiplication of options in the types of mortgages now available to householders); the range of investment vehicles available to individuals and firms has also expanded substantially (Hamilton *et al.* 2007). Though these changes have recently had severe consequences, they have been fundamental to growth over a decade or more in the economy, which is impossible without the availability of credit. The gains in financial system efficiency have also lowered the cost of capital for firms.

Central to all of the innovations described above has been the contribution of STEM practitioners. Although new graduates from many different disciplines have joined banking in various capacities, the great bulk of financial innovation in recent years has arisen from the ability to decompose and repackage different components of financial risk. The tools to achieve this have been created by mathematicians, physicists and engineers, many of them with PhDs. Senior academics report that, in recent years, some 50% of the engineering graduates from Imperial College and other top UK engineering

Table 3.1. The increase in global banking business in the last decade (from Jenkinson et al. 2008)

Value of…	At date 1	At date 2
Interest rate swaps and other derivatives	1997: $75 trillion	2007: $600 trillion (11 times global GDP)
Asset-backed securities	1998: £425 billion	Early 2007: $1460 billion
Global foreign exchange market turnover (daily average)	2001: $1200 billion	2007: $3100 billion

Box 3.1 Relationships between the research community and banking

We have been struck, despite the many—if sometimes hidden—contributions of STEM, by how modest seems to be the interaction between the science research community and banking. There are some notable links, almost all of which centre on business schools notably London Business School, the Cass Business School and some other centres, plus a number of chairs funded by the banking sector. But even so the bulk of the activity seems to be driven by HEIs rather than the industry and does not materially involve STEM. This contrasts with the situation in insurance (see Box 2.8). Certainly, many central bankers and some investment and retail bankers read academic papers in the *Journal of Monetary Economics, the Harvard Business Review*, the *Journal of Risk* and similar outlets, including the widely read *Risk* magazine. Equally certainly there are individual contacts between bankers and particular academics, many forged by contact while at the same university. But with the exception of the activities of modestly funded enterprises like the Financial Services Research Forum and think tanks like the Centre for Economics and Business Research, we have found few significant formal relationships. Overall, the active connections of the formal science base to financial services—as opposed to those of economics[21]—seem very small and have arisen serendipitously. One example we found, involving four investment banks and a lead university (UCL), came about because the bankers originally wanted an external body to provide courses for its new staff.

One possible reason for this is the large numbers of IT and STEM staff now employed inside financial services firms. One investment bank told us that, in total, these amounted to around a third of all of its staff. Naturally not all of these are in any sense researchers or innovators, but the critical mass existing internally goes some way to explain why looking outwards to external STEM seems uncommon. Another factor seems to be the different time scales involved: new products in investment banking are often constructed in anything from two days to three months; academic timescales seem glacial to many inside banks.

departments have gone straight to work in the City of London (which also draws in similarly skilled quantitatively expert individuals from many other countries), although data on the destinations of students from UK universities would seem to contradict this oft-heard anecdote (see Section 2.3.2). According to Sir Callum McCarthy, Chairman of the Financial Services Authority (FSA) until September 2008, these new tools and their originators have had as great an effect on financial markets as the advances in ICT which have enabled the former to operate. Surprisingly, though, despite this strong reliance on STEM-trained staff, there seem to be few links between banks and the academic research community (Box 3.1).

3.3 Causes of and lessons from the crisis

As described above, innovation in banking in recent years led to many benefits, but also resulted in the financial crisis that began in Autumn 2007 and caused a global recession in 'the real economy.' Readers may reasonably ask whether STEM and its practitioners have been major contributors to the recession as well as the previous growth. Such questioning of the role of scientists and technologists is normal: the International Herald Tribune for 24 February 1934 for example reported that scientists in the American Institute of Physics had begun a belated but intensive drive to rid themselves of blame for fostering the Great Depression through 'the perfection of labor-saving machinery.' A more recent crisis where sophisticated mathematics certainly played a role was in the collapse of Long Term Capital Management in 1998. This was a U.S. hedge fund which used trading strategies, such as statistical arbitrage, combined with high leverage. It failed spectacularly in the late 1990s, leading to a massive bailout by other major banks and investment houses, supervised by the US Federal Reserve, to prevent the collapse of the entire financial system. LTCM's board of directors included Myron Scholes and Robert C. Merton, two of the authors of the Black-Scholes options pricing formula, who shared the 1997 Nobel Prize in Economic Sciences for 'a new method to determine the value of derivatives.' The model provides the fundamental conceptual framework for valuing options and has become the standard in financial markets globally.

Many publications have appeared in recent months seeking to explain and assigning blame for the crisis (eg Tett 2009). For example, the editors of a Demos report (Collins & Harrington 2008, p8) said:

There is a gallery of possible culprits. The indebtedness of the personal sector in the quest for housing assets, which then were bid up to absurd levels; lax monetary policy over a long time in the USA; the failure of central banks and regulators to target asset price bubbles; banking products which nobody understands; hedge funds, short selling, securitisation; regulators with no handle on systemic risk; very poor credit rating; the inadequacy of the Basel II capital regime; the mix of banking with non-banking activities; excessive rewards for bankers for short-term objectives. Even this list is not exhaustive.

The Governor of the Bank of England (King 2009) has argued that the root causes of the financial crisis lay in the imbalances in the world economy which built up over a decade or more. He pointed out that the entry of the rapidly growing economies in Asia into the world trading and financial systems provided a huge new pool of savings. The perverse result was huge flows of capital from the poorer developing economies to the richer mature economies. As a result, nominal risk-free returns fell to levels not seen in a generation and money was lent on easier terms. That helped to push up further asset prices that had already risen as real interest rates were falling. It also led to an explosion in the size of the financial sector as new instruments were created to satisfy the search for yield. As well as lending to households and businesses, banks lent to other banks which

21 We see many common features between the quantitative/modelling end of Economics and many STEM subjects, notably in their shared use of mathematics. The Royal Society has recognised this by creating a channel for such quantitative social scientists to be nominated for election to the Society.

bought ever more exotic instruments created by the financial system itself. As a result, total debt in the UK relative to GDP almost doubled and rose sharply in other developed economies.

The Treasury Select Committee Second Report (House of Commons Treasury Committee 2009a) on the banking crisis concluded that:

The origins of the banking crisis were many and varied, including low real interest rates, a search for yield, apparent excess liquidity and a misplaced faith in financial innovation. These ingredients combined to create an environment rich in overconfidence, over-optimism and the stifling of contrary opinions. Notwithstanding this febrile environment, some of the banks have been the principal authors of their own demise. The culture within parts of British banking has increasingly been one of risk taking leading to the meltdown that we have witnessed. Bankers have made an astonishing mess of the financial system.

In contrast, the Chairman of the FSA singled out mathematics for *part* of the blame for the crisis (Lord Turner 2009):

The very complexity of the mathematics used to measure and manage risk, moreover, made it increasingly difficult for top management and boards to assess and exercise judgement over the risks being taken. Mathematical sophistication ended up not containing risk, but providing false assurance that other prima facie indicators of increasing risk (eg rapid credit extension and balance sheet growth) could be safely ignored. (p22)

The techniques entailed numerous variants to cope with the different mathematics of, for instance different categories of option. And their application required significant computing power to capture, for instance, relationships between different market prices, the complex nature of structured credit instruments, and the effects of diversification across partially but not wholly correlated markets. But the underlying methodological assumption was straightforward: the idea that analysis of past price movement patterns could deliver statistically robust inferences relating to the probability of price movements in future.

The financial crisis has revealed, however, severe problems with these techniques. They suggest at very least the need for significant changes in the way that VAR [Value At Risk]-based methodologies have been applied: some, however, pose more fundamental questions about our ability in principle to infer future risk from past observed patterns. (p44)

Similar arguments but with more optimistic conclusions were deployed two years earlier by Rebonato (2007). He argued that, for all its apparent quantitative sophistication and precision, much of the current approach to management of financial risk rests on conceptually shaky foundations. Ultimately, managing risk is about taking decisions under uncertainty and Rebonato claims that well-established scientific disciplines devoted to this (such as decision theory) have been largely neglected. He draws a parallel between weather forecasting and the statistical modelling of financial time series, and makes many references to lessons to be learned by the financial services community from physics, maths and statistics, notably in the handling of probability.

Set against this is a view expressed by a number of scientists and other analysts that the root cause lies in business practices, and that the mathematical models were little more than a 'fig leaf,' allowing banks to legitimate—with a cloak of spurious precision and scientific respectability—what they wanted to do in any case. In this view, it was the larger system (regulatory, political, even geopolitical) that provided a framework which led to a major breakdown. If correct, this would suggest that regulators around the world need at the very least not only a full understanding of the mathematical technologies deployed in banks, but also of the subtle and various sensitivities, feedback loops and potential instabilities produced in the global financial system by banks using these tools. In short, they need to understand how these complex systems function.

This view of the existence of complex adaptive systems in banking and other financial services—and how they can best be modelled—has emerged over the last three years (eg Kambhu *et al.* 2007; May *et al.* 2008). It has been buttressed most recently in a paper by Andrew Haldane, the Executive Director for Monetary Stability in the Bank of England, in April 2009 (Haldane 2009), which treated financial systems as complex, adaptive networks (see Sections 5.3, 6.5 and 6.6 for other examples of services as complex systems). He sees STEM approaches as a vital ingredient in enhancing understanding of financial system seizures, arguing the merits of learning from epidemiological experience and from the resilience of engineering networks in order to reduce the risk of contagion or breakdown in financial systems in future.

Although it is too soon to tease out in any definitive way the relative contributions of different causes of the crisis, our emerging views can be summarised under three headings.

- The root causes of the financial crisis and ensuing economic recession were multiple;
- The mathematical models used by banks to create new products are based on theory and the analysis of past data. Many of the models have technical limitations, for example questionable distributional assumptions or an assumption that past events are a good guide to future outcomes. There is an incentive for banks to improve their modelling and this has driven much of the innovation in the industry. The difficulty of quantitatively defining risk within these models has been graphically illustrated by Tett (2009). We believe there is much work to be done in enhancing the assessment of risk within individual product models and testing of their resilience. But it is also important for regulators to understand the impact upon overall system stability of the ever more refined models used by banks. It may well be in each individual bank's short term interest to adopt models and trading strategies which, taken together and amplified by like strategies adopted by other banks, have the effect of increasing the risk of a major dislocation to the system. We do not have good models for the overall behaviour of the financial system, which may not converge to a steady-state equilibrium but may instead exhibit path dependence and discontinuities. Given the importance of the banking system to the whole global economy, this is profoundly unsatisfactory;
- Ultimate responsibility for any failure rests with management and with those carrying out the auditing of risk: a lack of understanding of the complexities involved in modelling is no excuse for the subsequent failures.

Box 3.2 FT leader 21 March 2009

FINANCIAL TIMES

"Without fear and without favour"

Saturday March 21 2009

Maths and markets

Banks need quants and geeks to recover from the crisis

Markets + maths = mayhem. That equation sums up an erroneous view of the role played by mathematics in the banking crisis, which is gaining currency in financial and regulatory circles. For example, this week's report by Lord Turner, chairman of the Financial Services Authority, blamed "misplaced reliance on sophisticated maths" for lulling banks' top managers into a false sense of security about the risks they were taking. Terms such as quant, geek and rocket scientist, once used in affectionate respect, now have darker connotations.

Mathematicians tend to be shy and retiring, compared with other professional groups, and they have not leapt up to defend themselves in public. In private, however, they are seething – understandably so, since the problem was not the maths itself but the way banks used it.

Contrary to Lord Turner's assertion, the banks' sums were not sophisticated enough. They oversimplified, and assumed away the limitations and caveats of their models. They did this to convey an illusion of accuracy and precision, and so convince the market that they had everything under control.

The standard risk measure used by the industry from the mid 1990s, known as value-at-risk or Var, was criticised by mathematicians almost from the start for the way it drew inferences about forward-looking risk from past patterns of price movements. As a result, the risk of extreme bank-shattering events was greatly underestimated.

Essentially, financial institutions told their "quants" to build mathematical models that fitted market prices – and never mind if those prices were way out of line, on any fundamental analysis. As a result, mispricing was supported by a spurious veneer of scientific respectability. And the industry was caught in a "positive feedback loop" from which no one dared walk away.

For the future we need more – and better – maths to underpin individual banks and the enhanced regulatory regime that will oversee them. Some of the expertise required is already out there, in universities, waiting to be put to use.

But financial mathematics has been underfunded, given its economic importance, and both private and public sectors must commission more research in the field. For instance, we need to know more about the way human psychology affects market models – and about the scenarios in which models break down.

At the same time, senior bankers must become better informed about the mathematical basis of their industry. Total ignorance of the "black box" trading systems used by their companies is not an acceptable excuse for failure.

Finally, mathematicians should abandon their traditional reticence and fight strongly for their discipline. Then the financial world will appreciate the true equation: markets minus maths mean mayhem.

We have been told of a serious lack of understanding of even the rudiments of the mathematics underpinning the new products amongst many managers from board levels downwards. This applies to banks as well as other purchasers of securitised investments and other financial products (a lot of the first round of huge losses has been faced by some of the largest financial firms who were actually producing the instruments and holding many of them on their balance sheets).

In March 2009 the *Financial Times* published a leader article whose conclusions largely match our own views. This is reproduced in Box 3.2.

3.4 Conclusions and recommendations

Even if the responsibility for the financial crisis lies elsewhere, we still need to address how we can ensure both that STEM-related innovations do not exaggerate the scale of future crises (for there are sure to be some), and that any actions taken do not stifle innovation completely. We make three observations and four recommendations on this front.

The first observation is that (as noted above) many of the financial models created by STEM-trained bank employees seem to be inadequate for describing the highly complex systems they are modelling. It seems intrinsically unlikely that the uncertainty inherent in any system of markets, influenced by individuals, 'crowd mentality' and policy actions, can be captured by models such as those used to date by many organisations, especially in or around 'tipping points'. That scientific knowledge continually increases and technology improves does not materially reduce uncertainty in such systems.

Modelling risk and identifying uncertainty is hugely difficult in all complex systems. To maximise the chances of success requires the application of the very best of contemporary science and social science. We have been surprised to find that—in contrast to other parts of the financial services sector (notably the insurance and actuarial science domains, where there is a strong professional body which is closely coupled with new academic developments; see Box 2.8)—there seems to be relatively little interaction between the research base and the banks themselves (see Box 3.1). In banking, almost everything appears to be internalised. This may well be because of the high levels of secrecy and competition in areas where being 'first to market' is more important than protecting Intellectual Property Rights. The sheer number of STEM-trained staff within investment banks and some other financial institutions may also foster a false sense of confidence. We suspect that, in reality, this internalisation leads to a lack of contemporary cutting edge knowledge in a variety of disciplines and a lack of independent intellectual challenge. There are various ways to ameliorate this problem, for example by establishing independent centres of multi-disciplinary expertise drawn from the research base and focused on modelling risk and uncertainty in the financial services (funded by the taxpayer to avoid undue pressures from interested parties). Such centres should be drawn upon by the Financial Services Authority in their regulation of banks and other financial services institutions.

Modelling within banks and other financial institutions in order to devise new, sometimes tailored, products is one element of the problem. The other—and, from a societal point of view, the more important—is modelling of systemic risk across the whole global financial system. The latter seems an order of magnitude more complex. Experiments in such modelling work are certainly going on in the Bank of England (which has primary UK responsibility for contributing to systemic financial stability) and, no doubt, within other central banks. We strongly suspect, however, that this could with benefit be expanded with much more work being carried out on the systemic and macro issues, networked 'interconnectedness', determinants of stability and so on. The best STEM practitioners could make a hugely useful contribution. We recognise the confidentiality inherent in such work, not least because of market sensitivity, but we are confident that some form of beneficial partnership could be established.

Recommendation 1

BIS, working with the TSB and the Research Councils, should seek to create one or more world-leading and independent centres of modelling and risk assessment relevant to banking (and other financial services), drawing on all relevant sections of the research base. The success of such an endeavour would be maximised by mandating and formalising the engagement between the centre(s) and the Financial Services Authority (FSA). The FSA and HM Treasury should ensure this engagement comes about and is effective.

Recommendation 2

Linked to Recommendation 1, the Research Councils should engage at high level with the Bank of England and the Financial Services Authority to explore ways in which the research base can contribute to more effective modelling of systemic risk in financial services, perhaps through consideration of complex adaptive systems. This may well necessitate a global research effort.

The second observation relates to fostering professional competence in and understanding of complex models and risk by senior management in banks. We note that Lord Myners, the City Minister, has been reported as arguing that 'directors lack the expertise to challenge and tenacity to challenge ruinous business plans' and has suggested that bank directors might need compulsory seminars on financial stability (Barker 2009). On a more general level, we are concerned about certain aspects of the training available and the lack of any mandatory element of it in the wholesale part of banking (though it is mandatory for some parts of retail banking). This is unlike the situation in other professional domains. There is no shortage of providers of training: the Chartered Institute of Bankers of Scotland, the Institute of Financial Services and the Securities and Investment Institute or SII (and others) all provide courses at various levels and competition between them is fierce. The course curricula are approved by the Financial Services Skills Council (FSSC)—an employer-led body—under delegation from the Financial Services Authority. In addition, there are international players and qualifications such as the Chartered Financial Analyst (CFA) self-study qualification. The great bulk of the education available is at undergraduate level or below though there are now an increasing number of Masters level qualifications.[22] The SII for instance recognises three centres of excellence (Cass Business School, the ICMA Centre at the University of Reading and Edinburgh University) and 22 other HEIs providing approved financial services-related education and many of these operate Masters level courses.[23]

In terms of communications, we realise that it is very difficult for non-experts to understand fully the nature, characteristics, sensitivity and stability of sophisticated mathematical models, especially where managers are under huge competitive pressure to generate returns for shareholders (and themselves). But managers cannot manage effectively unless they have an adequate level of understanding of the models. We thus see a major need for education and awareness-raising. We believe that the range of courses available could with great advantage be extended to cover the nature of the mathematical models employed and the risks associated with them; in addition, these courses need to be mandatory for those at Board level and those at lower management levels in the banking and related sub-sectors though the nature of the curricula would inevitably differ for the different levels of management.[24] We also believe that the boards of the financial institutions and various professional and statutory bodies have a responsibility to put their houses in order, and the research base can make a major contribution. Hence this is best done through an employer-led body, the Financial Services Skills Council, acting together with the FSA and working with the research base. Though it is a (unique) local authority rather than a statutory body, we think that the City of London Corporation could with benefit also use its influence to enhance the quality and range of such education and training.

Recommendation 3

The Financial Services Authority and the Financial Services Skills Council (FSSC), supported by the City of London Corporation and relevant professional and statutory bodies, should institute and mandate competency levels in understanding of mathematical modelling and risk in complex systems. They should draw heavily upon the research base in this design but should also ensure that any license to manage should require demonstrable competence in this area achieved through formal training, irrespective of whether this management is at Board or lower levels.

We noted above that Financial Engineering and related courses—mostly at Masters level—have sprung up in the last five years in many Higher Education Institutions. Some courses at least appear to treat the modelling as simply an arcane branch of theoretical mathematics—without proper engineering considerations of testing, risk, safety tolerances, adherence to published standards, wider understanding of economic contexts and also any ethical considerations. We see this as a serious weakness.

Recommendation 4

The Funding Councils, in conjunction with the FSSC, should commission a review of the contents of financial engineering and related courses in the UK, examining their curricula, discussing with the relevant authorities what would be appropriate curriculum elements and commending the findings to the leadership in HEIs and accreditation bodies.

We have noted above that the level of interaction between bankers and the research base seems much less than in the insurance and some other industries. Implementing the recommendations made above should reduce this shortcoming but we think that there is much merit in a fundamental increase in the number of secondments of personnel between financial institutions, the FSA, the Bank of England and the research base. We recognise the difficulties involved and it is impossible to make a specific recommendation to this effect because of the diverse circumstances covered in such a matter. But we urge those parties to foster multi-directional exchanges of staff confident that knowledge exchange is best achieved through the

22 And the competition for entry to some of these is fierce: some 659 people applied for 75 places on the 2008 Oxford University MSc course on Financial Economics

23 http://www.sii.org.uk/web5/infopool.nsf/HTML/CUniversities?Opendocument

24 As this report went to the printers, the Treasury Select Committee also recommended that "serious consideration should be given to whether all non-executives—or a proportion of non-executives—sitting on bank boards should be required to have professional qualifications relating to banking or other areas of relevance such as accountancy." See http://www.publications.parliament.uk/pa/cm200809/cmselect/cmtreasy/519/51907.htm#a25

movement of people out of their comfort zone into areas where they will learn much of value.

Elsewhere in this report (see Box 1.2) we comment on the unsatisfactory level of detail in official statistics in regard to the ever-evolving services sector. We are pleased to note, however, that the Office for National Statistics is working with key players like HM Treasury and the Bank of England as part of an OECD action plan to collect statistics which may provide early warning of future crises. Inevitably these will mostly relate to the services and, quite probably, to the financial services, sector.

Finally, some politicians have proposed ways of avoiding future financial crises. For example, the Chairman of the Treasury Select Committee has blamed the complexity of the financial instruments as a key factor in the recent financial crisis and called for more standardised and simpler products. On the other hand, members of the financial services sector point out that this removes competitive advantage and leads to the commoditisation[25] of financial instruments where the UK would be competing against much lower wage economies. Other politicians have gone further and argued for science playing an extended role in future outside of the financial services to minimise the impact of future crises. Philip Hammond MP, Shadow Chief Secretary to HM Treasury, has argued that in the future 'We have to broaden our economic base to include more science, more hi-tech services, more green technologies, more engineering and more high-value manufacturing, drawing on a much wider range of industries, markets and people, and with a better geographical spread throughout the UK' (see Collins & Harrington 2008). The Prime Minister, in giving the Romanes Lecture on 27 February 2009 (Brown 2009), argued that we have to rebalance the UK economy away from financial services and that STEM could play a crucial role in that mutation.

Even if this is so and even in the depths of recession, however, it is clear that the financial services are certain to remain vitally important to the future prosperity of the UK. Quite apart from the sector's overseas earnings, the businesses and staff involved pay around 25% of all UK corporate taxes (House of Commons Treasury Committee 2009b, Q2820). And it is inevitable that innovation in the new forms of sophisticated financial products based on mathematical modelling will continue. For these reasons, we have to understand, communicate, manage and regulate much better the risks and uncertainties involved. STEM can play an important role in doing so.

25 The standardisation of services or products which leads to price decreases through strong competition

4 Innovation in the public sector

Summary

- In excess of £600bn is spent annually by the public sector in Britain, mainly on services for citizens. It follows that the quality of services and their value for money are important considerations to all governments and the electorate;
- Though slow to recognise the importance of innovation compared to the private sector, there have been promising developments in recent years and many studies and policies designed to foster innovation in service design and delivery. Many of them have alluded to the potential of web-based technology to improve services, but virtually none has identified the broader contribution—real and potential—of STEM;
- This chapter reviews a number of examples from central and local government and other public bodies where STEM has played a significant role in creating new services or transforming old ones. In addition, we have identified cases where public sector leaders have noted that private sector innovations through use of data mining, simulation and other STEM developments could contribute to greater personalisation of public services;
- There is a pressing need to expand good practice across the public sector and take advantage of STEM inputs. We recommend that a task force drawn from central and local government and the research base should define how best this should be done. Government should also seek to repeat the success of its HEIF knowledge exchange initiatives between universities and business with a parallel scheme between universities and public bodies;
- Some of those who contributed to this study complained about constraints on innovation in the private sector resulting from public sector innovation, and specifically the practices of certain government Trading Funds in regard to licensing and charging for public sector information. Government has made some changes to the business model of one Trading Fund in Budget 2009 but we believe more can beneficially be done;
- The CBI suggested that there may be scope for giving academic researchers suitably confidential access to large private sector databases. This could be helpful to businesses, researchers and government alike and we urge that the proposal be taken forward.

4.1 Introduction

The public sector has traditionally viewed innovation as an 'optional extra' or even an added burden, rather than a core activity that is both necessary and of significant value (Mulgan & Albury 2003). This is in contrast to the private sector, where innovation is perceived as vitally important in increasing profits and reducing costs, and even to survival itself. The pressure to reduce costs tends to co-exist in the public sector with many other policy priorities, with the result that innovation has been regarded until recently as a low priority and perceived as high risk.

It has been suggested in the literature however, that as public organisations represent the needs of so many, and are often entrusted with socially important tasks, the impacts of innovation in the public sector are even more valuable than comparable gains in the private sector (Donahue 2005).

The mindset regarding public innovation has changed somewhat in the last twenty years and in the past three to four years there has been much greater interest from policymakers. This has primarily been driven by the need to provide prompt improved and personalised public services to citizens (IDeA 2005 and HM Government 2009). Another important realisation has been that the public sector has to build services around citizens' requirements, rather than making them fit to their own organisation and structure (Kamarck 2003).

The introduction of 24 hours/7 days per week services from the private sector through ICT has also raised the expectations of the public. From a policy perspective, given the size of the public sector (in terms of GDP) and the size of its annual procurement budget (recently estimated at £175bn/annum; Lord Drayson 2009), there is a major opportunity to innovate in central government departments, local and regional public sector bodies, non-departmental public bodies, the supply chain and in the delivery of services.

4.2 Major triggers fostering public sector innovation

Though tightening budgets have been and remain a prime driver for public sector innovation, various recent reports have highlighted a number of other compelling reasons for public sector innovation. These reports are summarised briefly below.

Local government's Improvement and Development Agency (IDeA) highlighted various types of innovation identified in the literature as being important in public sector settings in its 2005 report (IDeA 2005), including:

- The revitalisation, devolution and decentralisation (eg from central government to regional or local government) of the Public Service;
- Improvements to systems and processes (eg streamlining business processes), and regulatory change (eg focusing on deregulation and simplification);
- Introduction of new IT projects or web services.

Several emerging patterns of innovation were also identified by the authors of the IDeA report, including:

- Provision of client-centred services;

- Delivery of services through partnerships (eg local/regional partnerships);
- New public management (eg introduction of private sector business practices);
- Improving users' experience of services.

One significant constraint on policymakers identified at that time was the lack of comprehensive information regarding innovation in public services. IDeA argued 'According to Mulgan and Albury (2003), while a substantial body of research has emerged in the past four decades on innovation in the private sector, a significant knowledge gap exists with regard to innovation within the public sector, where quality research on the subject is rather limited.'

Four years since the IDeA report was published, the personalisation of public services remains an important theme, but the tougher economic climate means that a new emphasis has been placed on cost-efficiency. Our consultations suggest that these are likely to be two enduring themes in public sector innovation for the next five years. Both themes are closely linked to the well-established 'transformational government' agenda.

The 'Transformational Government' Agenda was initiated in 2005 (Cabinet Office 2005). The stated aims of the government's strategy were to provide overall technology leadership in three key areas:

a) The transformation of public services for the benefit of citizens, businesses, taxpayers and front-line staff.

b) The efficiency of the corporate services and infrastructure of government organisations, thus freeing resources for the front-line.

c) The steps necessary to achieve the effective delivery of technology for government.

The 'Transformational Government' agenda is, in effect, a major drive to use innovation and technology to transform the Governmental services sector in the UK by creating and retaining 'the capacity and capability to innovate and use technology effectively as technology itself develops' (Cabinet Office 2005, p4). Government has claimed to have put in place several important measures relating to funding (eg investment in technology), customer-centred delivery, use of the internet and recruiting experienced ICT professionals to fill newly created Chief Information Officer (CIO) posts.

The 2007 review (Cabinet Office 2007b) of the strategy re-iterated the main aims of the agenda as follows:

- A focus on customers, and not suppliers, of public services;
- Integrating similar services in order to reduce duplication and enable personalisation;
- More professional project delivery;
- Delivering citizen-centred services;
- Developing 'Shared Services', in order to enhance the efficiency of back office operations and deliver better value for money for the taxpayer.

The Varney Report (Varney 2006) on service transformation focused on the need to improve still further public services as a whole, not just those provided by central government; many of the examples of enhanced services were found to be in local government. Though not emphasised explicitly, this transformation was to be achieved by much institutional innovation. For example, it proposed the creation of a 'change of circumstances service' that would allow citizens to inform government once—and only once—of their change in circumstances; initially this should cover bereavement, birth and change of address. Even before the losses of personal information by HM Revenue and Customs, Varney recognised the importance of ICT and information governance in bringing this about. Since then, provisions in the Statistics and Registration Service Act of 2007 and the Thomas and Walport report (Thomas & Walport 2008) have helped outline a regime within which data sharing can be realised safely.

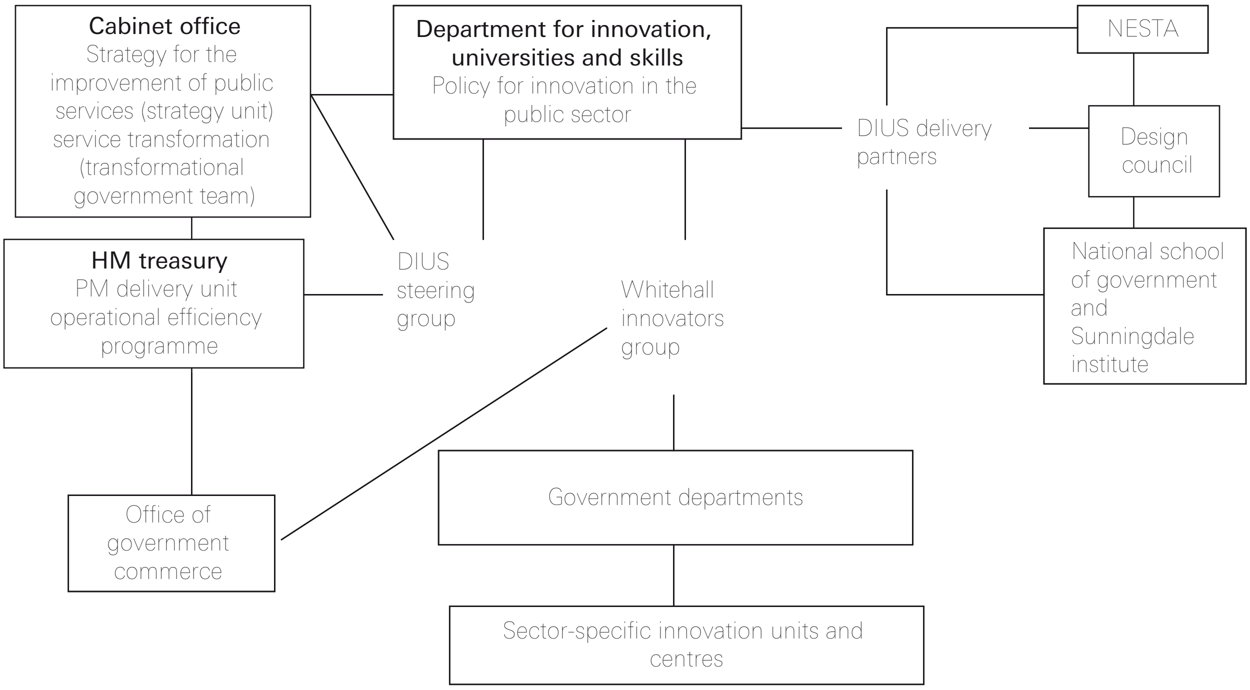
A National Audit Office (NAO) report also published in 2006 (NAO 2006) illustrated the scale of the challenge. This criticised public sector approaches to innovation for being 'overly top-down and dominated by senior management'. The report concluded that the Government could take a more systematic approach to innovation and could learn lessons from the private sector.

The NAO report also noted that data on the operational costs of governmental organisations and the costs of potential innovations need to be significantly improved. Policymakers and public sector practitioners are further hampered by the limited availability of technical data. For example, one of the stock datasets used by innovation policy analysts (the UK Innovation Survey) does not cover the public sector. The availability of better data would, it claimed, enable organisations to benchmark themselves against one another and determine where their innovation costs are above average.

NAO updated their report in March 2009 (NAO 2009), reviewing progress against their earlier recommendations. It found a significant improvement in certain respects: for instance, NAO identified around £3bn now being spent per annum on innovation across government, mostly in the Ministry of Defence, and various new developments. The responsibilities for innovation in government have been mapped and agreed (see Figure 4.1) and differences between the characteristics of innovation in the private and public sectors described. We take from all this that the importance of innovation in government—at least at senior levels—has now very much been recognised. That said, there is still some way to go: NAO made a number of significant recommendations for further enhancement, largely about reforming institutional mind sets and rules (eg it highlighted the need for DIUS [now BIS] to have a mechanism to measure the impact of its policies or other central government initiatives on innovation). But more significantly for us, although continuing improvements in ICT are assumed, there is no mention of STEM more generally and very few mentions of science in the NAO report—or indeed in virtually any other government report on the subject. Given that we have uncovered some promising examples of STEM-driven innovations in the public sector (see below) but are clear that much more could be achieved, we regard this as a significant opportunity.

Perhaps unsurprisingly, a 2008 Royal Society policy document (Royal Society 2008b) noted that, while the UK Government's

Figure 4.1. How various government initiatives to promote public sector innovation link together Source: NAO (2009).



science and innovation strategy has sought to strengthen the nation's innovation performance by boosting science spending and encouraging growth in private sector R&D expenditure, the innovation performance of the public sector has received much less attention. The Royal Society urged the Government to address public sector innovation by:

- Persevering with a more enlightened approach to public procurement (especially at the operational level where the required culture change will take time);
- Exploring the merits of developing new or extending existing knowledge exchange schemes for the public sector;
- Recognising and rewarding research that is aimed at policymakers when considering research assessment and funding.

In March 2008, Government agreed by signalling its intent to tackle this area through setting out a number of measures in the Innovation Nation white paper (DIUS 2008a). These measures built on previous commitments to reform public procurement practices and to support the TSB's 'Innovation Platforms', which bring Government, business and other stakeholders together to generate innovative solutions to major policy and social challenges.

More recently, NESTA launched a report (Harris & Albury 2009) making a case for 'radical innovation' in public services. They argued that society is facing many intractable long-term economic and social challenges—such as ageing, health and climate change—that can only be addressed by a radical new approach to innovation. In particular, they stressed the importance of 'rigorous experimentation', and the need to put users, consumers and citizens 'at the heart of innovation in public services' (p2), including as partners for designing and delivering services. NESTA made a number of recommendations relating to promoting innovation in central government, creating stronger incentives for the development of local solutions to problems, and opening up innovation in public services to a wider range of actors.

To coincide with publication of their report, NESTA launched a public services 'Innovation Laboratory'. This was proposed in 'Innovation Nation' as a way 'to develop and trial the most radical and compelling innovations in public services' (DIUS 2008a), to work closely with a Whitehall 'Innovation Hub' to share knowledge of innovation from this and other sources. It will consist of a number of practical projects in three areas: a 'Challenge Lab' to explore innovative ways of responding to critical social and economic issues; a 'Methods Lab' to test the best ways of fostering public sector innovation; and a 'Learning Lab' to disseminate knowledge.

While we welcome this initiative, we note that neither NESTA's report nor the 'Innovation Lab' make any mention of a role for STEM (other than occasional mentions of technology) in public services innovation.

In the 2009 budget announcement (HM Treasury 2009a), the Chancellor set out a number of measures to foster innovation in business, and also stressed the importance of measures of innovation success in Public Sector Agreement targets for government departments. Unsurprisingly in the light of current economic circumstances, the greatest emphasis on the importance of public sector innovation came under the theme of getting better value for money: various new innovation initiatives were created within the Public Value programme, such as Value for Money Panels (HM Treasury 2009a, p122–132). The Government's response to Sir David Cooksey's *Review and Refresh of Bioscience 2015* (Bioscience Innovation and Growth Team 2009) was also published in Spring 2009 (BERR 2009), and sets out priority actions in a number of areas, including stronger incentives to support participation in clinical research and steps to promote innovation in the NHS.

On 14 May 2009, the Government published its formal response to the Power of Information report[26] (see Boxes 4.1 and 4.2). This accepted many of the recommendations in the

26 http://blogs.cabinetoffice.gov.uk/digitalengagement/

Power of Information report and set up a new post of Head of Digital Engagement based in the Cabinet Office. Much of this response is infused with the need to promote innovation through the use of web technology. In particular government embraced the merits of Open Innovation, where citizens can contribute to the development of new tools which enhance government services. In illustrating how this would work, government cited the success of an earlier STEM-based open innovation competition—the challenge made by Parliament in 1714 to find ways to measure the longitude of ships at sea, eventually won by Harrison with his chronometer in 1765. The government's conduit for this is innovate.direct.gov.uk—a standing open online innovation space akin to that developed by the BBC.

4.3 Where we are

Based on all the thinking and government reports on innovation and related issues in the public sector, it is clear that the topic is now high on the political and managerial agenda. Seen from our own perspective, we have been able to identify some good STEM-based examples of innovations from across central and local government which have enhanced services (see Box 4.1).

Box 4.1 Successful STEM-based innovation in the public sector

Some public sector agencies have taken strategic approaches to innovation and have organised their STEM resources and capabilities to support better the identification and acceleration of innovative projects. We give several examples below.

(a) The National Health Service

The NHS cost taxpayers approximately £90bn[27] in 2007/08. Its success as a service and the value for money provided is therefore of huge importance to the UK. Many innovations in the NHS, in terms of medicines and healthcare, come directly from scientific research (often within pharmaceutical companies). But there are also many less obvious examples of STEM-inspired innovation in the NHS.

One such example is NHS Direct, which was born in three pilots in 1998, achieved national coverage through 22 pilots in 2000 and became a single national service in 2004. Staff at the national operations centre include statisticians and business analysts. Their job is to mine the data and devise new algorithms (see below).

The 36 individual NHS Direct sites and call centres are linked through a Virtual Call centre. This determines if an agent is available locally; if not another agent elsewhere takes the call. But NHS Direct is much more than a large and complex call centre, dealing with 20,000 calls a day. Two innovations that have underpinned the success of the system are statistical modelling of calling behaviour and the Clinical Decision Support System. The first is essential for predicting NHS staffing available to callers: it takes account of historical daily and seasonal patterns of calling plus outbreaks of flu, colds and other diseases in different parts of the country. Other information—such as the likely impact of National Health alerts (eg on the polonium poisoning in London which raised the number of daily calls by 7%)—can be factored into the modelling.

The Clinical Decision Support System uses nationally common assessment algorithms based on recent clinical experience. The algorithms—over 200 are now available to the nurse—contain a structured set of questions which guide her or him towards the best advice. The system also contains a triage tool which determines the priority with which the patient must be treated (eg whether an ambulance is needed). Finally, NHS Direct works with the Health Protection Agency to ensure that the information gleaned in all these telephone calls is aggregated, analysed (eg to track the spread of Norovirus across the country) and forwarded to health care professionals in the affected areas.

(b) The Meteorological Office

The natural environment affects human health. There are many cases in which the weather has a direct or indirect affect on the health of an individual. High temperatures cause up to a 30% increase in mortality amongst the elderly and very young. Cold is also still a big killer in the UK contributing to 30–40 thousand deaths each winter. Thunderstorms can cause asthma epidemics if they occur during high levels of either pollen or fungal spores in the summer.

Health forecasting is a new healthcare discipline initiated by the UK Meteorological Office. The forecasts help professionals and patients know when and where there is a risk of illness. Through this understanding, preventative action can be taken and healthcare capacity (ie hospitals and doctors) managed to reduce illness and death.

The main strand of the Health Forecasting project is forecasting the risk of exacerbation of chronic obstructive pulmonary disease (COPD).[28] There are 100,000 COPD-related hospital admissions in England each year and the NHS spends £600 million annually looking after people with COPD. Such forecasts are used to drive the provision of anticipatory care to COPD patients, helping to ensure patients with these long-term conditions achieve their potential for independence and wellbeing. This is being run in 40 Primary Care Trusts and evidence from several trusts show significant reduction in emergency admissions by up to 80%. The Met Office project won the 2007 Innovative Service Award category at the Health and Social Care Awards.

(c) The Cabinet Office and 'Show Us a Better Way'

This was a competition run in Autumn 2008 by the UK Cabinet Office to encourage innovative new uses of government data through 'data mashing' and 'scraping' of information from any government web site. It was totally dependent upon the new

27 See http://www.nhs.uk/aboutnhs/Pages/About.aspx;
28 http://www.metoffice.gov.uk/health/

opportunities provided by Web 2.0 technologies. The project was driven by central government's commitment to maximising the utility of its data better to inform citizens and to provide personalised services. Some 450 entries were received, most of which sought to utilise geographical data (eg that provided by Ordnance Survey or the Meteorological Office). A first prize of £20,000 was awarded. The competition is now being replicated by the US government.

Immediately after the winners were announced a complication arose because of constraints on implementation due to Ordnance Survey licensing terms and conditions and requirements placed on that organisation as a government Trading Fund. This demonstrates the complex way in which different government policies interact and how STEM is an important enabler of innovation but other factors can constrain implementation. The Budget 2009 (HM Treasury 2009b) announcement on changes to the Ordnance Survey Business model (discussed in Section 4.5) was designed to tackle this issue.

(d) Ordnance Survey (OS)

OS is an unusual government body. It is a government department yet pays its own way by sales and licensing of data it collects and integrates. In effect it is an information utility. It has a turnover of some £118m, pays dividends to government and has 1450 staff.

Thirty years ago, OS was a traditional national mapping organisation. The impact of science and new technology on OS has been profound over the last 20 years or more. New approaches, notably the use of refined forms of GPS in field surveying, have halved the time taken to survey individual properties in the last five years. New digital cameras have extended the flying season by nearly 50% because of their superior ability to cope with shadows, etc. Since OS became the first national mapping organisation in the world to convert all its maps into digital form in 1995 and especially since these were converted into 'object form' in 2002, there has been a significant overall reduction in staff: at the beginning of the 1970s, the total OS staff was over 3,000. But, just as important, the range of products spun off from the database has been widened and quality has been improved by automated checking of topology and other factors. Much of this has been achieved in partnership with commercial enterprises, some of them small in size. The 500,000 historical maps of Britain, for example, have been digitised by a number of private sector businesses for commercial exploitation including Landmark (see Box 2.2).

Some of the responses to our call for evidence and subsequent discussions with organisations brought out criticism of OS' licensing practices and charging levels (see above). This has been the centre of a much wider campaign.[29]

(e) Environment Agency

The Agency's Flood Warning Direct system works by linking a computerised map to a database of properties and registered user details. By drawing a polygon on the map, a flood warning can be created, and notification will automatically be sent to registered users within the affected area via their preferred means.

Britain was hit by severe flooding in the Autumn of 2000, affecting 10,000 properties in over 700 locations, with total costs being in the region of £1 billion. The Environment Agency carried out an investigation into the circumstances which contributed to the scale of the damage, with the resultant report featuring recommendations for improvements to flood warnings, emergency planning and flood defences.

Ministers sought a new seamless, integrated flood warning service which could deliver a better service. At the time there were 32 different systems operating across the country, and some were obsolete.

User feedback showed that the system would be most effective if it could deliver flood warnings in the way that best suited the individual user: by telephone, text message, fax, or email. Business cases set out what users wanted from the system, and the supplier was brought in at this early stage to help design the solution. Successes to date include a reduction in the number of systems, growth to 300,000 registered users, a decrease in unit cost per customer, a reduction in the time it takes to issue a flood warning from 56 minutes to 11 minutes, and the success rate for ensuring people see a warning up to 75 per cent. (Source: NAO 2009)

(f) Local government

Various examples of service innovation in local government which make use of STEM have been noted by the Improvement and Development Agency (IDeA). These include the Kent TeleHealth Project which allows patients successfully to self manage their own chronic conditions. By monitoring them from a distance and increasing their awareness of their condition, the project is designed to reduce hospital admissions and increase early interventions, thereby helping people to live more independent lives. Indeed, to take this further the local government community has set up an Innovation Catalyst to generate, incubate and spread innovation in local government and forged a link with Research Councils.

(g) Bank of England

The Bank employs a team of scientists to devise innovative ways to make counterfeiting of the £45bn of banknotes in circulation more difficult and to detect forgeries. Counterfeiting currently occurs at a rate of 0.006%, relatively low by international standards (personal communication from Andrew Bailey, Executive Director Banking & Chief Cashier at the Bank of England).

29 See, for instance, various sections of a report by the government's Advisory Panel on Public Sector Information (APPSI 2008).

Box 4.2 Embryonic STEM-based innovations in government

The **Department for Transport** (DfT) has sought innovative ways of using data from different sources to develop new transport-related services. A pilot study (Landshoff *et al.* 2008) recommended the creation of a 'National Transport Information Incubator' (NATII)—a neutral environment where owners of different datasets could identify ways to join their data together to provide new high-value services. It was envisaged that the NATII would provide expertise in data manipulation, idea generation, technical tools, collaboration and evaluation, and access to experts from industry, government, and public agencies. To demonstrate the feasibility of the NATII, an application called 'My Journey' was developed for the British Airports Authority (BAA) using the internet to provide real-time journey planning via mobile phones for passengers travelling from Stansted airport. The project was delivered in effectively a 4/6-week period, saving 12 months over BAA's expected development time, thereby demonstrating that operable systems can be rapidly conceived from technologies at low readiness levels. (In 2006, the National Audit Office found that innovation projects in the public sector take, on average, 24 months to deliver; NAO 2006.)

The NHS Institute for Innovation and Improvement was set up in 2005 with funding from the UK Government's Department of Health. The Institute, which has 180 staff, is based on the Warwick University campus and enjoys a good relationship with departments such as the Warwick Manufacturing Group and the Business school. The Institute exists to enable the NHS system to transform health and healthcare for patients and the public. It does this by developing ideas at the leading edge of service and product innovation and supporting the NHS to employ them to good effect. Important use is made of developments in new technology and science, as well as social sciences—for example in understanding how best new devices and services should be designed to maximise the potential for improvement.

The National Health Service's **National Innovation Centre (NIC)** is part of the National Institute and was launched in September 2006. The NIC has a mandate to speed the development, adoption and uptake of a pipeline of innovations coming from the NHS, academia or the healthcare industry that are likely to deliver benefits to patients. It provides a range of web-enabled and added-value scientific, technical, engineering, finance, legal and intellectual property development services. These services provide a supportive innovation ecosystem designed to stimulate and enable open innovation across, between and within business, academia and the NHS itself. Through the NIC's web-enabled infrastructure, potential suppliers from across the European Union are able successfully to compete, win, and deliver contracted work.

4.4 Designing better public services

Many new innovations are at an embryonic stage in government (see Box 4.2). Through initiatives like the Transformational Government agenda, public services are being driven to provide an integrated service as seen from the customer perspective. One particularly important development is the range of new 'service design' approaches being developed using techniques such as 'structured walk-throughs' and touch points (see Box 4.3) in combination with disciplines such as ethnography and social anthropology, among others. The main aim of these approaches is to enable service deliverers to understand the service from the user perspective.

Although the service design methodology is relatively new in the UK, its proponents claim that it is area in which the UK is as advanced as anywhere in the world in terms of new methods and implementation.

In the course of our research we engaged several UK companies in this field including Think Public, Live|work, Bontoft Design, and Engine Service Design. The evidence suggests that there is scope for greater interchange of ideas, methods and technologies between service designers and other parts of the STEM community, which is likely to be valuable for the future.

One of the interviewees, Live|work, described the importance of service design thus; 'most service organisations have a long way to go to move away from production type mindsets towards a more customer centred service oriented approach. For example, discussions about increasing service outputs tend to reveal a great deal about production metaphors—instead

Box 4.3 Service design

Structured design processes are commonplace in product development, but their use in the design of services has only become more widespread in recent times.

The research undertaken in this study identified a range of specialist companies undertaking 'service design', for both public and private sector clients. This approach uses STEM-based structured thinking and analysis and is primarily concerned with understanding the total service experience from the perspective of the user. Specific techniques include:

- using multi-disciplinary teams to analyse problems and develop solutions;
- 'journey mapping'—the process of tracking and describing the experience customers have as they encounter a service;
- 'touch points'—interfaces between the service and customers/stakeholders;
- 'interaction design'—for example to enhance customer interfaces such as websites and mobile devices;
- using ethnography and social anthropology to understand users' engagement with services;
- segmenting user communities according to different needs;
- participative development approaches—for example with designers, patients and hospital staff participating.

there is a greater need to think about the qualities of personalisation, experience and sustainability.'

Service design, which incorporates STEM-based approaches to problem solving, can help in these regards.

4.5 STEM and public sector innovation

Government has made strenuous efforts in recent years to foster innovation and has set up a plethora of bodies to take this forward. But the expressed concerns and objectives of these bodies mostly ignore STEM.

There are a few exceptions to this generalisation. Some agencies have clearly recognised the role of STEM in delivering good quality public services and value for money. They have successfully engaged the STEM supply chain in their innovation processes (see Box 4.1 and Box 4.4).

But across Government more generally, the appreciation of STEM's role in under-pinning innovation is much less developed. The single overall exception is in regard to ICT: the 'Transformational Government' agenda, for instance, is essentially a technology policy. The wider concept of STEM—and notably the importance of technical skills, research and disciplinary knowledge—is not explicitly mentioned in either the 'Transformational Government' strategy or in the vast majority of other studies of public sector innovation or policy and strategy documents.

Given the importance of data mining, mathematical modelling, finite element analysis, visualisation, simulation and other STEM approaches we have seen used widely across the private sector (eg Boxes 2.5 and 2.8), we find this lack of engagement with the research base surprising and somewhat disappointing. Indeed, it contrasts with government's very substantial 10 Year Science and Innovation Investment Framework designed to support innovation which has certainly helped private sector innovation. The potential for more and successful innovation in the public sector is high and government should seize the opportunity immediately.

Recommendation 5

In view of the importance of the public sector to the national enterprise and national productivity and competitiveness, we strongly recommend more detailed work on how STEM can be exploited more successfully to foster public sector innovation. This needs to be through a team drawn from central and local government and from the research base. This recommendation is primarily addressed to the Cabinet Office—which has a continuing role through its strategy for 'excellence and fairness in public services'—and to the Department for Business, Innovation and Skills (BIS).

The age-old challenge facing potential beneficiaries and those working in relevant areas in the research base is how to find each other. Navigation through the thickets of the research base or of the public service is often immensely time-consuming. Everyone to whom we spoke voiced frustration at this process. We note that the Higher Education Innovation Fund (HEIF) scheme of bringing together universities and businesses is having some real success and suspect that some equivalent and long-term scheme will be needed to build a better innovation ecology for the public sector.

Recommendation 6

We urge BIS to discuss with the Funding Councils how to emulate the success of the HEIF scheme with partners from the public services and the research base.

Thus far, this section has considered only innovation in the public sector. Some innovation in the public sector, however, has arguably constrained that in the private sector. In particular, government is the custodian of various important data sets which private sector firms—often SMEs—have sought to exploit. Many of the most valuable data sets are those provided by the Trading Funds, some of which are monopoly suppliers in some areas. This situation has long been a matter of public debate, notably through the Guardian's *Free our Data* campaign. Multiple reports on the issues involved have been commissioned or produced by the Cabinet Office, the Office of Fair Trading (OFT) and HM Treasury. A report by Cambridge economists (Newbery *et al.* 2008), commissioned by BERR and HM Treasury, argued strongly that there was greater public benefit from making available such information at marginal cost— as is the practice of the US federal government and for other UK government information—than under the present cost recovery model. Beyond the pricing model to be used, a number of respondents to our consultation were vociferous

Box 4.4 Transport for London (TfL)

TfL recruits approximately 60 to 70 graduates per annum specifically for their STEM degree experience. One example of innovation arising from collaboration and co-working between internal and external researchers is centred on cooling the London Underground—a serious service problem, especially in high summer. The context for this is a research programme covering issues such as physiological factors (eg at what temperatures and humidity levels did passengers feel uncomfortable). From this, requirements and specifications for cooling systems were evolved. A revolutionary response was developed in association with London South Bank University (LSBU), using ground water to provide a cooling medium for large heat extractors. This reduces the need for energy-intensive cooling systems. The technology won a Carbon Trust award in 2007. Piloted at Victoria Station, there are plans to clone the facilities at up to 30 other stations and there is also potential to introduce the technology to other underground rail systems across the world.

The collaboration worked by providing the ability to relate theory and academic insights to a practical engineering solution that could be installed in London Underground stations. TfL believes the 10-year partnership with LSBU was fundamental to the success: in other cases, TfL has found it necessary to engage consultants because of the differing time scales of business and university groups. Finally, the lack of STEM staff in the UK and an emerging skills gap is of critical concern to TfL and its supply chain (TfL 2009).

about the practices of some of the Trading Funds. One respondent for example said:

the UK government operates a shameful policy of deliberately restricting industrial access to information related to weather, climate and climate change, in stark contrast to the US government, which operates policies that provide free access to such information. These restrictions are a source of friction on innovation and growth within all UK industries that need to use this information.

Though there has been widespread concern about the pricing model used by Trading Funds, especially Ordnance Survey, a number of other private sector bodies have made it clear that they are less concerned about government charging for data (assuming the price is relatively low or 'fair') and more concerned about licensing, equity of treatment, speed of action and other operational matters. The results of an inquiry by the Shareholder Executive into these issues—largely focussed on Ordnance Survey—were announced in Budget 2009.[30] This reiterated that OS funding would continue to be based on a commercial, revenue-funded basis rather than reverting to a Parliamentary vote. But it set out various changes to the OS business model to reform the licensing framework, create new commercialisation pathways, provide some data sets free of charge via the internet, facilitate access to OS data via an application programming interface cut costs of running OS to give greater value for money to customers and to create a separation between the data collecting and processing entity with a clear public task and a separate innovative trading entity. Monitoring of the success of these changes will be regularly undertaken by OFT and the Office of Public Sector Information. The OFT—which had been critical of OS' business practices—has welcomed the announcement in saying 'the OFT looks forward to the commitments which Ordnance Survey has given to stimulate innovation, make data and services more widely available and increase competition for the benefit of consumers in this geographical information market.'[31] All this should go some way to addressing the complaints we received, although judgement should be reserved until detailed implementation plans are published. We also believe that there is a wider issue here in two respects: the inconsistency of rules and business models for different Trading Funds is confusing and the interaction between 'charged for' information (eg the geographical framework provided by Ordnance Survey) and free information (such as all official statistics) has proved antipathetic to much innovation.

Recommendation 7

We note the Government's publication of changes to the OS business model and welcome the intention of making OS information more readily available. But we urge the Shareholder Executive and HM Treasury to move towards a situation where there is one model for the supply of government information, thereby simplifying matters for commercial organisations and facilitating innovation.

A very welcome argument put to us by the CBI was that commercial enterprises owned large amounts of data about their customers which might well be of value to the research base for research. Clearly there would be some difficulties arising from the non-randomness of samples, the need to ensure anonymity and confidentiality plus the costs to the firms involved, but this idea has real merit. We know that the Economic and Social Research Council (ESRC) has been engaged in discussions with 'lifestyle' firms to make available their data to the academic research sector. We think there is scope for taking this further, with mutual benefits.

Recommendation 8

We recommend to the UK Research Councils that they should explore with the CBI and other relevant representative bodies the scope for freeing commercial data for academic and other research.

30 See http://www.shareholderexecutive.gov.uk/news/index.aspv and http://www.ordnancesurvey.co.uk/oswebsite/media/news/2009/april/businessstrategy.html

31 http://www.oft.gov.uk/advice_and_resources/resource_base/market-studies/completed/public-information

5 Services at a tipping point powered by STEM

Summary

- There is high potential for services to undergo a major transition, with major growth in markets for personalised yet ubiquitous services, enabled to a large degree by STEM developments and exploitation of ICT;
- Scientific advances are very likely to open up completely new service possibilities based on analysis of data from pervasive sensing and monitoring of activities;
- Increasingly, the economic value from scientific developments is likely to be realised through services;
- Service industries and supply chains are becoming increasingly globalised, representing both opportunities and challenges for UK organisations, government and policymakers;
- STEM will also play a major role in enabling, stimulating and supporting service-based responses to many of the big, intractable social and economic problems that society is facing—for example in health, energy, environmental, information and knowledge systems;
- The technological advances and the convergence of existing technologies may well result in changes to the nature of the relationship between experts, service suppliers and customers;
- One consequence of these changes is that interconnected services will come to resemble 'complex systems', which are inherently non-deterministic. This will require the development of new scientific approaches to understand, develop, manage and create value from the service systems of the future;
- The development and deployment of 'innovation technology' could enable a radically different way of innovating in services (and other sectors), providing greater opportunity for users and external partners to participate in organisations' innovation processes;
- These profound changes could give rise to many challenges. These include: issues of managing non-deterministic systems; ensuring security, privacy and data protection; dealing with public trust and with confidence in data quality; and ensuring resilience and reliability in service delivery.

The preceding chapters have described the importance of STEM for services innovation to date. They have presented evidence of the extent to which STEM capabilities have already contributed to the development of new or improved services. However, we believe we are at the early stages of a fundamental revolution in the range, nature and availability of services, and think that the impact of STEM on services—and *vice versa*—will increase greatly in the coming years.

Commentary on future developments is necessarily speculative and uncertainty exists about the direction, rate and extent of change. We shall not engage in predicting detailed future outcomes in this report other than by highlighting issues from trends in evidence collected during our enquiries. We outline below six key STEM-related issues for the future of services innovation.

5.1 Growing global scale of service markets and supply chains

Physical and digital infrastructures and devices are converging such that it is possible to envisage a world in which many more activities and services may become instrumented and interconnected. For example, 'cloud computing' is just one of a portfolio of emergent digital infrastructures offering the possibility to create an 'internet of services' linking with an 'internet of things'. The ability to capture near real-time data from massively sensed environments, and to share, manipulate and use this data through next generation broadband internet provides foundations for integrating, managing and delivering new types of interactive services to literally billions of people. Given even existing technologies and recent experience, these services could connect through multitudes of mobile devices and trillions of sensors embedded throughout the physical world (Palmisano 2008; Siegele 2008; Chen-Ritzo *et al.* 2009).

Thus we anticipate growing global demand for personalised digital services as users become more reliant upon powerful, mobile internet-based communication systems. This is particularly marked where services can be not only selected but also delivered electronically—the so-called 'virtual delivery'—but also occurs where selection is made via the internet and delivery of physical goods is effected by normal channels (eg via amazon.com). Companies and organisations are moving towards co-creation and development of services working with communities of users—such as in the computer games industry—harnessing the power of the many (Von Hippel 2005; Tapscott & Williams 2007). Some community-based developments are already challenging official sources of services, such as Openstreetmap's alternative to Ordnance Survey mapping.[32]

Service industries and supply chains in areas such as healthcare, education, environmental sustainability, energy, design and construction, transport and logistics are developing on an increasingly international scale, and markets themselves are increasingly globalised.

One of the consequences of recent STEM developments is that the entry costs to some markets have dropped

32 See http//:openstreetmap.org

dramatically: for example, even small firms can now use sophisticated (sometimes open source) software previously affordable only to large organisations. Because of this, we see many SMEs prospering in services where agility matters and virtual delivery of the services is possible—this is illustrated in the case of the online music business and community, Propellerhead (Jeppesen & Frederiksen 2006).

Given all this, we see significant market opportunities for innovative UK firms—large and small—operating in these spheres. But the corollary is also true: UK organisations face rapidly growing competition from overseas firms—like Amazon and Google—that, for example, develop new business models to deliver mass-customised services. As Friedman (2007) has argued, geography is much less important than previously in a world where even law services (apart from the most specialist) can be commoditised or partially tailored and supplied over the internet from new centres anywhere in the world.

5.2 Advances in STEM will have profound effects on services

As indicated above, we anticipate that services are on the cusp of a major transition or 'tipping point.' This is driven in the main by new demands and market-facing technological advances (themselves arising from earlier scientific work). Our view is partly based on what has happened in the recent past: twenty years ago we could scarcely have imagined Google, Second Life, ubiquitous globalised positioning, instant access to research on all aspects of health and online banking services (Rayport & Sviokla 1995; Battelle 2005; Castronova 2007; Au 2008; Schultze *et al.* 2008). But our belief in a tipping point in services is also based on looking ahead as scientists: the potential of recent developments in ICT—particularly communications, networking and visualisation technology—is only just beginning to be realised in services, especially those delivered in the public sector. Near-future developments may well dwarf the effects of what we have seen thus far. This is demonstrated by the open-source approach to software development and the creation of mash-ups, enabling applications to be developed, shared and to interact with each other, without breaking-down when one link in the chain is altered. Applying these same principles to services, we anticipate a revolution in delivery of services through enabling data to be shared and exploited by new partnerships and new services to be composed from sub-services and mixed-and-matched to maximise their value.

Cheaper, more efficient and pervasive computing, still greater adoption of communications technology by consumers and competitors, and convergence of technologies such as embedded intelligence and pervasive sensing and monitoring could all drive fundamental changes in many services. As we have already indicated, we expect services to shift progressively away from commoditised, mass-market approaches, and become ever more personalised and ubiquitous, with associated changes in the relationship between experts, service suppliers and customers. All of this necessitates trust on the part of customers (see Section 5.6 below) so it may well be that existing, well-known service suppliers have at least a transitory advantage because of their brand recognition and public trust in them.

All of the above does not take account of the continuing rapid advances in physical and life sciences, which will open up completely new service possibilities. We think that increasingly the economic value from scientific developments is likely to be realised in services (and the 'servicisation' of consumer products), rather than through the physical product development process alone. For example, breakthroughs in the speed and cost of DNA sequencing, combined with greater knowledge about the association between particular genes and disease risks, will have major implications in many different service areas such as personal health care, genealogy and the pharmaceutical industry (see Box 5.1). Though controversial, brain scanning is already being used as a commercial tool to understand preferences and choices through neuroscience. As we have repeatedly argued, greater personalisation in all areas of services seems certain to become the norm. Though we cannot predict with accuracy what will be available even five years from now, we know that the world will be a very different place thanks to STEM and the massive investments in it by governments in the UK and elsewhere.

5.3 Services delivered through complex systems

Dramatic changes in the nature of services will require new scientific approaches to understand, develop and manage them. As changes in technology enable closer and deeper interaction with users and greater personalisation of services—notwithstanding that they may be provided from anywhere in the world—people will become key components in the system. Combined with the increasing tendency for services to be inter-linked, their dynamic, constantly evolving nature, and their long and complex supply chains, the result is an inherently non-deterministic, complex system with 'emergent properties' that are not predictable by separate analyses of the individual components.

Indeed, it has been suggested (see Chapter 3) that one reason for the failure to foresee the near-collapse of the financial system in 2008 was the reliance on models with deterministic characteristics, which did not adequately account for the complexity and non-deterministic nature of the modern financial system.

Designing and managing these systems, and the problems they pose, will require the development of theories and tools to cope with the systems' lack of predictability. This will involve integration of knowledge from social science, management science, economics, and STEM disciplines. Insights from studies of complex systems in other areas, such as biological ecosystems, may be particularly valuable in areas as distant as financial systems (Chapter 3).

5.4 Service-based responses to major societal challenges

Developing effective solutions to many of the major intractable social, economic and natural challenges facing society (eg low carbon futures, poverty and threats to public health) will frequently require extensive scientific research. But implementing these solutions will increasingly involve services organisations. For example, quantitative evidence from massively sensed environments with real-time feedback can

Box 5.1 Impact of cutting-edge technology from life sciences on the services sector

New services based on developing technologies in the life sciences and biotechnology are likely to have a significant impact on the service sector landscape. For example, new services emerging from the field of genomics, although still in their infancy, are expected to have a profound effect on healthcare tailored to the individual (i.e. personalised medicine) and public and private healthcare systems more widely. The developing genomics service industry could also have far-reaching effects in other fields such as environmental health (e.g. via bacteria or pathogen detection/identification) and agriculture (through targeted breeding).

One of the first service companies to harness the opportunities from cutting-edge biotechnology research in this area is University of Oxford start-up Oxford Ancestors, which is involved in the field of 'recreational genomics'. Founded in 2001 by Professor Bryan Sykes, Oxford Ancestors provides a service which enables customers to have small portions of their DNA sequenced, giving them information on their ancestry. A similar enterprise is 23andMe, an American company which, in addition to providing information on ancestry, provides customers with details of inherited traits and common diseases and conditions to which they may be susceptible.

The potential market for 'recreational genomics' and other applications is considerable and the UK's competitiveness in research and technology offers an advantage in these growing service sectors. Indeed the UK research base has spawned numerous hi-tech spinouts in this and related areas. For example, Oxford Nanopore Technologies is developing a new method of high-throughput DNA sequencing. But although many of the new technologies which underpin these innovative services are developed in the UK there is no guarantee that they will be exploited here. Cambridge start-up Solexa, for example, developed its own novel method of high-throughput DNA sequencing but was acquired by US-based company Illumina in November 2006.

This brings to the fore a familiar challenge for policymakers and businesses in the UK—to ensure that conditions are in place so that promising research and early stage technologies in which the UK is highly competitive can support new and globally significant service industries. But other challenges also apply in these emerging fields. For example, the growth of markets in these areas will depend in part on the development of suitable regulatory frameworks to deal with issues such as the use and protection of resulting personal information.

be used to design and develop more effective ways of managing demand in the utilities industries.

The systems-based approach to understanding services discussed above may well be of critical importance in the development of solutions to these problems. Their complexity and scale cannot be properly understood or adequately dealt with by traditional means alone: the conceptualisation, design and implementation within silos of service solutions in complex environments is rarely effective. This has profound implications for organisations as well as individuals: governments, for example, will have to be much more 'joined up' between departments if they are to formulate policies and implement effective solutions (often through the private sector) in this increasingly complex and indeterminate world. At the very least, government has a vested interest in exploiting STEM expertise in the research base to seek to understand and model this growing complexity through use of new science and technology.

5.5 'Innovation technology' and the changing nature of services innovation

The process of innovation in services itself appears to be changing (Tether 2005). The convergence of various technologies—including eScience, simulation, modelling and virtual prototyping—provides a possible solution to the challenge of coordinating innovation processes. This new digital toolkit is sometimes referred to as 'innovation technology' or 'IvT' (Dodgson *et al.* 2005; Gann & Dodgson 2007).

Visualisation systems have the potential to extend the digital infrastructure that underpins many innovation processes, and to build upon the developments of computer-aided design and manufacturing (CAD/CAM) and 'artificial environments'. They allow innovators to look for, and experiment with, new ideas in ways that were previously unachievable. This may involve searching for specific combinations—or even outliers—in massive datasets (eg of human individuals) in which pattern recognition capabilities are enhanced by novel ways of visualising data (Gann & Dodgson 2008).

Simulation enables design and development teams to explore options and test combinations of ideas in a virtual environment. This digital simulation process can reduce the cost and time involved in combining different components and elements. It also allows more stakeholders, including lay people, customers and regulators, to become involved at earlier stages in the innovation of products and services. Other benefits include enabling much greater development of services 'offline,' via virtual sampling and testing before launch (Schrage 2000; Thomke 2003).

These developments, combined with wider knowledge of the competitive advantages resulting from 'open' or 'distributed' innovation processes, seem likely to lead to more firms engaging networks of external partners in their innovation projects (see Foreword by Seely Brown in Chesbrough 2003).

5.6 Meeting future challenges

It is scarcely surprising that such profound change as postulated above will give rise to some—at least potentially deleterious—consequences. These developing capabilities pose issues of privacy and ethical behaviour on the part of those creating databases, exploiting the results of data mining and supplying services. Surveillance techniques are already a matter of public concern; new technologies beyond RFID will exacerbate these still more. Even in current circumstances, private sector service suppliers probably know more about their customers than governments know about the citizens (who are the same people) (Zittrain 2008).

In addition, new STEM-based developments will shift the pattern of benefits and costs. For example, personalised health checks are now being offered to the public by the private sector using various scanning technologies. Their uptake by individuals concerned about possible genetically-related or other latent disorders is increasing. These tests may find previously unrecognised health problems in some individuals which would be difficult to pick up in any state-based, mass health system like the NHS. But such tests also generate a large number of 'false positives'—ie exaggerations of the health dangers—and these are already leading to an additional load on the NHS to prove them of no concern.

The big challenge for governments is thus to balance the promise and capabilities of the new STEM-derived opportunities to provide services with the retention of public trust. This demands joined-up and long-term thinking and action. Moreover, to be successful it requires contributions from scientists and social scientists, politicians, Learned Societies, and many others.

6 Discussion

6.1 Introduction

In this section, we discuss the key issues raised in the evidence gathering phases of the project and set out recommendations for ways to enhance the contribution of STEM to services innovation.

6.2 Improve understanding of services and service innovation models

Summary

- Services innovation, and particularly the role of STEM, has been a notable 'blind spot' for science and innovation policymakers. Policymakers and potential collaborators would be aided by a more sophisticated understanding of innovation in services, and in particular the relationship between STEM and service innovation;
- A better appreciation of innovation processes (and appropriate policy interventions) requires a broad understanding of the relationships between service organisations, various actors in the STEM supply chain, other non-STEM inputs, service users and customers;
- Poor understanding of innovation models and practices is compounded by the relative lack of academic and case study material and suitable statistical information available for analysis. As a result there are significant knowledge gaps and associated challenges for policymakers, innovation practitioners and potential collaborators in the STEM supply chain;
- Given the economic importance of these sectors these knowledge gaps need to be addressed as a matter of urgency. The development of services-related research communities and agendas is addressed in more detail in Section 6.5.

In his review of UK science and innovation policy (Lord Sainsbury of Turville 2007), Lord Sainsbury recommended that more detailed work was required to understand better how innovation occurs in the UK's service sectors so that policy interventions could be better targeted and more effective. Since then the CBI, NESTA and BERR [now BIS] have all published reports which have attempted to illuminate service innovation practices and processes (see Chapter 1). Other studies are underway eg the Technology Strategy Board (TSB) is exploring ways to support innovation in high value services and the Royal Academy of Engineering is conducting a study on the impact of ICT on competitiveness in the UK.

These endeavours have added to the understanding of services innovation and, at the same time, have raised the profile of services in the policy community. Nevertheless, service innovation remains poorly understood and we believe that still better knowledge of service innovation models is required.

6.2.1 Service innovation models remain poorly understood

The heterogeneity of services and the (often) fast pace of change in service environments mean that there are several developing innovation models in services (mirroring the wide range of models which apply to manufacturing). In their response to our call for evidence BMT Group (a research and technology consultancy, with a strong history in the maritime sector) provided an example of the innovation process for one of their web-based information services (see Box 6.1). This illustration shows the complex interplay of internal and external factors in the innovation process. Other perspectives on innovation also describe the growing complexity of innovation processes (see Section 6.2.2).

However, the Government's approach continues to reflect an exploitation process which is essentially linear and which is easily tracked and influenced (the Warry Report (EIG 2006) is a good example of this). Policymakers and universities must avoid the temptation to rely on a 'one size fits all' theory of service innovation.

6.2.2 Science and research in non-linear innovation models

The latest thinking from leading innovation theorists and practitioners describes innovation models which are increasingly distributed, more 'open' and often international or global in nature (see Box 1.3). In these models innovation involves many players (eg suppliers, customers, users, regulators and competitors) and is characterised by expanded and more complex value chains. Innovation can occur at many places in the value chain, often several steps removed from the most visible point.

Our own work has shown that many service innovations are made possible by pervasive 'high-tech' infrastructure, the application of deep domain STEM knowledge and the application of generic skills like numerical analysis and modelling and that, in some cases, the resultant innovation is a change in business model. Future generations of innovation model may emphasise to an even greater extent the development of new business models, based on the convergence of transformative technologies (see Chapter 5).

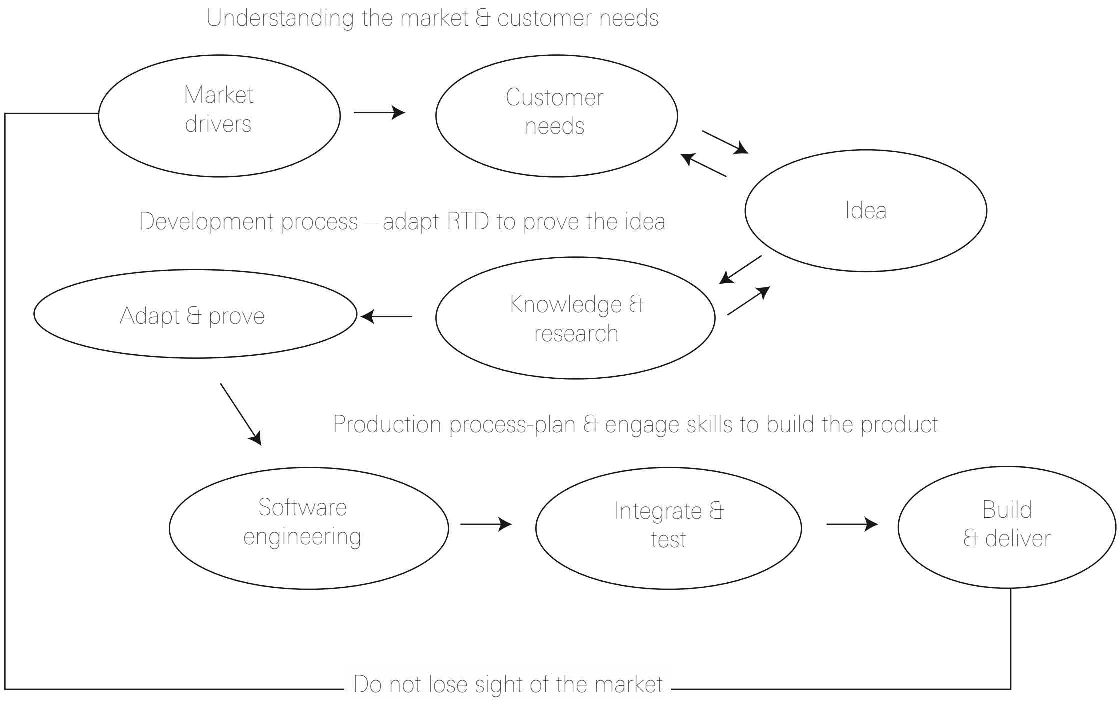
If innovation policy is to support innovation practice, it is important for Government to respond to these evolving trends. The challenge is to understand the dynamics that drive these complex models, to properly understand the role of the research base in relation to the full range of inputs and to develop policies which reflect and support these changing practices. Understanding all this necessitates abandoning the linear model of innovation.

6.2.3 Implications of changing innovation models

The emergence of more sophisticated innovation models also requires research communities and other actors in the STEM supply chain to revise their thinking and approaches to innovation. For example, universities which elect to pursue

Box 6.1 An example of a service sector innovation model

Since 1985, BMT has been involved in pioneering and developing innovative marine environment information systems. The evolution and development of these services is based on a good understanding and constant focus on market needs, proposing innovative products based on an understanding of underlying technologies and adopting new research findings that may be developed internally, externally, or in collaboration. The model below illustrates the innovation process management in BMT (reprinted with permission from BMT Group).



innovation-related missions must work out how to interact with value chains in established or emerging service areas. Researchers will need to position themselves within networks of innovators and spot the most likely and/or valuable collaborators (not always the lead or most visible innovator).

Researchers and funders must also become better at spotting opportunities for research to support and develop underpinning capabilities within these chains. This will necessitate extensive market research, the identification of key business personnel and the development of a functioning theoretical framework for innovation processes. Knowledge exchange mechanisms should recognise and support these needs (see Section 6.7).

More generally, we are concerned that policies which are formulated without reference to a sufficiently robust evidence base risk having little, or even negative, impact on services sector innovation. Understanding what works, where and how remains a big task.

We highlight several matters which require particular attention.

6.2.4 Official statistics are too crude

As outlined in the introduction (see Section 1.3.1) we are concerned that official statistics relating to the services sector presently leave much to be desired—almost all official statistics currently available are based on the 1992 Standard Industrial Classification (SIC). The 2007 SIC now being introduced is claimed in evidence to us still to be inadequately fine-grained to capture and track changing forms of economic activities in the services sector and related areas. For example, the diversification of firms' business models and the blurring of boundaries between services and manufacturing sectors limits the usefulness of current official statistics as aids to policy.

This is not a new observation. In 2004, the Allsopp Report (Allsopp 2004) for HM Treasury (which was accepted by the then Chancellor) urged that 'the core [statistical] systems need to be rebalanced to provide proper detail and coverage of the service sectors'. Since then, a number of other Allsopp recommendations have been implemented but this one has not been tackled comprehensively. We understand that this has been due to financial constraints. If so, we believe that the accurate description of three quarters of the economy merits financial support.

Recommendation 9

We urge the Office for National Statistics—and, if necessary, HM Treasury—to take the steps necessary to resolve these long-standing issues. We note that the imperative from the financial crisis has led to a substantial programme of international work on improving indicators and statistics which might predict future crises (see Chapter 3). In so far as this work results in any further changes to SIC classifications, we would wish to see that these also address the needs expressed in the evidence to us.

6.2.5 Universities demonstrate variable understanding of services innovation processes

We invited firms and universities to provide examples of service innovations to which STEM had contributed significantly. Although universities provided lots of examples, not all were of innovation. Many were illustrations of STEM-related collaboration or knowledge exchange. This is not unhelpful—these may be considered indicators of healthy engagement from which innovations may develop in time. However, it suggests a degree of confusion about the difference between knowledge exchange and innovation itself. In short, many people working inside universities appear to equate knowledge exchange with innovation.

Furthermore, a number of respondents mentioned services 'audiences' for academic outputs without citing specific partners or customers. The absence of a clear demand-side customer or driver is suggestive of an approach in which the institution is attempting to 'push' knowledge and skills towards the market—a 'broadcast' approach to innovation and knowledge exchange. This was also noted in the recent review of 'third stream funding' in HEIs, which commented that 'the extent to which Knowledge Exchange Offices (KEOs) seek out knowledge exchange opportunities for academics to pursue varies substantially within the HE sector', and that while 'KE staff are ideally placed to identify demand-led, multidisciplinary packages of research … this capability still remains elusive for most KEOs' (PACEC 2009, p71). We believe that universities' limited insights into services innovation processes hamper effective knowledge exchange.

One firm, BMT Group, specifically addressed the importance of understanding the innovation process in its written evidence;

First there is a need to establish a more formal analysis of the innovation process … and then map it onto the particular service sector of interest. I believe that there is a deep inconsistency in the understanding of knowledge transfer and innovation management across both academia and industry; and there is need for industry and academia to share a common view of the innovation process and to agree respective contributions to it.

We make specific recommendations regarding universities' familiarity with service innovation models and their knowledge exchange strategies later in this chapter (see Recommendation 24 and Recommendation 25).

6.2.6 Academic and policy literature is under-developed

Our literature review and case study analysis showed that, although the body of work on the nature of services and services innovation is growing, there is a striking paucity of services-related academic and policy literature compared to manufacturing. Though there are academic journals in which service-relevant research is published, these tend to be management and business studies journals. There are fewer outlets for the dissemination of research related to STEM-based work in service settings.

We believe that the dearth of academic literature in this area reflects the fact that services and services innovation are relatively low priorities for research funders and are perceived to be of little interest to academics. In short, research related to services is poorly esteemed in academia (an issue dealt with in further detail in Section 6.4). The paucity of academic literature also reflects (and is possibly a consequence of) the 'patchiness' which characterises academic engagement with services more generally.

Recommendation 10

Research funders must develop the body of academic work concerning services innovation. The recently established Innovation Research Centre, together with the Economic and Social Research Council should take a lead in the development of knowledge of service innovation models by commissioning and undertaking new research and analysing and synthesising existing literature and data.

6.2.7 Public services innovation is poorly understood

Despite growing recognition of the importance of innovation in the delivery of public services, understanding of innovation in that sector remains patchy at best (eg Harris & Albury 2009). This is discussed at length in Chapter 4, in which we conclude that the role of STEM in public sector innovation is still a peripheral issue. Some public agencies have recognised the role of STEM in delivering high quality public services and have successfully engaged the STEM supply chain in their innovation processes. But these examples are the exception to the rule—initiatives to foster innovation within Government have mostly ignored STEM.

In view of the importance of the public sector to national prosperity, we recommend the establishment of a team, drawn from central and local government and from the science base, to undertake detailed work on how STEM can be exploited more successfully to foster public sector innovation (see Recommendation 5). We also urge BIS and the Funding Councils to emulate the success of the Higher Education Innovation Fund with partners from the public services and the science base (see Recommendation 6) and encourage the Cabinet Office and HM Treasury to resolve the problems which arise from public sector competition with the private sector in exploitation of government's information holdings (see Recommendation 7).

6.3 The importance of STEM is underestimated

Summary

- Academic and policy studies of services innovation have largely overlooked the role of STEM. Some have claimed it is of little importance;
- This is partly because the nature and extent of the contribution of STEM is hidden from view;
- There are several reasons for STEM's low visibility in service innovation: the concept of STEM is not widely recognised outside of academia, STEM is deeply embedded within firms and their supply chains, links between services and the research base are often

informal (and sometimes secret), and service innovation processes are complex and poorly understood;

- Several measures can be taken to raise awareness of the importance of STEM in services, including the development of better statistics and surveys, and reviews of service value chains and steps to enhance STEM capabilities within and between services organisations.

Neither academic nor policy studies of services innovation have addressed the role of STEM to any significant extent. For example, reports from NESTA and BERR recognised the importance of technology in services innovation, but contained few references to other facets of STEM. Policymakers have not understood or accounted for the role of STEM in services innovation in the same way they have recognised the role of STEM in manufacturing innovation.

Indeed, some recent work has misunderstood and vastly underestimated the contribution of STEM to services innovation. NESTA's 2007 report on 'Hidden Innovation' said,

Science-based innovation—in the form of new-to-the-world products and technological processes—primarily takes place in only six per cent of the UK's economy … An 'innovation gap' has opened up between the types of innovation that matter most directly to the rest of the UK economy and the established policy interventions that are intended to promote innovation—particularly given the size and importance of the UK's service-based sectors and public sector.

(NESTA 2007, p4)

In this account, the impact of science on innovation (described narrowly as the introduction of novel products and technologies) is considered to be, if not negligible, then certainly marginal. Large parts of the UK economy, including services, have been characterised as un-reliant on STEM for their innovation activities. The evidence presented here shows that this account, and the narrative which has developed around it, is over-simplistic. Our study shows that the contribution of STEM to services innovation is extensive and widely diffused. We are convinced that over-simplistic analyses which downplay the role of STEM will reinforce an approach to innovation policy which is itself overly simplistic.

6.3.1 Hidden STEM

STEM has made many highly acclaimed and high impact contributions to service innovations—especially in technological developments which have enabled the 'pervasive infrastructure' referred to in Section 2.2. Individual scientific developments which have already precipitated major transformations in services industries and public services include:

- The development of the world wide web led by Sir Tim Berners-Lee FRS, which has underpinned many fundamental changes in the way services are delivered and consumed over the past two decades (see Section 2.2);
- The technique for DNA fingerprinting invented by Sir Alec Jeffreys FRS at Leicester University with Medical Research Council support. The technique is now used widely in different service environments including health, policing, security and environmental services;
- The game theory and mathematical modelling by UCL economists, supported by ESRC, which underpinned the government's auction of 3G radio spectrum and raised £22.5bn for the taxpayer;
- The search algorithm which was the initial basis of Google's success;
- The development of derivative and hedging products that were built on mathematics and made possible by advances in computing.

Evolving technologies like grid computing seem certain to add to this list of transformational STEM developments.

However, the full extent of STEM's contribution is hidden from view—that is to say, it is not easily visible to those outside the process, and is consequently under-appreciated by the service sector, policymakers and the academic research community.

But our work has also revealed many examples of 'hidden STEM' in the services sectors (eg Box 6.2) which support much of the 'hidden innovation' described in earlier work by NESTA (2006, 2007). Several factors contribute to the low visibility of STEM in service innovation models and practices:

- The importance of fundamental STEM underpinnings to many of the innovations in services over the past two decades are not well appreciated by many stakeholders. Even where high profile advances in computing and communications have supported service innovations, these have not always been recognised as STEM developments;
- The concept of 'STEM' is itself not widely recognised by services organisations, who tend to think in terms of capabilities rather than academic disciplines;
- STEM and innovation capabilities are deeply embedded (and hence not easily visible) in many services organisations—either internally or in their supply chains (see Sections 2.2 and 2.3);
- There are indications that STEM is 'siloed' within services organisations, either in departments or teams tasked with specific functions or within projects which are disconnected from other parts of the business (project-based working is common in sectors such as engineering and design consultancy);
- Links between services firms and academics are under-reported, because they are very often informal in nature (see Section 6.4);
- In addition, there are often high levels of secrecy surrounding services firms' engagements with academic departments and individuals;
- Service innovation models are often complex, involving relationships between multiple partners and several iterations of innovation meaning that the visible contribution of science or research in the value chain may be concealed (see Section 6.2).

Box 6.2 Hidden STEM in logistics and distribution innovations: Tesco.com and Wincanton

Tesco.com is part of Tesco, and is responsible for the internet service and delivery part of the business. Tesco.com employs 400–500 people at Head Office and 25,000 people in delivery and in stores (currently around 340 stores). Tesco.com is heavily reliant on STEM inputs, primarily through ICT.

Two examples of STEM-based innovations that have taken place at Tesco.com are the development of a new delivery scheduling system and a picking router. The delivery scheduling system is a real time scheduling operation for delivery vans that functions while the customer is using the web so that they can be offered a real delivery window. To develop this, Tesco commissioned an external mathematician who had previously worked for Tesco on other statistical and mathematical problems.

The picking router was designed for use by in-store pickers (personal shoppers who fill orders placed via tesco.com) and complements the new delivery scheduling system. The in-store pickers use a 'Teampad' which wirelessly downloads picking lists (ie what is to be picked and in what order, with respect to the most efficient navigation of the store layout) and uploads what has actually been picked. This increases the efficiency and speed of the in-store pickers as the shortest route to obtain all of the groceries is calculated and used.

A similar STEM innovation was developed by Wincanton, which designs and delivers supply chain solutions and employs 30,000 people throughout Europe. Wincanton, in collaboration with one of their customers, developed an automatic layer picking system and machines for use in their automated warehouse to help reduce costs in the supply chain. Engineering expertise played a significant role in the development of both the system and the machines.

Finally, the low visibility of STEM in services innovation processes is in part explained by the fact that services innovation is itself not fully understood (see Section 6.2). A number of these issues are discussed in detail above.

6.3.2 Making sense of the statistics

The UK Innovation Survey (DIUS 2008b) has been used extensively to measure and describe different facets of innovation performance in the private sector. The survey has proven useful in some regards, but evidence collected in the course of our study suggests that there are reasons to doubt the accuracy or completeness of some of its findings. In particular, the survey provides only a partial view of the role of STEM in services innovation, does not cover the public sector and probably underestimates the level of interaction between firms and the research base, by virtue of under-reporting and a focus on direct links between firms and academic institutions (see Sections 6.4 and 6.7). Indeed, a 2007 DTI study on services innovation noted this particular shortcoming of the UK Innovation Survey:

The evidence currently considers <u>direct</u> links to the science base only. Services may gain access through other routes (use of university graduates, through technology, input or spillovers from other firms). For example, within the knowledge-intensive services, science graduates may play an important role in knowledge transfer. Services may simply utilise different types of research. For example, experiential services use of 'empathic research', trend watching etc. may be best gathered through private sector companies.

… the <u>links between the science base and services cannot be fully understood by an examination of the available survey data</u>, and a wider consultation with service industries may be beneficial.

(DTI 2007 p11, emphasis added)

Our inquiries demonstrate that these suppositions were correct: services do access STEM and other knowledge through university graduates, technology, and informally from the STEM supply chain.

Recommendation 11

We recommend that BIS should not rely on the UK Innovation Survey alone to assess the extent and state of links between the academic STEM community and the services sectors. Specifically, we endorse and repeat a recommendation first made by the Council for Science and Technology in 2003 (CST 2003) that Government should undertake a large-scale review of service value chains to understand where the key intersections with the research base occur. This will provide a more detailed picture to complement (or balance) the picture painted by the UK Innovation Survey.

6.3.3 Understanding the role of 'embedded STEM'

Many services innovations depend upon technological developments which originate elsewhere in the value chain, and which are ultimately STEM-inspired or dependent. In this way, STEM is 'embedded' in technology acquired by services firms. Firms also access STEM through suppliers in the form of consultancy or technical support. Internal R&D, often with a significant STEM component, is a major enabler of innovation in some firms—especially knowledge-intensive services. In some cases, this lessens the need for collaborations with external organisations, though (as discussed in Section 1.6.1) internal R&D is often a pre-requisite for profitable external collaborations, insofar as it supports the development of 'absorptive capacity'. We note in Chapter 3, however, that an overwhelming concentration on internalised R&D can have major deleterious effects (in that example, for the banking industry).

Recommendation 12

Given the apparent significance of 'embedded STEM', a large-scale review of service value chains (see

Recommendation 11) should be used to explore ways that STEM capabilities within or between services organisations can be leveraged and their contribution to innovation processes enhanced. The Royal Society would be happy to advise BIS based on the information and experience gathered in the course of this study.

This work should be undertaken by BIS and relevant Trade Associations (perhaps in association with the R&D Society). This work should be linked to STEM skills assessments undertaken by Sector Skills Councils (see Recommendation 18). A key audience for this work should be private sector service organisations, many of whom are unaware of the potential contribution of STEM to their own innovation successes.

Recommendation 13

BIS and the Research Councils must use the information garnered from these studies to ensure that future science and innovation policies move beyond the linear model of innovation. Policies must better recognise the complex innovation ecosystem that applies to services and the significance of 'embedded STEM'. This should help redress the balance of science and innovation policy, which has tended to focus very largely on the university system, with metrics that do not capture much of the important informal inputs (see Section 6.4).

6.4 Engagement with the public research base

Summary

- Services firms tend to innovate in more external and interdependent ways than manufacturing firms, but only a small proportion have direct links to the research base, giving rise to the impression that the research base has little to offer to the majority of services organisations;
- For some services organisations, however, links with the research base are critical to their innovation processes—even for some firms for whom STEM is not a core part of their business;
- The publicly-funded research base could play a more significant role in innovation in services than it currently does. The paucity and weakness of existing links represents a missed opportunity for both services organisations and universities;
- There are a number of barriers to effective engagement, including mismatch of expectations, differing cultural norms, poor understanding of services innovation processes in academia, low esteem for services-related research, and poor alignment of objectives between businesses and academia.

The role of the public research base in services innovation is, in most cases, an indirect one—only a small proportion of services firms have direct links with universities or public sector research institutes. The research base can input at several 'nodes' in the innovation value chain, and indirect links—such as the flow of skilled graduates and the diffusion of knowledge and technology via innovation intermediaries such as suppliers and consultants—are often more important than direct ones.

Indeed, the general characteristics of services innovation and the dynamics which shape them (for example, rapid development, often driven by customer needs or directly by users, often protected by 'secrecy' and unlikely to be patented, sometimes incremental in nature, a solution to a specific problem), mean that innovation capabilities (including STEM capabilities) are often internalised within organisations, kept close at hand in the supply chain or are acquired in the form of bought-in expertise or technology. Universities are, typically, not well placed to respond to or engage in these processes.

For a few firms, however, direct links with the public research base are critical to their innovation processes—even for some 'type 2' organisations (see Section 1.2) for whom STEM is not a core part of the business. Some organisations' innovation processes have been transformed by developing deep and well-integrated networks with academia (see Box 6.3). The experiences of these firms, and others that told us they would like develop closer links with the academic STEM community, suggest that the publicly-funded research base could play a more significant role than it currently does. We share the view expressed by the Council for Science and Technology in 2003 (CST 2003), in that we do not see the weakness of links between services and the research base as especially problematic; rather, we believe that this may represent a missed

Box 6.3 STEM, universities and innovation in the services sector

Many examples of innovation sparked between universities and businesses are described in the responses to our call for evidence. Here we highlight three examples to show the range of activities which already exists.

(a) Scottish universities and the Police

The Scottish Institute for Policing Research (SIPR) is a strategic collaboration between twelve of Scotland's universities and the Association of Chief Police Officers in Scotland, led from the University of Dundee. It is designed to create a range of opportunities for conducting relevant, applicable research to help the police meet contemporary challenges through innovation and for achieving international excellence for policing research in Scotland. The activities are organised around three networks: police/community relations; evidence and investigation; and police organisation. SIPR brings together university researchers working in at least 15 different disciplines—from forensic science to psychology, computing, to international relations, criminology to human geography—to work with the police to undertake high quality, relevant research and to ensure that such research provides a robust evidence base to inform policing policy and practice.

A key aim of SIPR has been to bring about a step change in research capacity by using resources to appoint new lecturers, post-doctoral research assistants and PhD students.

(b) The University of Manchester Centre for Service Research
This recent development—relevant because it demonstrates the evolution of Higher Education thinking—has identified service design and technology and knowledge intensive business services as areas for research. The Centre plans to develop reliable UK economic data on knowledge intensive service activities to underpin service innovation. In addition, it has recognised that the academic curriculum will need to be shaped to meet the needs of the services sector. A Masters course in Service Design, Management and Innovation has been created to give students the ability to apply scientific, engineering and managerial methods and tools to identify, design and deliver and evaluate innovative services.

(c) The University of Portsmouth and rescue services
A university human physiology team has made advances in the analysis of the response of the human body to extreme conditions, particularly heat and cold. Contracts with a number of organisations, including the Royal Navy, the RNLI and service companies working on oil platforms in the North Sea, have led to the improvement of life-saving equipment and survival clothing for those who fall into extremely cold water. The same team has worked with the Fire Service on the clothing needed for protection against extreme heat. Both of these activities have enabled the rescue services to operate more successfully and to save more lives. In addition, the team has advised athletes on ways to improve their performance in extremes of temperature, including advice to the 2008 Olympic squad.

opportunity for services to capitalise on the available STEM supply chain, to innovate more extensively and for universities to extend their range of influence.

Many other HEIs already appear to be engaged in work that could potentially benefit innovative services organisations. Some examples from responses to our call for evidence include the:

- University of Sussex—undertaking research in digital security, data analysis and visualisation;
- University of Exeter—undertaking research in real-time data acquisition and processing, analysis and feedback, and high-density data storage;
- University of Surrey—developing assisted living technologies such as remote patient monitoring.

6.4.1 Barriers to effective engagement between services and the public research base

Our evidence highlighted a number of barriers to effective engagement which may be restricting the role that the public research base plays in services' innovation. Broadly speaking, we find that a mismatch of expectations and differing cultural norms can prevent or hamper collaboration.

One of the main constraints is that, on balance, the UK research community is not responding to (and is at risk of being out of touch with) new and emerging innovation models and practices in services (see Section 6.2). Though there are some notable exceptions, the academic community appears to be largely unaware of the opportunities that new (increasingly 'open') service innovation models present.

Where problems were reported, a recurrent theme was the poor alignment of objectives, expectations, timescales and incentives between businesses and academics. Two commonly given examples are:

- Services businesses often want rapid answers to specific questions, whereas academics typically want to tackle more intellectually demanding questions over longer time-scales;
- While academics normally wish to publish data and information, companies may prefer not to do this, as they benefit from secrecy in the short term. This, and other issues relating to intellectual property rights (IPR), were identified by some services organisations as barriers to effective collaboration. Others took steps to agree terms for IPRs arising from collaborative work at the very outset of their relationships, thereby nullifying the potentially damaging effects of disputed IPR on future work. By comparison, very few universities thought of IPR as a major problem in their engagements with services organisations, though one university did call for a wholesale review of IPR.

Moreover, certain other aspects of academic cultures and structures appear to discourage academic engagement with services issues. These issues are discussed in greater detail below.

Service-related work is poorly esteemed
We encountered several references to the low esteem in which knowledge exchange generally, and work with services organisations in particular, is held within academia. For example, many outside and inside the academic community have pointed to the ossifying effect of the Research Assessment Exercise (RAE). While a valuable trigger to force out third rate research when first introduced, in focusing on the outputs of papers in academic journals as a measure of quality it appears to have undermined engagement with activities perceived to be of low status (as in many elements of the services sector); the relative paucity of high reputation journals in the field may also have contributed. It was claimed that there was not equality of recognition for work carried out in services sectors by STEM researchers/postgraduates.

Recommendation 14

We agree with the view expressed by many contributors, including the Research Councils, that the RAE did little to encourage engagement between universities and top class STEM innovators in services, and may even have discouraged academics from collaborating with service innovators. We strongly recommend to the Higher Education Funding Councils that the new Research Evaluation Framework should not replicate this unfortunate situation.

Incentives for collaboration are pitched 'at the wrong level'
Almost forty universities or university departments responded to our call for evidence. Although the majority of links with services organisations reported by universities tended to be 'formal and direct', the importance of informal one-to-one

relationships and personal 'chemistry' was widely highlighted in evidence received both from academics and businesses. This is consistent with the message from the recent review of the Higher Education Innovation Fund (HEIF) for HEFCE (PACEC 2009).

Many successful interactions are built on, or include an element of, personal relationships between individual points of contact—individual academics and a project leader in a services organisation or links initiated or brokered by alumni, for example. These links often occur with little reference to university management or dedicated knowledge exchange offices (eg Technology Transfer Offices). This is another example of the 'hidden' contribution of STEM.

These informal links offer a degree of flexibility, can be very user-led and allow for the development of greater or more formalised collaborations. Indeed, evidence collected during the project clearly shows that, once established, relationships have a tendency to grow and diversify in nature. Napier University, for example, said formal relationships (eg consultancy, KTPs) often develop from informal ones. The University of the West of England reported that an inquiry triggered by an alumnus led to a collaborative supply chain research project. Brunel University said that members of staff visit every student on a placement 'facilitating knowledge transfer between the company and the University, and giving rise to consultancy and other end user engagement activities'. The University of Leicester said that 'informal relationships play an important part in the development of more formal activity, indeed most are set-up through individual academic contacts with business.'

So, it follows that some incentives and rewards for engaging with users need to be pitched directly at the level of the individual academic, and not solely at the institutional level. Indeed, the recent review of HEIF (see above) found that most academics engaging in KE activities are motivated by benefits to their 'core activities' or the strategic mission of the HEI, rather than financial rewards, and noted that this has implications for the design of incentive structures for third stream activities.

6.4.2 Greater dialogue and questions of culture

Several organisations who provided evidence called for greater dialogue and information sharing between HEIs and services organisations as a way to foster improved relationships and understanding of innovation processes and culture, beyond the formal mechanisms of 'knowledge exchange' currently in place (see Section 6.7).

The essence of successful engagement is two (or more) way exchange and identification of mutual advantages and benefits. This implies a commitment of time on the part of firms too. One insurance firm told us 'We need to see more enlightened companies who are prepared to invest sufficient time and resources (supported by the right philosophy and structures) to enjoy the opportunities of innovation with the STEM community'.

6.4.3 Competition between universities and services organisations

Although most of this chapter focuses on *barriers* to engagement between universities and businesses, we heard of one instance where the opposite situation was deemed to be a problem: levels of engagement were such that universities were competing with small companies in offering services to other organisations.

One company, a design consultancy, told us that initiatives such as innovation vouchers, designed to encourage businesses to engage with 'knowledge providers' (generally universities), were frequently being used to commission web or product design services from university design departments. It was claimed that in effect the taxpayer was subsidising unfair competition between universities and design consultancies, which are generally not eligible to accept innovation vouchers.

6.5 Build and support services research communities and agendas

Summary

- STEM will play multiple roles in enabling, stimulating and supporting service-based responses to many of the major social, economic and environmental challenges we face. Greater engagement between services and academia is necessary to ensure that the potential of STEM is fully realised in areas such as health, energy, environmental, information and knowledge systems, which represent considerable opportunities for the UK;
- A number of interfaces already exist between academia and service organisations, drawing on academic expertise from different departments and frequently receiving funding and leadership from services organisations;
- However, support for such efforts appears to be largely piecemeal, with the exception of TSB Innovation Platforms and elements of the Research Councils' cross-cutting themes. The scale of current efforts does not match the size of the opportunity or reflect the UK's strengths in research and business;
- New 'Grand Challenges' and research agendas are required to establish an 'ecosystem' of service-related research and tools. Existing programmes should be expanded to encompass services where appropriate.

As outlined in Chapter 5, we believe that the relationship between STEM and services will change dramatically in the coming years. As a result there will be multiple roles for STEM—to help solve major social, economic and environmental challenges, to help navigate and sustain innovative new service business models and to help support the future competitiveness of innovative services nationally and globally.

In light of these challenges and opportunities, we believe it is necessary to increase the scale of cooperation between services and the academic research community (including the STEM communities) by developing common research agendas and building research communities.

6.5.1 The current situation

In the course of our evidence gathering we learned of research and other activities in areas such as visualisation, human-systems interfaces and supply chain logistics that could be applied much more widely in service settings. We also learned of a number of university-based research initiatives that are uniquely service-related or which have dedicated services components.

Many of the examples we came across are bespoke interfaces between academia and services organisations, which are intrinsically multi-disciplinary and draw on academic input from various departments and, in some cases, different institutions. There is often a significant leadership role and/or financial contribution from one or more services organisations (see Box 6.4).

The existence of these initiatives is a welcome sign that parts of the academic community are organising themselves to address service-related issues. Also welcome is the active involvement of services organisations in the development of research agendas and curricula and the support lent to these various initiatives by research funders such as the Research Councils. The investments that Research Councils have made and are intending to make in research relevant to the services sector (for example, via the RCUK Digital Economy Programme[33] or ESRC's Retail Industry Business Engagement Network[34]) are set out in their comprehensive collective submission to the Royal Society's call for evidence. In these and other initiatives the UK has some valuable building blocks—the foundations of a nascent services research community in academia. These individual initiatives have the potential to contribute to a more coherent view of services and to the advancement of services research agendas.

But with the exception of the TSB's Innovation Platforms and elements of the Research Councils' cross-cutting themes, the support from funding bodies appears to be largely piecemeal.

Box 6.4 The MAN Group and Oxford University

In September 2007 the Oxford-Man Institute of Quantitative Finance was established as an interdisciplinary research centre in the University of Oxford. Man Group is a global provider of alternative investment products for private and institutional investors. It provided three forms of support; a grant of £10.5m to cover the first five years' core costs, £3.3m to permanently endow a chair and (perhaps most importantly) the Man Group's own research laboratory co-located with the Institute to provide practitioner insights. Some 70% of the Institute's faculty and research students are members of the Mathematical, Physical and Life Sciences Division of the University—ie STEM inputs are central to the new Institute's ability to produce new insights and innovation. The Institute conducts curiosity-driven research and approximately one third of the research laboratory members regularly publish articles in academic journals.

33 The Digital Economy Programme is an RCUK cross-research council programme, designed to support the transformational potential of ICT across business, society and government. The programme will invest £46M in research in 2008–09, and up to £34M in training. See: http://www.epsrc.ac.uk/ResearchFunding/Programmes/DE/Introduction.htm

34 See: http://www.esrcsocietytoday.ac.uk/ESRCInfoCentre/research/CapacityBuildingClusters/RetailCBC.aspx?ts=1

In our view, this support could be more effective if combined or strategically aligned to clearly identified challenges. The scale of the ambition should match the size of the opportunity. Current efforts, though welcome, do not reflect the comparative advantage enjoyed by the UK (in terms of the abundance of relevant, excellent science), the proportion of the workforce currently working in services or the economic advantages to be gained from developing world leading innovative services (see Section 5.1).

6.5.2 Greater scale and convergence is required

At present the academic services research community is fragmented and largely uncoordinated. Greater convergence and scale is required—the building of 'critical mass'—to accelerate the development of service-based responses to many of the intractable problems faced by modern societies, economies and business. For example:

a) Developing low carbon energy systems.

b) Healthcare (see Box 6.5 for a specific example about the development of a one hundred year health record).

c) The stability of interdependent financial systems (see Chapter 3).

We believe that it is necessary to:

- Establish UK and international research communities in services innovation (a stronger UK research community is probably a necessary precursor);
- Develop collaborative international research agendas in services-related fields;
- Ensure that opportunities to exploit STEM in services are properly recognised;
- Align research and market opportunities;
- Ensure parity of esteem between services-related research and academic research in other areas;
- Develop multi-disciplinary capabilities.

We set out below an approach to help achieve these aims. The success of these measures will also depend on the development of appropriate skills (see Section 6.6) and improved engagement between services and the academic community (see Section 6.7 for more detailed comments on knowledge exchange).

6.5.3 Grand Challenges in services

Here, we outline a structured approach to the development of research agendas based on a 'Grand Challenge' model. We believe this kind of approach would provide the necessary stimulus and framework for large-scale research efforts and at the same time attract the talent and ideas needed to underpin growing research communities. Over time, we would expect that the establishment of high-profile research priorities in the form of a series of Grand Challenge programmes (similar to some existing TSB Innovation Platforms and cross-cutting Research Council themes) would contribute to increased esteem for services-related research more widely (see Section 6.4).

Box 6.5 Developing Grand Challenges—the 'one hundred year health record'

Grand Challenges could be formulated on the basis of a question, for example 'what would it take to do develop a one hundred year health record?' Posing the question entails the specification of some conditions: for example, the record must be accessible worldwide, must be applicable in different health systems and be 'smart' enough to span a patient's lifetime while avoiding technological obsolescence.

In this case, the solution is only partly technological. It would entail the development of a functioning framework comprising new interoperable standards and protocols to enable the record to be accessed and utilised anywhere in the world.

Amongst other challenges, this would require at least multi-level security (for various classes of readers); data storage standards and media; medical semantics for interpreting data; provenance and personal identity services to check who is allowed to access and modify records; language translation; integrity services to guarantee a high level of accuracy; reliability and replication services to guarantee availability; imaging interchange standards for X-rays, ultrasounds, MRI scans, PET scans, etc.; pathology lab standards and semantics; and drug standards and semantics.

Similarly, it would require the alignment of legal and regulatory frameworks, not to mention the alignment of incentives for different research communities and suppliers.

The example of the development of a one hundred year health record (see Box 6.5) shows how the identification of a specific challenge could stimulate the alignment of technologies, technical competences and disparate research agendas.

Grand Challenges have the advantage of concentrating funding on intractable but real problems and attracting parallel investments from other public and private sources—which will be a necessary pre-condition for the development of a coherent services research community in the UK.

The suggested approach is not dissimilar to the aspirational, challenge-based model used by the United States Defense Advanced Research Projects Agency (and to a lesser extent within the UK's Ministry of Defence). In both cases, these mechanisms are closely linked to public procurement and financial support for demonstrator projects to help accelerate the identification and development of solutions. As has been well documented elsewhere (CBI/QinetiQ 2006; Georghiou 2007; HM Treasury 2007), such strategic procurement is a powerful tool that could be used to establish routes to market for innovative products and services.

The UK Research Councils and the Technology Strategy Board (TSB) already administer large-scale, challenge-oriented programmes (see Box 6.6), several of which have explicit service-related elements to them. There are advantages in using these existing models as frameworks for the identification and establishment of further service-related Grand Challenges. However, concerns have been raised about the modest extent to which service organisations have engaged in the formulation of the existing themes and their subsequent operation. In addition, TSB initiatives are not widely known by or participated in by services firms (see Section 6.7). We bear this in mind in developing our recommendations below.

We believe that these established models may represent a suitable framework for the development of service-related Grand Challenges and we recommend two courses of action that should be pursued in parallel.

Box 6.6 Existing challenge-orientated research programmes

(a) Technology Strategy Board Innovation Platforms

The TSB Innovation Platforms, initiated in 2005, draw together business, government and research perspectives and resources to generate innovative solutions to challenges facing the UK. They aim to accelerate the speed of technology development in key areas, from fundamental research through to exploitation and create potential export markets for UK business. Six specific areas have been targeted by the TSB:

- Intelligent transport systems and services;
- Low impact buildings;
- Assisted living;
- Network security;
- Low carbon vehicles;
- Detection and identification of infectious agents.

Each of the Innovation Platforms are at different stages of development, with the network security and low carbon vehicles platforms being at a more advanced stage than the others. Research in each of these areas is expected to mature over time at an accelerating rate, as knowledge is built up and technologies refined. These platforms are delivered in association with the Research Councils, Regional Development Agencies and others in a number of ways including roadmapping and prioritisation, networks and flexible funding models.

(b) RCUK Cross Council Themes

These are designed to address the major research challenges over the next 10 to 20 years using novel, multi-disciplinary approaches across the different research councils. Six priority areas have been identified, which are:

- Energy;
- Living with environmental change;
- Global uncertainties; security for all in a changing world;
- Ageing: lifelong health and well being;
- Digital economy;
- Nanoscience through engineering to application.

Recommendation 15

Research Councils and the TSB should expand their portfolios to encompass new service-related Challenges. In doing so they should examine whether new approaches (other than cross-Council themes and Innovation Platforms) are more appropriate to meet these challenges and, if so, develop options for alternative approaches.

Recommendation 16

The Research Councils and the TSB should evaluate existing programmes to ascertain whether they adequately address opportunities in services, whether existing programmes could be enhanced by additional service-related elements, and whether they are benefitting from sufficient input and engagement from service organisations. Similarly, the Research Councils and TSB should ensure that future programmes adequately support emerging service industries and consider the role that service-based responses will play in meeting major economic and social challenges. This is particularly important given the apparent decline in services organisations collaborating with the public research base and an increased perception of barriers to collaboration (see Section 2.5).

To initiate the identification of new Grand Challenges and research agendas the TSB and the Research Councils should commission a series of workshops to bring together leading international researchers from disparate, relevant fields and key research users and service developers. The objective should be to identify common pre-competitive issues and to develop technology and service roadmaps that might form the bases of large-scale research agendas. The Royal Society would be pleased to work with the TSB and Research Councils to take forward this recommendation. These steps should enable service developers, service users, research communities and research funders to combine to create an ecosystem of service-related research and other outputs that are currently a long way from the market (for example, diagnostic tools and analytic model building capabilities in areas such as epidemiological modelling of the spread of infections and the development of response scenarios).

The active collaboration of the key parties will also be vital to identify emerging problems which could inhibit or slow down the development of innovative services—issues such as the impact of data integrity, data security and human trust in services and the machinery of systems (the infrastructure itself). The latter was explored with specific reference to the impact of ICT on healthcare in a previous Royal Society study (Royal Society 2006b).

To succeed, service-related Grand Challenges will also require—and thereby provide a stimulus for—the development and close alignment of numerous cross-cutting theoretical and intellectual competences in areas such as:

- Analysing, quantifying and managing risk;
- Managing uncertainty in modelling and simulation;
- Grid computing;
- Quantitative data analysis, data security, standardisation or validation of data sets (eg where firms are meshing together data sets from different sources);
- Service design (see Box 4.3);
- Queuing theories;
- Dynamics in human-systems interaction.

Recommendation 17

It is essential that Grand Challenges include provision to develop and align these or similar competences. To do so would add value across the range of Grand Challenges by sharing knowledge and expertise and reducing costs. Options would include the physical co-location of resources and expertise in centres of excellence or the establishment of virtual centres or networks (perhaps using the Knowledge Transfer Network model).

6.5.4 Align research and market opportunities

STEM has spawned entirely new global services (eg Google, Amazon) and is a crucial enabler of many others. As discussed in Chapter 5, service industries and supply chains in areas such as healthcare, education, environmental sustainability, energy, construction, transport and logistics are developing on an increasingly international scale, and markets themselves are increasingly globalised. As such, they represent significant market opportunities for innovative UK firms operating in these areas but also threats given the reduced entry price to many markets which STEM has enabled. This combination of opportunity and threat should be recognised in research priorities, public policy, education and training programmes.

The TSB's Innovation Platforms and the Research Councils' cross-cutting themes have been, to varying degrees, business-facing. It is essential that any Grand Challenges in services areas have similar regard to market opportunities and application. If correctly conceived and orchestrated, Grand Challenges such as the 'one hundred year health record', outlined in Box 6.5, could help to accelerate business entry into new and emerging markets. This brings to the fore the need for active engagement by services in these and other knowledge exchange activities (discussed in more detail at Section 6.7).

At the strategic level this requires the intimate involvement of service organisations in setting the overall direction and themes of challenge programmes and in identifying specific research and education priorities. At the operational level this means that service Grand Challenge programmes should be inherently collaborative, financially attractive and must be easily accessible to firms. Indeed, the programmes should, where appropriate, be demand-led. In terms of outputs, Grand Challenge programmes should be focused on developing tools and suites of solutions for industry as well as on graduate or postgraduate training and collaborative research programmes.

Problem-solving is clearly important to many services, but we have also observed that services are becoming more strategic in their innovation activities as competitive advantages are sought over longer timescales. Innovation models are diversifying to encompass problem-solving (tactical innovation) and longer-term considerations (strategic innovation)—for example with regard to issues of environmental sustainability or whole life cycle approaches to services (eg Rolls-Royce, Section 1.3.1). In other sectors too, service firms are engaged in fundamental research. For example, the Oxford Man Institute (see Box 6.4) strives to be 'academically outstanding, developing into the leading centre in our field'. To this end, the Institute conducts curiosity driven research for the public domain and Man Group has co-located its corporate research laboratory with the Institute. By contrast, a leading provider of advice to the insurance industry argued that there is 'a negligible amount of research in academia' in their specific field of interest or expertise, necessitating the conduct of in-house research by a team of more than fifty doctorate-level scientists (although other organisations in the insurance industry do make extensive use of relevant academic research). It is important, then, that the research components of Grand Challenge programmes retain the scope to address fundamental research of importance to services and that their existence and programmes are made very well known to the target audiences.

6.6 Develop a truly multi-disciplinary capability

Summary

- Services organisations place a high value on STEM-trained employees but employers identified problems with workforce skills, highlighting particular difficulties in finding employees with good 'multi-disciplinary' skills—which are essential in most modern service organisations. There was also some dissatisfaction with university leavers' 'soft skills', such as team-working and communication;
- Three distinct skill sets are valued by employers: 'deep disciplinary' knowledge of a particular STEM discipline and associated analytical skills ('I-shaped' people); an overview of a range of subjects, without deep expertise in any particular one ('jacks of all trades' or 'hyphen-shaped' people); and deep knowledge of one discipline, combined with some knowledge of other subjects (STEM and non-STEM), as well as associated professional skills and tools such as ICT, business awareness, and analytical skills ('T-shaped' people);
- The evidence we received suggests that universities are generally doing a good job at producing I-shaped graduates. Courses such as service science, management and engineering (SSME) are developing which will produce hyphen-shaped graduates. But there is little current capability for training T-shaped people (with the exception of a small number of postgraduate programmes);
- Anticipated developments in services and the importance attached to T-shaped people by the many organisations responding to our inquiry means it is essential that Higher Education Institutions give this serious consideration. We make a number of recommendations as to how this could be taken forward, and how existing training could be improved to recognise better the skills required in the likely working environments of most STEM graduates.

6.6.1 Skills for innovation

Rapidly changing markets, the adoption and diffusion of new technologies and practices and the pressure of competition place ever-increasing demands on businesses, including rapidly changing skills requirements. Evidence shows that firms depend primarily on workforce skills to gain a competitive advantage and improve business performance—the CBI has said 'our surveys show that employers value workforce and management skills as being the most important factors in gaining competitive advantage' (CBI 2005). Many innovative services rely on the regular intake of good quality STEM graduates to refresh their innovation capabilities (see, for example, Box 6.7).

Box 6.7 Google

Google is the apotheosis of how innovation in STEM can transform a few people into a world-leading services company. Google evolved from a research project by Larry Page, a PhD student in the Computer Science department at Stanford University. Page's dissertation explored the mathematical properties of the web, treating its link structure as a huge graph and the number and nature of links to a particular page as an indicator of its importance. From this, Page and Sergey Brin (another Stanford PhD student who joined the project later on) evolved a page ranking algorithm and a search engine based on the rankings, forming a company based on the technology in 1998 in a garage in Silicon Valley. From these small beginnings, the company has since grown to over 10,000 employees worldwide.[35]

While Google originated in California and has its headquarters there, it employs over 600 staff in the UK, including over 100 software engineers who develop a range of products, including next-generation mobile applications, information-retrieval algorithms, large-scale cluster computing, systems software and several innovative search products. It is very clear that STEM skills—exemplified by those of the two founders and the CEO—are central to Google's innovation and the services they now provide to hundreds of millions of customers. In addition to the software engineers, many analysis and sales staff have a mathematical or other quantitative background. Thus STEM expertise is critically important to Google. In its evidence to this inquiry it stated:

'The main challenge is to ensure that there is a good supply of people with STEM skill sets as they are key to the development of the firm. STEM expertise is endemic within Google and while the firm can never be sure where the next innovation or product is going to come from, it needs a good supply of university graduates with new ideas and concepts.'

Accepting that the primary role of universities is to educate and not simply to equip students with skills for employment, there is still an important role for universities to play in meeting skills challenges, particularly as eighty-two percent of core STEM first degree graduates going into full-time employment in 2006/07 entered services organisations (see Section 2.3).

Our evidence showed that universities also have a role to play in the development of workforce STEM skills and that some major employers understand that situation. For example, BT established the BT Centre for Major Projects Management at Oxford University's Saïd Business School specifically to "address the shortage of suitably qualified and experienced personnel in the area of programme management". Moreover, BT is helping to promote a new MSc in Major Project

35 http://www.google.com/intl/en/corporate/execs.html

Management throughout their value chain, ie to suppliers, collaborators, clients etc. In this instance, BT is using a university partner to help develop an 'ecosystem' approach to the development of STEM knowledge and skills throughout the value chain. Several other universities and research centres told us that they are providing continuing professional development or workplace learning to service employers. In at least one case, the research centre is providing a modular course which leads to professional certification.

The continuing development of workforce STEM skills is likely to grow in importance as demographic changes over the next decade will mean a decrease in the number of 18 and 19 year-old home students entering UK universities (UUK 2008). Unless they recruit from overseas, firms will be less able to rely on graduate and post-graduate recruitment to refresh their STEM capabilities and will increasingly need to up-skill and retrain the incumbent workforce.

6.6.2 STEM skills and service innovation

A 2006 Royal Society report into the supply of and demand for STEM skills (Royal Society 2006a) observed that recruiters of STEM graduates have traditionally looked for technical knowledge and intellectual capability in those that they employ, but that there has been an increased emphasis in recent years on combining subject expertise with good interpersonal skills, practical employment experience and commercial understanding.

Our current study bears out this observation in relation to many service sector employers. The application of deep disciplinary knowledge (for example, environmental science, geology, medicine, chemistry, meteorology etc) remains important, especially to providers of specialist technical expertise and services, eg risk intermediaries providing services to insurers, or engineering design specialists (see Box 6.8 for an example from Arup).

Box 6.8 Arup

Arup is a British-based engineering services company with 10,000 employees world-wide, about 6,500 of them being based in the UK. The company is chiefly concerned with the engineering design of buildings and structures.

Architects and clients push building innovation in seeking iconic buildings which often extend the use of materials in novel ways and/or which demand step-changes in sustainability. The role of design engineers is to meet these requirements safely, efficiently and effectively. To achieve this, Arup has extended a scientific approach to construction design and monitoring called the 'observational method'. Using this approach designers build on existing standards and design codes and previous monitoring results by using incremental improvements and observing outcomes as they occur. If the monitoring data are consistent with predictions then work continues. If the monitoring data is outside the design predictions then predefined contingency plans are triggered.

The science of design involves three-dimensional modelling, and the inputs to this include geology, hydrogeology and geophysics, with Finite Element Analysis being widely used, for example to anticipate how sub-structures and soil conditions interact.

Half of all Arup staff have STEM qualifications, with a quarter having MSc or PhD degrees; several CASE and EngD studentships are supported at any one time. Company profits are reinvested in the form of bonuses to staff and in buying time to complete pure research. Arup has moved progressively from devising their own software to using commercial tools; the cost of development of these is spread over many more users.

The National Stadium, Beijing, used initially for the 2008 Olympic Games. Reproduced by courtesy of Arup.

Also deemed important are well-honed problem solving skills and the ability to undertake rigorous logical analysis (a skill gained from exposure to and familiarity with the deductive process).

But for many firms, the main contribution of STEM is the deployment of generic skills in numerate analysis, mathematical and computer modelling, database design and management and data mining etc (see Section 2.3). This is particularly the case for firms engaged in process or service improvement, where the innovation process may be incremental and therefore not very visible (for example in improvements to existing computer software). Similar observations were made in our report '*A Degree of Concern*' (Royal Society 2006a) which showed that STEM graduates who elect to pursue non-STEM careers often benefit from the high level of analytical, mathematical and modelling skills that they gained on such courses.

6.6.3 Areas of concern

There is some dissatisfaction with the quality and quantity of STEM skills available to employers in services (see Section 2.3). In some cases the concerns are about the lack of 'soft skills' such as ability to work effectively in teams and presentation skills. These concerns are not restricted to services employers, nor do they apply only to STEM graduates and can be addressed in standard undergraduate courses or career development.

Of greater concern were numerous reports of shortages of specialists in certain disciplines (eg engineering) or absences of graduate courses in areas such as market analytics. In some cases this is leading firms to recruit graduates educated overseas. This has been commonplace in highly globalised services like financial services, but is now extending to other employers.

However, we have been most struck by the importance attached to multi-disciplinary skills and, in particular, by the strength of criticisms from business (but also academia) of silo thinking and activity in UK universities. A virtually unanimous set of comments from the business community was that they valued high quality domain-specific skills possessed by graduates of UK universities but were often disappointed in the so-called 'complementary skills' they possessed.

In their evidence to us, the Research Councils' reported hearing the same message from service sector employers—that 'T-shaped people' are in short supply (ie people who have deep domain knowledge and understanding but also have a breadth of skills and knowledge outside this domain). We consider below what 'T-shaped people' mean in the context of the service sector.

One current example is provided by dunnhumby (see Box 2.5 on page 17). The firm employs 850 staff, some 150 of whom are graduate analysts working with the SAS statistics package, and a few are PhD statisticians. The company needs not only proficiency in maths and statistics, but also an interest in understanding people's behaviour, an ability to communicate well and business acumen. They have found it essential to have staff who look for insights, rather than simple statistical summaries. dunnhumby draw their staff from various countries, especially from universities with courses in marketing analytics (in which the company considers the UK to be weak).

It is clear from our discussions with academics and business people that integration of knowledge and skills across STEM subjects and with other disciplines poses problems within academia. It is widely recognised that UK universities are not, on the whole, organised to provide an effective multi-disciplinary capability.

The UK was claimed to have no equivalents to the MIT Media Labs, Stanford MediaX, the Brookings Institute or the German Fraunhofer Institutes. Notwithstanding the welcome development of new multi-disciplinary entities like the Hartree Centre, the University of Warwick's International Digital Lab and various major research programmes with participation by several Research Councils and researchers from many disciplines (see Section 6.5), we very take seriously the claim that the UK is lagging behind its international competitors in this regard. In the Royal Society report on postgraduate training and research we highlighted the need for diversity and flexibility of approach to education to match the increasing complexity of the workplace (Royal Society 2008a). We also note the increasing global competition for the best students and the major investments that other countries have made in their HE systems. The review of the skills required by the services sectors (see Recommendation 18) should include a consideration of the provision of multi-disciplinary research centres and any lessons that can be learned from the approaches taken to HE overseas.

In conclusion, there is a clear requirement for a genuinely new approach to multi-disciplinary education which is more focused on the characteristics of services and service systems. This need is only going to grow in future (see Chapter 5). There is, as yet, no consensus about the set(s) of skills required, hence our recommendation of a review of the needs of employers below (see Recommendation 18) and an expectation that several different responses will be appropriate.

6.6.4 Developing a response

In 'A Higher Degree of Concern' (Royal Society 2008a) the Royal Society highlighted the importance of employer involvement in education, to help ensure that graduates possess the skills and attributes that are required in the working environment. To this end, the Society called for increases in collaborative approaches to teaching and learning to ensure that businesses and other employers are engaged in curriculum development, course design and delivery.

Given the diversity of the services sector and rapid developments in it, we take it as axiomatic that the HE sector embraces a diversity of approaches to meeting skills needs for innovation in services—and that these are balanced with the other demands on the sector.

Some firms, like academia, still operate in silo-based approaches with teams from different disciplines working separately under the same programme umbrella. For these firms, traditional domain-specific specialists may continue to be appropriate—albeit with appropriate training in 'soft skills'.

Some employers do require graduates with an overview of a range of different subjects. In this context, we welcome the introduction of new courses such as Service Science, Manufacturing and Engineering (SSME), while noting from previous attempts in other disciplines the likely difficulties that may arise (see Section 6.6.6).

Perhaps more difficult is how to address the lack of T-shaped people. It should be stressed that the concept of the 'T-shaped person' refers not simply to the equipping of STEM graduates with 'soft skills'—it requires the incorporation of domain knowledge and attributes from other disciplines and some 'professional skills and tools' such as IT competence, business awareness and generic analytical skills. It therefore requires a different response. We believe it is inevitable that the demand for these types of graduates will increase in the future.

Clearly, there is no single set of multi-disciplinary skills that will serve the full range of service innovators. However, developments in services models and innovation practices (see Chapter 5) do provide some indications about the types of knowledge and the mix of skills that will be needed to understand and create value from service systems in the future.

As services become ever more personalised and interconnected (see Chapter 5), the resulting systems will become increasingly complex, unpredictable and non-deterministic. Designing and implementing innovations within such systems will require people (or teams of people) who combine certain aspects of STEM expertise with other types of skills and knowledge gained from disciplines such as economics, history, geography, management or law. Of particular importance will be the ability to take account of the 'human dimensions' in complex systems (see Chapter 3), eg people who have the mathematical skills and competence with sophisticated tools to model complex systems involving millions of users but who also have some knowledge of social sciences and human behaviour in different cultures.

Given the pervasive nature of ICT, now and in the future, and the clear need for excellent analytical and problem solving skills and abilities (both in the service sector and elsewhere), these must be core components of all undergraduate courses.

6.6.5 How might this be delivered?

As outlined above, we expect the skills needs of the service sectors to be delivered in a diversity of ways.

The proposed Grand Challenges (see Section 6.5) can make an important contribution by stimulating the establishment of research agendas, prompting the formation of research teams and identifying cross-cutting topics such as dynamics in human-systems interaction. These are very likely to be research-led, with any training almost certainly focused at the PhD and masters levels. However, we would expect that the resultant research would inform the teaching agenda and thereby stimulate and inform undergraduate STEM courses.

We welcome the development of services-oriented STEM courses at postgraduate level, such as the MSc in Financial Computing at University College, London and the MSc in Service Design, Management and Innovation (starting in September 2009) at Manchester Business School's new Centre for Service Research. There are already several such examples which successfully combine disciplines (STEM and non-STEM alike) or which attract graduates from diverse academic backgrounds. In many cases these courses have been designed with a high degree of employer involvement. Similarly, we note that some professional doctorates such as the Engineering Doctorate (EngD) are well regarded in this sense.

Similarly, PhDs conducted as CASE awards with service firms (see knowledge exchange in Section 6.7) or linked to the Grand Challenges can also provide postgraduate employees with the multi-disciplinary background favoured by employers.

However, it is doubtful that the various demands of service employers for new interdisciplinary skills will be met by post-graduate programmes alone as the numbers of people passing through these courses will remain very small.

We strongly support the continuation of core-STEM degrees at undergraduate level. The deep STEM knowledge gained from traditional three-year undergraduate degrees will continue to be valued by a wide variety of employers, from services and other sectors. However, we must explore options for modifications to the way that traditional STEM undergraduate degrees are taught, for example including some modules from outside the core discipline (eg economics, quantitative social sciences, database and search technologies). A 3rd or 4th year multi-disciplinary programme could offer the chance to motivate, excite and initiate interest in related topics, which characterises multi-disciplinary T- shaped graduates. A possible move towards 4-year courses, stimulated by the Bologna process (but constrained by cost to students and government alike), would facilitate the development of multi-disciplinary elements to traditional STEM courses.

Some interim steps to make STEM disciplines more relevant can be taken now by STEM degree providers. For example the use of case studies or speakers from the service sector can provide a wider context for the techniques or knowledge being taught. Work placements or final year projects undertaken jointly with service sector firms can be particularly effective. As highlighted above, the Grand Challenge programmes and related initiatives could serve to expose STEM graduates to the challenges and opportunities of innovation in the service sectors. While we recognise the logistical difficulties, partnerships between STEM and non-STEM departments to make introductory lectures available to each other's undergraduates could also be beneficial.

6.6.6 A systems-based approach to understanding services

One solution may lie in the wider adoption of systems-based approaches to understanding services. A more systematic approach to studying services should result in better design, management and understanding of services and, at the same time, provide a suitable context in which to integrate disciplines such as social sciences, management science, economics and STEM. These sorts of educational programmes may particularly benefit firms who do not require graduates with deep knowledge in one of the existing disciplines.

However, we note that when this has been attempted in the past, as with systems science and complexity theory—both of which have existed for several decades and have been widely applied in scientific, engineering and social science contexts—the tendency has been for people to organise themselves into disciplinary silos, with the result that the desired new interdisciplinary approaches have struggled to impose themselves.

The emerging Service Science, Manufacturing and Engineering (SSME) or 'Service Science' concept is also intended to join up a broad range of disciplines, but is specifically concerned with ensuring that graduates are better equipped for the workplace. Service Science may ultimately help the development of multi-disciplinary capabilities but in this regard SSME programmes seem to have been slow to emerge and only partially successful to date.

A more profitable approach to redesigning academic curricula and delivery (at least as far as services are concerned) may be to focus in on service design, which seeks to understand the delivery of services from a user perspective and to develop better solutions (see Box 4.3 on page 40).Developments such as the Masters course in Service Design, Management and Innovation offered by the University of Manchester Centre for Service Research might provide good models for new courses, and should be closely monitored by degree providers and Funding Councils.

6.6.7 Conclusions

Services are intrinsically multi-disciplinary, requiring the integration of many different skills (STEM and non-STEM alike). Indeed, innovation is often spurred by the coming together of individuals and knowledge at the margins and intersections of disciplines and skill sets.

There is a clear requirement for a new approach to multi-disciplinary education which is more focused on the characteristics of services and service systems and that the need is only going to grow in future (see Chapter 5).

We envisage that the vast majority of undergraduate STEM courses will remain domain-specific and that these graduates will remain attractive to employers in services for their potential contributions to the innovation process. However we believe it is necessary to ensure that steps are taken to make education and training more appropriate to the needs of the service environments where the large majority of STEM graduates find employment. This is important to maintaining the competitiveness of UK HE sector.

However, we caution against an approach which reduces the issue to a prescribed list of skills as there is no specific or unchanging skill set for innovation—in services or manufacturing. In short, services (like other sectors) need a mixture of STEM skills—people with good core disciplinary skills and knowledge but also those with multi-disciplinary expertise and flexible and enquiring mind.

We therefore emphasise the importance of diversity in skills and knowledge but stress that core scientific competences remain important in many innovation environments, and therefore encourage continued support for core STEM degrees.

The lessons of the past are that the creation of a single new subject or discipline is unlikely to be the only answer. Rather, it seems necessary to nurture a range of approaches which draw together key components from different disciplines and which utilise various means to cross-fertilise knowledge and skills—secondments, work placements and other forms of knowledge exchange and the configuration of genuinely interdisciplinary research teams, for example.

More structured and detailed engagement with employers is required to determine the exact nature of the problems and the actions which might best resolve them. We believe that this would be an appropriate time to undertake a large-scale systematic exploration of STEM skills needs in key sectors led by relevant Sector Skills Councils and overseen by the UK Commission for Employment and Skills (UKCES). This would build on a more general recommendation by NESTA for the UKCES to analyse the extent and quality of 'innovation-ready' skills in the UK (NESTA 2008b).

Recommendation 18

We recommend that UKCES, in consultation with key stakeholders including service sector employers and professional and statutory bodies should identify any overarching concerns and unmet needs and address their observations to the Higher Education Funding Councils, Research Councils, Technology Strategy Board and HE providers. Based on the results of these explorations these bodies should support the modification of existing STEM courses, the development of new academic courses and post-graduate training modules.

In the meantime, until the results of this review are known, we believe universities and services sector firms could take some actions to improve the situation.

Recommendation 19

Given that 82% of STEM graduates go into the service sectors, we recommend that providers of STEM courses take immediate steps to ensure that their graduates are better equipped to deal with the challenges they will face. Specifically, they should:

- Ensure that ICT and analytical skills remain core to STEM courses;
- Use case studies and speakers from the services sectors to illustrate the context in which graduates may use their degree;
- Enable STEM graduates to take relevant modules and lectures from other STEM and non-STEM disciplines.

Recommendation 20

In order to improve the training of STEM graduates, we recommend that more service sector firms should:

- Provide work placements for undergraduates;
- Seek opportunities to engage with STEM course providers, both undergraduate and postgraduate, to inform the development of curricula and to explore their participation in courses.

6.7 Increase the scale of knowledge exchange

Summary

- The 'outward-looking' approach that services organisations take to innovation presents significant opportunities for engagement with the STEM supply chain. Yet services organisations appear to be poorly

connected with the research base, and there is little awareness within services of formal knowledge exchange mechanisms. Links with the research base, so far as they exist, are often informal, frequently via alumni;

- Services organisations and the research base would benefit from higher levels of knowledge exchange, and both parties expressed an interest in closer working relationships;
- The approach to knowledge exchange taken by some universities fails to take into account the nature of services innovation or services business models. Some services find that these approaches impede rather than promote knowledge exchange;
- While informal links can often be beneficial, there would be advantages to exploring mechanisms to support the exchange of senior staff between academia and business;
- We make recommendations for ways to increase awareness of formal knowledge exchange mechanisms in the services sectors, and urge university Knowledge Exchange Offices to adapt their activities to better suit services business models and innovation practices.

The tendency of services to be more 'outward-looking' than manufacturing firms in their approaches to innovation (see Box 1.3 and Section 1.3) presents significant opportunities for the key actors in the STEM supply chain to engage in knowledge exchange (KE) activities with services. Knowledge exchange instruments based on collaboration, networking and placements allow the circulation of talented individuals between communities, expose organisations to new ways of thinking and working and enable the constant refreshment of knowledge and ideas.

Although there are some well established KE mechanisms in operation between the research and business communities, relatively few such mechanisms operate specifically in the space between the research base and the services sectors—including public services.[36] This is unsurprising given the lack of appreciation of STEM contributions to services identified earlier (see Section 6.3).

We believe that an exercise promoting higher levels of knowledge exchange between the research base and services organisations would be beneficial. The success of these measures will depend in part on parallel efforts to build esteem for service-related work in academia and changes to ensure that incentives for collaboration are pitched at the right level (see Section 6.4.1).

The wider adoption of 'open' innovation approaches means that opportunities to collaborate are only likely to increase. But, even with the measures outlined here, HEIs will only capitalise if they can develop a better understanding of service innovation models and use this knowledge to make more informed choices about their knowledge exchange strategies.

6.7.1 The current situation

Policy messages from the Department for Business, Innovation and Skills, the Research Councils and HM Treasury about engaging user communities and creating 'economic impact' appear to be having an effect on the UK HE sector—the HEIs which responded to our call for evidence were eager to demonstrate that they are engaging employers, forging new relationships, operating in new ways and, in doing so, supporting innovation. The large number of written submissions received from universities is indicative of the importance that respondents attach to demonstrating that they are actively engaging service organisations (and business more generally).

However, the balance of evidence received during our study has led us to conclude that service companies are, on the whole, not well connected or networked with the academic STEM community. We do not necessarily view this as a problem—universities and academics should not be expected to play a leading role in services innovation. Nevertheless, there are compelling reasons to believe that both parties would benefit from higher levels of engagement.

Indeed, various organisations made clear to us their desire for closer working relationships and better knowledge exchange and many others demonstrated the benefits that flow from such collaborations. For example, a law and order agency told us that they would benefit from greater access to the sorts of technical skills and knowledge in data mining, modelling and profiling that have helped Tesco to better understand their customers. One major investment bank told us that there are projects and problems which are common to the sector, but which require extensive collaboration between competitors and external experts (for example, the creation of defined standards for models of derivatives.)

More fundamentally, we believe that graduate education and training and academic research would benefit from greater exposure to the ideas, expertise, people and cutting-edge research which exist in business.

6.7.2 KE mechanisms can link service organisations to external STEM capabilities

As shown earlier (see Section 6.4), most innovative services organisations have few or no direct links with the publicly funded research base. For some firms, however, KE mechanisms play an important role in linking service organisations to external STEM capabilities. We encountered several examples that illustrate the impacts of government support for business-university collaboration in services, most notably Knowledge Transfer Partnerships (KTPs) and the Higher Education Innovation Fund (HEIF). CASE studentships[37] and other forms of placement were also cited as useful mechanisms in some submissions.

36 We have noted and will watch with interest one particular example—ESRC's public sector Placement Fellowship Scheme which encourages and supports social science researchers to spend time within government departments and public sector agencies.

37 Collaborative Awards in Science and Engineering; these are doctoral training grants for graduates to undertake research on a subject selected and supervised jointly by academic and industrial partners.

Many 'type 1' organisations[38] participate in STEM-based networks and collaborations and are well equipped to identify and utilise relevant STEM expertise from the research base and other sources. By contrast, the evidence suggests that in service sectors where STEM is not a core part of the business (ie the vast majority of service organisations) collaborative networking is much less common[39] and schemes such as KTPs, KTNs and the European Framework Programme for Technological Research and Development are little known.

6.7.3 The role of the Technology Strategy Board

The resourcing made available to the Technology Strategy Board and the seven Research Councils amounts to more than £3bn annually (with the much greater share going to the Research Councils). Given this, we wonder why what they are doing is not more widely known: most of the senior business people that we spoke to in the services sector knew little or nothing about the work of these bodies (see above). We are also not sure how the success of their activities with the services sector will be measured and generic lessons drawn out.

Knowledge Transfer Networks (KTNs) can provide opportunities for 'consortia' of SMEs to engage one another and the public research base. A short review of the areas covered by the 24 KTNs show that many (more than half, in our view) are expressly relevant to services. There are, for example, networks in Resource Efficiency, Intelligent Transport Systems, Industrial Mathematics and Digital Communications. We strongly welcome the recent addition of a KTN for Financial Services.

As discussed earlier (see Recommendation 17) KTNs could play a role in developing and supporting the technical and theoretical competences needed to underpin new Grand Challenges in services.

We welcome the growth in the number of KTPs in services (which now exceed those in manufacturing—see Section 2.5) but note that they are still proportionally low given the size of the services sector. We believe that in implementing Lord Sainsbury's recommendation to double the number of KTPs (Lord Sainsbury of Turville 2008, Recommendation 4.5) the TSB must endeavour to ensure that the distribution of KTPs more closely matches the balance of the economy.

We also note that, while there seem to be good numbers of KTP associates from engineering and technology backgrounds entering services, numbers of KTPs in services involving other STEM graduates appear very low. It is not clear to us whether this reflects a lack of demand or a lack of engagement with sponsoring STEM departments.

Recommendation 21

We recommend that the TSB and Research Councils evaluate the applicability of their knowledge exchange schemes to the services sectors and develop and publish strategies for their active promotion in these sectors—especially to 'type 2'[40] organisations.

Recommendation 22

In particular, the Technology Strategy Board should review the Knowledge Transfer Partnerships (KTP) programme for its accessibility to services and to KTP associates with STEM backgrounds. Subject to the outcome of this evaluation, the TSB and BIS should consider ways to stimulate and meet demand in services and develop and implement a strategy for doing so.

Recommendation 23

In developing and structuring the KTNs, the TSB should emphasise cross-cutting technical and theoretical competences which are required and valued across sectors.

6.7.4 The role of knowledge exchange specialists

At the university level, links with industry and public sector organisations are often facilitated by dedicated knowledge exchange professionals. Knowledge exchange offices and officers (KEOs) occupy an increasingly important space in business/university relations. There were 7,400 full-time equivalent KE staff in UK universities in 2007 (HEFCE 2008) compared to 1,529 in 2001 (HEFCE 2003). This growth in numbers is largely the result of the Government's efforts to build KE capacity in the UK Higher Education sector—to date the Government has dedicated over £900m[41] to the development of KE capacity in universities via the Higher Education Innovation Fund (HEIF), initiated in 2002.

Several contributors expressed strong concerns about KEO's operational models, saying that they are ill-suited to service innovation models and business practices. (For example, traditional exploitation models emphasise intellectual property (IP) and licensing, whereas services often rely on devising new business models—often with little IP protection or immediate financial gain). These views appear to be supported by evidence which shows that an increasing proportion of service organisations who collaborate with HEIs consider dedicated knowledge exchange specialists (often referred to as Technology Transfer Officers) as barriers to effective collaboration (see Section 2.5.1).

Given how little is known about service innovation models more widely (see Section 6.2) it is perhaps not surprising that university-driven KE processes are not well adapted to services innovation. However, in view of the considerable sums of money which have been invested in building universities' KE resources and the potentially pivotal role KEOs play in building business-university relationships, it is vitally important that KEOs gain and apply a better understanding of the various emerging innovation models which pertain in services. This knowledge should help universities to make

38 Organisations where STEM is the core business and whose revenues are based on their ability to deliver STEM expertise, outputs and solutions (eg Contract Research Organisations). In these organisations, the customer/client is essentially buying STEM expertise (see Section 1.2).

39 There are notable exceptions in the financial services sector, especially insurance. Indeed, there are a number of industry-led STEM-based knowledge sharing networks operating in these sectors, such as the Lighthill Risk Network and the Willis Research Network.

40 Organisations where STEM is a useful or essential tool/methodology that is used to meet other business objectives/services (eg insurance, retailing goods and services, and financial trading). In Type 2 organisations, the customer is buying a service with certain attributes/features but is not concerned with how STEM is incorporated into the service (see Section 1.2)

41 See http://www.hefce.ac.uk/econsoc/buscom/heif/heif.asp

more informed decisions about their knowledge exchange strategies and to carefully select entry points in service value chains. In turn, this should help the development of more profitable relationships between services and academics.

Recommendation 24

The findings from the expanded body of research into services innovation (see Recommendation 10) should be promoted to knowledge exchange professionals whose role is to facilitate industry-university links.

Recommendation 25

The Institute for Knowledge Transfer should work closely with service sector firms or their representatives, including those in financial services, retail and the public sector, to develop knowledge and guidance for knowledge exchange professionals in universities.

6.7.5 Improving access to expertise

The evidence gathered from the semi-structured interviews conducted for this project includes several accounts of firms who encountered very significant difficulties in identifying and accessing academic expertise.

As described earlier (see Section 6.4.1) links with the research base are very often informal. Though deemed valuable (often more so than formal links), these sorts of relationships do have some clear limitations. For example, links made and maintained through alumni can, in practice, be limited to contact between employees and their former supervisors or cohort, which means that technical knowledge dates quite rapidly and that the best expertise may not be identified. Knowledge needs to be refreshed constantly to ensure that firms are familiar with the 'state of the art' and emerging trends and developments—this is vital if firms are to develop and harness good ideas for exploitation in the market.

While more informal links can often be beneficial, firms also need to consider whether there is a need for more formal, wider networks built on links to 'cutting edge' technical knowledge and research, which could include engagement with academics—especially those at more senior levels. These could complement, rather than replace, informal networks or links.

Recommendation 26

We recommend that the Research Councils, Funding Councils and universities explore opportunities to foster and support the exchange of more senior academic and research staff into business and vice versa, perhaps by fellowship schemes or other means. This could draw on industry fellowship schemes that tend to focus at junior levels.

We received much evidence where the flow of knowledge was as much from commercial organisations to universities as the other way. Interpretations of the Knowledge Transfer concept (and the concept of Technology Transfer) appear in many cases to be built upon the relatively simple linear model of innovation proceeding from 'blue skies' and applied research in universities to commercial exploitation. The reality is demonstrably more complex than that. It should not be assumed that the benefits of collaboration and networking flow in one direction only, with services acting as passive recipients of outputs from the research base. High levels of knowledge, expertise and original research which characterise the STEM in services supply chains have potential to add value to academic activities (including the shaping of curricula and graduate training) and collaborations between the two communities.

Recommendation 27

We recommend that Government departments, the various funding bodies and representatives of the HE sector all adopt the term Knowledge Exchange in preference to Technology Transfer or Knowledge Transfer, to better reflect the nature of the processes. At the operational level, we urge universities to review their knowledge exchange strategies to ensure and acknowledge that they are capturing the benefits of business input and perspectives on activities such as curriculum development and the direction and content of research programmes.

7 Enhancing services innovation: conclusions and recommendations

7.1 Introduction

The service sector in the UK has grown significantly over recent decades and it now accounts for around three quarters of jobs and GDP. Services include some of the highest performing sectors of recent years—financial services, business support services, retail and the creative industries among them.

Innovation is an important driver of economic growth, particularly in high wage 'knowledge economies', so innovation in services is particularly important for the UK. As demonstrated in preceding chapters STEM is deeply embedded in the UK service sectors and its impact on service innovation processes is extensive and widely diffused—though not always easily visible to those outside the process.

With appropriate policies in place STEM will play an important role in the development of services in the future.

In this chapter we present a summary of the conclusions and recommendations of the report, grouped thematically. We have focused our recommendations on those areas where public policy can create additional value from Government investments in STEM.

7.1.1 Build and support services research communities and agendas

STEM will play multiple roles in enabling, stimulating and supporting service-based responses to many of the major social, economic and environmental challenges we face. Greater engagement between services and academia is necessary to ensure that the potential of STEM is fully realised in areas such as health, energy, environment, information and knowledge systems, all of which represent considerable opportunities for the UK.

A number of interfaces already exist between academia and service organisations, drawing on academic expertise from different departments and frequently receiving funding and leadership from services organisations.

However, support for such efforts appears to be largely piecemeal, with the exception of TSB Innovation Platforms and elements of the Research Councils' cross-cutting themes. The scale of current efforts does not match the size of the opportunity to advance service-based solutions to globally significant challenges or reflect the UK's strengths in research and business, which could help the UK to take leading positions in new and emerging markets.

Greater convergence is required in order to:

- Establish international research communities in services innovation;
- Develop collaborative international research agendas in services-related fields;
- Ensure that opportunities to exploit STEM in services are properly recognised;
- Align research and market opportunities;
- Ensure parity of esteem between services-related research and other forms of academic research.

Recommendations:

Research Councils and the Technology Strategy Board (TSB) should expand their portfolios to encompass new service-related Grand Challenges. In doing so they should examine whether new approaches (other than cross-Council themes and Innovation Platforms) are more appropriate to meet these challenges and, if so, develop options for alternative approaches. ***(Recommendation 15)***

The Research Councils and the TSB should evaluate existing programmes to ascertain whether they adequately address opportunities in services, whether existing programmes could be enhanced by additional service-related elements, and whether they are benefitting from sufficient input and engagement from service organisations. Similarly, the Research Councils and TSB should ensure that future programmes adequately support emerging service industries and consider the role that service-based responses will play in meeting major economic and social challenges. This is particularly important given the apparent decline in services organisations collaborating with the public research base and an increased perception of barriers to collaboration. ***(Recommendation 16)***

It is essential that Grand Challenges include provision to develop and align cross-cutting theoretical and intellectual competences in areas such as managing uncertainty in modelling and simulation, service design, quantitative data analysis, data security, standardisation or validation of data sets and dynamics in human-systems interaction. To do so would add value across the range of Grand Challenges by sharing knowledge and expertise and reducing costs. Options would include the physical co-location of resources and expertise in centres of excellence or the establishment of virtual centres or networks (perhaps using the Knowledge Transfer Network model). ***(Recommendation 17)***

7.1.2 Develop a truly multi-disciplinary capability

Services organisations place a high value on STEM-trained employees but employers have identified problems with workforce skills, highlighting particular difficulties in finding employees with good 'multi-disciplinary' skills—which are essential in most modern service organisations.

The evidence we received suggests that universities are generally doing a good job at producing graduates with 'deep disciplinary' knowledge and associated analytical skills. Courses such as Service Science, Management and Engineering are developing which will produce graduates with an overview of a range of services-related subjects. But with the exception of a small number of postgraduate programmes, there is little current capability for training 'T-shaped people'—those with deep knowledge of one discipline, combined with some knowledge of other subjects (STEM and non-STEM), and associated professional skills and tools such as ICT, business awareness, and analytical skills.

Anticipated developments in services and the importance attached to T-shaped people by the many organisations responding to our inquiry means it is essential that Higher Education Institutions give this serious consideration. More structured and detailed engagement between educators and service organisations is required to determine the exact nature of employers' needs and the actions which might best address them.

Recommendations:

We recommend that the UK Commission for Employment and Skills, in consultation with key stakeholders including service sector employers and professional and statutory bodies should identify any overarching concerns and unmet needs and address their observations to the Higher Education Funding Councils, Research Councils, Technology Strategy Board and HE providers. Based on the results of these explorations these bodies should support the modification of existing STEM courses, the development of new academic courses and post-graduate training modules. ***(Recommendation 18)***

Given that 82% of STEM graduates go into the service sectors, we recommend that providers of STEM courses take immediate steps to ensure that their graduates are better equipped to deal with the challenges they will face. Specifically, they should:

- *Ensure that ICT and analytical skills remain core to STEM courses;*
- *Use case studies and speakers from the services sectors to illustrate the context in which graduates may use their degree;*
- *Enable STEM graduates to take relevant modules and lectures from other STEM and non-STEM disciplines* ***(Recommendation 19)****.*

In order to improve the training of STEM graduates, we recommend that more service sector firms should:

- *Provide work placements for undergraduates;*
- *Seek opportunities to engage with STEM course providers, both undergraduate and postgraduate, to inform the development of curricula and to explore their participation in courses.* ***(Recommendation 20)****.*

7.1.3 Increase the scale of knowledge exchange

The 'outward-looking' approach that services organisations take to innovation presents significant opportunities for engagement with the STEM supply chain. Yet services organisations appear to be poorly connected with the research base, and there is little awareness within the services sector of formal knowledge exchange mechanisms (including those delivered by the TSB). Links with the research base, so far as they exist, are often informal or indirect.

Effective engagement is made difficult by the existence of a number of barriers, including mismatch of expectations, differing cultural norms, poor understanding of services innovation processes in academia, low esteem for services-related research and poor alignment of objectives between businesses and academia. Government has put in place measures to encourage business-university collaboration, but we are concerned by the results of two major surveys which showed an apparent decline in services organisations collaborating with the public research base and increased perception of barriers to collaboration.

There is much potential for improvement here: various organisations made clear to us their desire for closer working relationships and many others demonstrated the benefits that flow from such collaborations.

The approach to knowledge exchange taken by some universities fails to take into account the nature of services innovation or services business models. Some services find that these approaches impede rather than promote knowledge exchange.

While informal links can often be beneficial, we believe that there would be advantages to exploring mechanisms to support the exchange of senior staff between academia and business.

Recommendations:

We recommend that the TSB and Research Councils evaluate the applicability of their knowledge exchange schemes to the services sectors and develop and publish strategies for their active promotion in these sectors—especially to organisations in which STEM may be a useful tool for developing and delivering services (eg providing insurance, retailing goods and services, or financial trading) without being a core output of the business. ***(Recommendation 21)***

In particular, the TSB should review the Knowledge Transfer Partnerships (KTP) programme for its accessibility to services and to KTP associates with STEM backgrounds. Subject to the outcome of this evaluation, the TSB and the Department for Business, Innovation and Skills (BIS) should consider ways to stimulate and meet demand in services and develop and implement a strategy for doing so. ***(Recommendation 22)***

In developing and structuring the KTNs, the TSB should emphasise cross-cutting technical and theoretical competences which are required and valued across sectors. ***(Recommendation 23)***

Findings from the expanded body of research into services innovation (see Recommendation 10) should be promoted to knowledge exchange professionals whose role is to facilitate industry-university links. ***(Recommendation 24)***

The Institute for Knowledge Transfer should work closely with service sector firms or their representatives, including those in financial services, retail and the public sector, to develop knowledge and guidance for knowledge exchange professionals in universities. ***(Recommendation 25)***

We recommend that the Research Councils, Funding Councils and universities explore opportunities to foster and support the exchange of more senior academic and research staff into business and vice versa, perhaps by fellowship schemes or other means. This could draw on industry fellowship schemes that tend to focus at junior levels. ***(Recommendation 26)***

We recommend that Government departments, the various funding bodies and representatives of the HE sector all adopt the term Knowledge Exchange in preference to Technology Transfer or Knowledge Transfer, to better reflect the nature of the processes. At the operational level, we urge universities to review their knowledge exchange strategies to ensure and acknowledge that they are capturing the benefits of business input and perspectives on activities such as curriculum development and the direction and content of research programmes. ***(Recommendation 27)***

We agree with the view expressed by many contributors, including the Research Councils, that the Research Assessment Exercise did little to encourage engagement between universities and top class STEM innovators in services, and may even have discouraged academics from collaborating with service innovators. We strongly recommend to the Higher Education Funding Councils that the new Research Evaluation Framework should not replicate this unfortunate situation. ***(Recommendation 14)***

7.1.4 Improve understanding of service innovation models and the role of STEM

Services innovation, and particularly the role of STEM, has been a notable 'blind spot' for science and innovation policymakers. Unless policymakers develop an improved understanding of increasingly distributed, 'open' innovation processes in services it is unlikely that innovation policy will be able to support innovation practice.

A better appreciation of innovation processes (and appropriate policy interventions) requires a broad understanding of the relationships between service organisations, various actors in the STEM supply chain, other non-STEM inputs, service users and customers.

Poor understanding of innovation models and practices is compounded by the relative lack of academic and case study material and suitable statistical information available for analysis. As a result there are significant knowledge gaps and associated challenges for policymakers, innovation practitioners and potential collaborators in the STEM supply chain.

For example, it is difficult to understand the structure of the services sector because the boundary between it and other sectors is increasingly blurred. The official statistics on services are largely based on definitions last substantially revised in 1992. Though a new (2007) scheme is being implemented, it will not be used across all official statistics until at least 2011 and, even then, we have been told it will still not depict the emerging services.

Given the economic importance of these sectors these knowledge gaps need to be addressed as a matter of urgency.

Recommendations:

We urge the Office for National Statistics—and, if necessary, HM Treasury—to take the steps necessary to address the inadequate coverage of the service sectors by official statistics. We note that the imperative from the financial crisis has led to a substantial programme of international work on improving indicators and statistics which might predict future crises.

In so far as this work results in any further changes to standard industrial classifications, we would wish to see that these also address the needs expressed in the evidence to us. ***(Recommendation 9)***

Research funders must develop the body of academic work concerning services innovation. The recently established Innovation Research Centre, together with the Economic and Social Research Council, should take a lead in the development of knowledge of service innovation models by commissioning and undertaking new research and analysing and synthesising existing literature and data. ***(Recommendation 10)***

We recommend that the Department for Business, Innovation and Skills (BIS) should not rely on the UK Innovation Survey alone to assess the extent and state of links between the academic STEM community and the services sectors. Specifically, we endorse and repeat a recommendation first made by the Council for Science and Technology in 2003 (CST 2003) that Government should undertake a large-scale review of service value chains to understand where the key intersections with the research base occur. This will provide a more detailed picture to complement (or balance) the picture painted by the UK Innovation Survey. ***(Recommendation 11)***

Given the apparent significance of STEM capabilities which are embedded internally or in service supply chains, a large-scale review of service value chains (see Recommendation 11) should be used to explore ways that 'embedded STEM' capabilities can be leveraged and their contribution to innovation processes enhanced. The Royal Society would be happy to advise BIS based on the information and experience gathered in the course of this study. ***(Recommendation 12)***

BIS and the Research Councils must use the information garnered from the studies outlined above to ensure that future science and innovation policies move beyond the linear model of innovation. Policies must better recognise the complex innovation ecosystem that applies to services and the significance of 'embedded STEM'. This should help redress the balance of science and innovation policy, which has tended to focus very largely on the university system, with metrics that do not capture much of the important informal inputs or characteristics of innovation which differ from those in manufacturing. ***(Recommendation 13)***

7.2 Case studies

Given the economic importance of the banking and public sectors in the UK and the significance of innovation in these settings, we have looked in detail at the distinctive role of STEM in these domains.

7.2.1 Innovation in the banking sector

The UK has enjoyed a huge competitive advantage in financial services over an extended period, bringing substantial advantages to the UK economy. Developments in ICT and financial modelling have fostered particularly rapid innovation, enabled by STEM-trained staff, notably computer scientists and mathematicians.

However, vast imbalances in capital funds between countries, mispricing of risk and the collapse of the US sub-prime mortgage market triggered a global banking crisis in autumn 2007 which led to a sudden, massive and ongoing reduction in credit availability with dire consequences for governments, taxpayers, consumers, companies and banks world-wide. This financial crisis has led in turn to a near-global recession in 'the real economy'.

There are a wide range of opinions on the causes of the crisis, but some commentators have attributed at least some blame to the inappropriate use of mathematical tools, whose properties and consequences were not properly understood by those responsible for managing their exploitation. It is clear that many and various flaws in the banking sector culminated, ultimately, in systemic failure. Aside from a cavalier approach to risk, these include the reliance on apparently complex (but in some cases actually simplistic) tools and financial products, low levels of understanding and oversight by senior management and the inappropriate regulatory and geopolitical frameworks which underpinned global financial systems.

Recommendations:

BIS, working with the TSB and the Research Councils, should seek to create one or more world-leading and independent centres of modelling and risk assessment relevant to banking (and other financial services), drawing on all relevant sections of the research base. The success of such an endeavour would be maximised by mandating and formalising the engagement between the centre(s) and the Financial Services Authority (FSA). The FSA and HM Treasury should ensure this engagement comes about and is effective. ***(Recommendation 1)***

The Research Councils should engage at a high level with the Bank of England and the Financial Services Authority to explore ways in which the research base can contribute to more effective modelling of systemic risk in financial services, perhaps through consideration of complex adaptive systems. This may well necessitate a global research effort. ***(Recommendation 2)***

The FSA and the Financial Services Skills Council (FSSC), supported by the City of London Corporation and relevant professional and statutory bodies, should institute and mandate competency levels in understanding of mathematical modelling and risk in complex systems. They should draw heavily upon the research base in this design but should also ensure that any license to manage should require demonstrable competence in this area achieved through formal training, irrespective of whether this management is at Board or lower levels. ***(Recommendation 3)***

The Higher Education Funding Councils, in conjunction with the FSSC, should commission a review of the contents of financial engineering and related courses in the UK, examining their curricula, discussing with the relevant authorities what would be appropriate curriculum elements and commending the findings to the leadership in HEIs and accreditation bodies. ***(Recommendation 4)***

7.2.2 Innovation in the public sector

Recognition of the importance of innovation in government has grown in recent years. Some public agencies have recognised the role of STEM in delivering high quality public services and have successfully engaged the STEM supply chain in their innovation processes. But these examples are the exception to the rule—initiatives to foster innovation within Government have mostly ignored STEM. There is a pressing need to expand good practice across the public sector and take advantage of STEM inputs.

Some of those who contributed to the study complained about constraints on innovation in the private sector resulting from public sector innovation, and specifically the practices of certain government Trading Funds in regard to licensing and charging for public sector information. Government has made some changes to the business model of one Trading Fund in Budget 2009 but we believe more can beneficially be done.

The CBI suggested that there may be scope for giving academic researchers suitably confidential access to large private sector databases. We think this could be helpful to businesses, researchers and government alike.

Recommendations:

In view of the importance of the public sector to the national enterprise and national productivity and competitiveness, we strongly recommend more detailed work on how STEM can be exploited more successfully to foster public sector innovation. This needs to be through a team drawn from central and local government and from the research base. This recommendation is primarily addressed to the Cabinet Office—which has a continuing role through its strategy for 'excellence and fairness in public services'—and to BIS. ***(Recommendation 5)***

We urge BIS to discuss with the Funding Councils how to emulate the success of the Higher Education Innovation Fund with partners from the public services and the research base. ***(Recommendation 6)***

We note the Government's publication of changes to the Ordnance Survey (OS) business model and welcome the intention of making OS information more readily available. But we urge the Shareholder Executive and HM Treasury to move towards a situation where there is one model for the supply of government information, thereby simplifying matters for commercial organisations and facilitating innovation. ***(Recommendation 7)***

We recommend to the UK Research Councils that they should explore with the CBI and other relevant representative bodies the scope for freeing commercial data for academic and other research. ***(Recommendation 8)***

7.3 Developing a policy response

The financial crisis of the past two years, and the ensuing global recession, has brought the debate about the structural mix of the UK economy sharply into focus. It seems certain that the balance between sectors will change, but services will continue to dominate economic activity for the foreseeable future.

Moreover, the increasingly globalised nature of service industries and supply chains, the development of service-based responses to many of the major social, economic and environmental challenges facing society and the advent of ever more personalised and ubiquitous services represent both opportunities and challenges for UK organisations, government and policymakers.

The absence of a coherent policy for the promotion of innovation in services threatens to undermine the ability of firms based in the UK to develop and maintain leading positions in highly competitive and globalised service industries.

We believe that the implementation of these recommendations would enable the UK Government to maximise the economic potential of these sectors and to create additional value from investments in STEM. The Royal Society looks forward to playing an active role in the further development of the UK's science and innovation strategy.

References

Akkermans H & Vos B (2003). *Amplification in service supply chains: an exploratory case study from the telecom industry*. Production and Operations Management **12**, 204–223. doi: 10.5555/ijop.2003.12.2.204

Alam I & Perry C (2002). *A customer-oriented new service development process*. Journal of Services Marketing **16**, 515–532. doi: 10.1108/08876040210443391

Allsopp C (2004). *Review of statistics for economic policy-making*. Final report to the Chancellor of the Exchequer, the Governor of the Bank of England and the National Statistician. HM Treasury: London. March 2004. Available online at http://www.hm-treasury.gov.uk/consult_allsopp_index.htm

APPSI (2008). *The impact and success of legislation on the re-use of public sector information: the views of the UK Advisory Panel on Public Sector Information*. Advisory Panel on Public Sector Information: London. 31 July 2008. Available online at http://www.appsi.gov.uk/2008/07/31/APPSIsResponseToTheReviewOfTheDirective200398ECOnTheReuseOfPublicSectorInformation

Au WJ (2008). *The making of Second Life: notes from the new world*. Harper Collins: New York

Barker A (2009). *Myners urges 'radical' shake-up of bank boards*. Financial Times. 5 April 2009. Available online at http://www.ft.com/cms/s/0/aa6c69ac-2208-11de-8380-00144feabdc0.html

Battelle J (2005). *The search: how Google and its rivals rewrote the rules of business and transformed our culture*. Nicholas Brealey Publishing: London

Bell D (1973). *The coming of post-industrial society: a venture in social forecasting*. Basic Books: New York

BERR (2009). *Government response to 'Review and refresh of Bioscience 2015' report*. Department for Business, Enterprise and Regulatory Reform: London. Available online at www.berr.gov.uk/files/file51169.pdf

BERR/DIUS (2008). *Supporting innovation in services*. Department for Business Enterprise and Regulatory Reform/ Department of Innovation Universities and Skills: London. Available online at http://www.berr.gov.uk/files/file47440.pdf

Bioscience Innovation and Growth Team (2009). *The review and refresh of Bioscience 2015: a report to Government by the Bioscience Innovation and Growth Team*. Department for Business, Enterprise and Regulatory Reform: London. January 2009. Available online at www.berr.gov.uk/files/file49805.pdf

Brown G (2009). *Science and our economic future*. The Romanes lecture: Oxford, 27 February 2009. Available online at http://www.number10.gov.uk/Page18472

Bruneel J, D'Este P, Neely A & Salter A (2009). *The search for talent and technology: examining the attitudes of EPSRC industrial collaborators towards universities*. Advanced Institute of Management Research: London. January 2009. Available online at http://www.aimresearch.org/uploads/File/pdf/Academic%20Publications/AIM%20Search%20Talent_2009.pdf

Cabinet Office (2005). *Transformational Government—enabled by technology*. The Stationery Office: London. November 2005. Available online at http://www.cabinetoffice.gov.uk/cio/transformational_government/strategy.aspx

Cabinet Office (2007a). *The Government's response to 'The Power of Information: An independent review by Ed Mayo and Tom Steinberg (2007)'*. The Stationery Office: London. June 2007. Available online at http://www.opsi.gov.uk/advice/poi/index

Cabinet Office (2007b). *Transformational Government—our progress in 2007*. Annual Report 2007. Cabinet Office: London. Available online at http://www.cabinetoffice.gov.uk/cio/transformational_government/annual_report2007.aspx

Castells M (2000). *The rise of the network society*, 2nd edition. Blackwell: Oxford

Castronova E (2007). *Exodus to the virtual world: how online fun is changing reality*. Palgrave Macmillan: Basingstoke, UK

CBI (2005). *CBI response to Leitch review on skills*. CBI: London. June 2005. Available online at http://www.cbi.org.uk/ndbs/positiondoc.nsf/1f08ec61711f29768025672a0055f7a8/531C3A10BA2B1F348025711B00509B1E/$file/leitchresponse0605.pdf

CBI/QinetiQ (2006). *Innovation and public procurement: a new approach to stimulating innovation*. CBI: London. October 2006. Available online at http://www.cbi.org.uk/ndbs/positiondoc.nsf/1f08ec61711f29768025672a0055f7a8/6B8BFF65F9E0D6E18025720300500DB8/$file/innovationbrief1006.pdf

CBI/QinetiQ (2008). *Excellence in service innovation*. CBI: London. Available online at http://www.cbi.org.uk/pdf/Excellenceinserviceinnovation.pdf

Chamberlin G, Clayton T & Farooqui S (2007). *New measures of UK private sector software investment*. Economic & Labour Market Review **1**, 5, 17–28. Available online at http://www.statistics.gov.uk/cci/article.asp?id=1798

Chen-Ritzo C-H, Harrison C, Paraszczak J & Parr F (2009). *Instrumenting the planet*. IBM Journal of Research and Development **53**, 3, in press

Chesbrough HW (2003). *Open innovation: the new imperative for creating and profiting from technology*. Harvard Business School Press: Boston, MA

Cohen WM & Levinthal DA (1990). *Absorptive capacity: a new perspective on learning and innovation*. Administrative Science Quarterly **35**, 128–152

Collins P & Harrington P (2008). *After the apocalypse: lessons from the global financial crisis*. Demos: London. November 2008. Available online at http://www.demos.co.uk/files/Apocalypse%20-%20%20web%202.pdf

Coming in from the cold (2009). The Economist **390**, 8613, 11. 10 January 2009. Available online at http://www.economist.com/opinion/displaystory.cfm?story_id=12899493

CST (2003). *Knowledge intensive services and the science base*. Council for Science and Technology: London. Available online at http://www2.cst.gov.uk/cst/reports/#1

CST (2006). *Innovation and wealth creation—services sector and public procurement*. Council for Science and Technology: London. Available online at http://www2.cst.gov.uk/cst/reports/#1

den Hertog P (2000). *Knowledge intensive business services as co-producers of innovation*. International Journal of Innovation Management **4**, 91–528

DIUS (2008a). *Innovation nation*. Department for Innovation Universities & Skills: London. Available online at http://www.dius.gov.uk/reports_and_publications/~/media/publications/ScienceInnovation_web

DIUS (2008b). *Persistence and change in UK innovation, 2002–2006: report of the UK Innovation Survey 2007*. Department for Innovation, Universities and Skills: London. December 2008. Available online at http://www.dius.gov.uk/innovation/innovation_nation/annual_innovation_report

Dodgson M, Gann D & Salter A (2005). *Think Play Do: technology, innovation and organization*. Oxford University Press: Oxford

Dodgson M, Gann D & Salter A (2008). *The management of technological innovation: strategy and practice*. Oxford University Press: Oxford

Donahue JD (2005). *Dynamics of diffusion: conceptions of American federalism and public-sector innovation*. Ash Institute for Democratic Governance and Innovation, John F. Kennedy School of Government, Harvard University: Havard. Available online at http://www.innovations.harvard.edu/cache/documents/6771.pdf

Drew S & Morgan D (2007). *Launch of the Index of Services as a National Statistic*. Economic & Labour Market Review **1**, 3, 39–46. Available online at http://www.statistics.gov.uk/cci/article.asp?id=1741

DTI (2007). *Innovation in services*. Occasional Paper no. 9. Department for Trade and Industry: London. Available online at http://www.berr.gov.uk/files/file39965.pdf

EIG (2006). *The Warry Report: increasing the economic impact of the Research Councils*. Research Council Economic Impact Group: Swindon. 14 July 2006. Available online at http://www.rcuk.ac.uk/innovation/impact/warry.htm

Ellram LM, Tate WL & Billington C (2004). *Understanding and managing the service supply chain*. Journal of Supply Chain Management **40**, 4, 17–32

ETB (2006). *SET and the City: financing wealth creation from science, engineering and technology*. Engineering and Technology Board: London. September 2006. Available online at http://www.etechb.co.uk/_db/_documents/setandthecity.pdf

European Commission (2007). *Towards a European strategy in support of innovation in services: challenges and key issues for future actions*. Europe Innova paper no. 4. Office for Official Publications of the European Communities: Luxembourg. Available online at http://www.europe-innova.org/servlet/Doc?cid=8975&lg=EN

Ferguson N (2008). *The ascent of money: a financial history of the world*. Allen Lane: London

Friedman TL (2007). *The world is flat, 3.0: a brief history of the twenty-first century*. Picador: London

Frohlich MT & Westbrook R (2002). *Demand chain management in manufacturing and services: web-based integration, drivers and performance*. Journal of Operations Management **20**, 729–745. doi: 10.1016/S0272-6963(02)00037-2

Galindo-Rueda F (2008). *Developing an R&D satellite account for the UK*. Economic & Labour Market Review **1**, 12, 18–29. Available online at http://www.statistics.gov.uk/cci/article.asp?ID=1903

Gann D & Dodgson M (2007). *Innovation Technology: how new technologies are changing the way we innovate*. NESTA Provocation 05. National Endowment for Science, Technology and the Arts: London. September. Available online at http://www.nesta.org.uk/innovation-technology-how-new-technologies-are-changing-the-way-we-innovate/

Gann DM & Dodgson M (2008). *Innovate with vision*. Ingenia **36**. September. Available online at http://www.ingenia.org.uk/ingenia/articles.aspx?Index=509

Georghiou L (2007). *Demanding innovation: lead markets, public procurement and innovation*. National Endowment for Science, Technology and the Arts: London. February 2007. Available online at http://www.nesta.org.uk/assets/Uploads/pdf/Provocation/demanding_innovation_provocation_NESTA.pdf

Haldane AG (2009). *Rethinking the financial network*. Speech delivered by Andrew Haldane, Executive Director Financial Stability, Bank of England, at the Financial Student Association: Amsterdam, 28 April 2009. Available online at http://www.bankofengland.co.uk/publications/speeches/2009/speech386.pdf

Hamilton R, Jenkinson N & Penalver A (2007). *Innovation and integration in financial markets and the implications for financial stability*. Reserve Bank of Australia Conference: Sydney, Australia

Harris M & Albury D (2009). *The innovation imperative*. National Endowment for Science, Technology and the Arts: London. 09 March 2009. Available online at http://www.nestalab.org.uk/the-innovation-imperative/

HEFCE (2003). *Higher education—business interaction survey 2000-01*. Higher Education Funding Council for England: Bristol. March 2003. Available online at http://www.hefce.ac.uk/Pubs/hefce/2003/03_11.htm

HEFCE (2008). *Higher education—business and community interaction survey 2006-07*. Higher Education Funding Council for England: Bristol. July 2008. Available online at http://www.hefce.ac.uk/pubs/hefce/2008/08_22/08_22.doc

HESA (2007). *Destinations of leavers from Higher Education Institutions Longitudinal Survey of the 2002/03 cohort: key findings report*. Higher Education Statistics Agency Limited: Cheltenham. Available online at http://www.hesa.ac.uk/dox/dlhe_longitudinal/0203/DLHE_Long_2002_03_FINAL.pdf

HM Government (2009). *Working together, Public Services on Your Side.* Cabinet Office: London. March 2009. Available online at http://www.hmg.gov.uk/workingtogether.aspx

HM Treasury (2007). *Transforming Government procurement*. HM Treasury: London. January 2007. Available online at http://www.hm-treasury.gov.uk/ent_services_procurement.htm

HM Treasury (2008). *Facing global challenges: supporting people through difficult times*. HM Treasury pre-budget report November 2008. HM Treasury: London. Available online at http://www.hm-treasury.gov.uk/prebud_pbr08_repindex.htm

HM Treasury (2009a). *Budget 2009: building Britain's future*. Hc 407. The Stationery Office: London. 22 April 2009. Available online at http://www.hm-treasury.gov.uk/bud_bud09_repindex.htm

HM Treasury (2009b). *Operational efficiency programme: final report*. HM Treasury: London. April 2009. Available online at http://www.hm-treasury.gov.uk/d/oep_final_report_210409_pu728.pdf

House of Commons Treasury Committee (2009a). *Banking Crisis: dealing with the failure of the UK banks*. Seventh Report of Session 2008–09. HC 416. The Stationery Office Limited: London. 1 May 2009. Available online at http://www.publications.parliament.uk/pa/cm200809/cmselect/cmtreasy/416/416.pdf

House of Commons Treasury Committee (2009b). *Banking Crisis: Volume I—oral evidence*. HC 144-I Session 2008-2009. The Stationery Office Limited: London. 1 April 2009. Available online at http://www.publications.parliament.uk/pa/cm200809/cmselect/cmtreasy/144/144i.pdf

Howells J & Tether B (2004). *Innovation in services: issues at stake and trends*. A Report for DG Enterprise of the European Commission, under contract INNO-Studies 2001. Lot 3 (ENTR-C/2001). Commission of the European Communities: Brussels. Available online at http://www.europe-innova.org/servlet/Doc?cid=6372&lg=EN

Hughes JC (2008). *SIC 2007: implementation in ONS*. Economic & Labour Market Review **2**, 8, 41–44. Available online at http://www.statistics.gov.uk/elmr/08_08/downloads/ELMR_Aug08_Hughes.pdf

IDeA (2005). *Innovation in public services: literature review*. Improvement and Development Agency: London. September 2005. Available online at http://www.idea.gov.uk/idk/aio/1118552

Jenkinson N, Penalver A & Vause N (2008). *Financial innovation: what have we learned?* Reserve Bank of Australia Conference: Sydney, Australia

Jeppesen LB & Frederiksen L (2006). *Why do users contribute to firm-hosted user communities? The case of computer-controlled music instruments*. Organization Science **17**, 1, 45–63

Kamarck EC (2003). *Government innovation around the world*. Ash Institute for Democratic Governance and Innovation, John F. Kennedy School of Government, Harvard University: Harvard. November 2003. Available online at http://unpan1.un.org/intradoc/groups/public/documents/apcity/unpan015626.pdf

Kambhu J, Weidman S & Krishnan N (2007). *New directions for understanding systemic risk*. A report on a conference cosponsored by the Federal Reserve Bank of New York and the National Academy of Sciences. The National Academies Press: Washington, D.C. Available online at http://books.nap.edu/openbook.php?record_id=11914&page=R2

King M (2009). *Speech at the CBI dinner*: East Midlands Conference Centre, Nottingham, 20 January 2009. Available online at http://www.bankofengland.co.uk/publications/speeches/2009/speech372.pdf

Landshoff P, Simmons M, Joshi R, Gill C, Waugh C & Patman J (2008). *National Transport Information Incubator (NaTII): enabling the power of information*. Report of a Department for Transport funded pilot study. Department for Transport: London. Available online at http://www.dft.gov.uk/pgr/scienceresearch/technology/natii/

Lerner J (2006). *The new financial thing: the origins of financial innovations*. Journal of Financial Economics **79**, 2, 223–255. doi: 10.1016/j.jfineco.2005.01.004

Library House (2007). *Funding growth in a changing world*. Available online at http://www.libraryhouse.net

Lord Drayson (2009). *Foundation for Science and Technology lecture*. The Royal Society: London. 04 February 2009. Available online at http://www.dius.gov.uk/news_and_speeches/speeches/lord_drayson/fst

Lord Sainsbury of Turville (2007). *The Race to the Top: a review of Government's science and innovation policies*. The Stationery Office: London. Available online at http://www.hm-treasury.gov.uk/d/sainsbury_review051007.pdf

Lord Turner (2009). *The Turner review: a regulatory response to the global banking crisis*. Financial Services Authority. March 2009. Available online at http://www.fsa.gov.uk/pubs/other/turner_review.pdf

Marrano MG, Haskel J & Wallis G (2007). *Intangible investment and Britain's productivity: Treasury Economic Working Paper Number 1*. HM Treasury: London. October 2007. Available online at http://www.hm-treasury.gov.uk/pbr_csr07_intangible.htm

May RM, Levin SA & Sugihara G (2008). *Complex systems: ecology for bankers*. Nature **451**, 893–895. doi: 10.1038/451893a

Mayo E & Steinberg T (2007). *The Power of Information: an independent review by Ed Mayo and Tom Steinberg*. Cabinet Office: London. June 2007. Available online at http://www.opsi.gov.uk/advice/poi/index

Mulgan G & Albury D (2003). *Innovation in the public sector*. Strategy Unit, Cabinet Office. October 2003. Available online at http://www.cabinetoffice.gov.uk/strategy/work_areas/innovation.aspx

NAO (2006). *Achieving innovation in central government organisations*. National Audit Office: London. 25 July 2006. Available online at http://www.nao.org.uk/publications/0506/achieving_innovation_in_centra.aspx

NAO (2009). *Innovation across central government*. National Audit Office: London. 26 March 2009. Available online at http://www.nao.org.uk/publications/0809/innovation_across_government.aspx

NESTA (2006). *The innovation gap*. National Endowment for Science, Technology and the Arts: London. Available online at http://www.nesta.org.uk/assets/Uploads/pdf/Research-Report/innovation_gap_report_NESTA.pdf

NESTA (2007). *Hidden innovation: how innovation happens in six 'low innovation' sectors*. National Endowment for Science, Technology and the Arts: London. June 2007. Available online at http://www.nesta.org.uk/hidden-innovation-report/

NESTA (2008a). *Taking services seriously*. National Endowment for Science, Technology and the Arts: London. Available online at http://www.nesta.org.uk/assets/Uploads/pdf/Research-Report/taking_services_seriously_report_NESTA.pdf

NESTA (2008b). *Total innovation: harnessing all forms of innovation to maximise competitive advantage*. NESTA policy briefing. National Endowment for Science, Technology and the Arts: London. May 2008. Available online at http://www.nesta.org.uk/total-innovation-policy-briefing-pubs/

Newbery D, Bently L & Pollock R (2008). *Models of public sector information provision via trading funds*. Report commissioned by the Department for Business, Enterprise and Regulatory Reform (BERR) and HM Treasury. Office of Public Sector Information: London. February 26 2008

ONS (2008). *UK Standard Industrial Classification of Economic Activities 2007 (SIC 2007): structure and explanatory notes*. Office for National Statistics. December 2008. Available online at http://www.statistics.gov.uk/statbase/Product.asp?vlnk=14012

PACEC (2009). *Evaluation of the effectiveness and role of HEFCE/OSI Third Stream Funding: culture change and embedding capacity in the Higher Education sector toward greater economic impact*. A report to HEFCE by PACEC and the Centre for Business Research, University of Cambridge. Higher Education Funding Council for England: Bristol. January 2009. Available online at http://www.hefce.ac.uk/pubs/rdreports/2009/rd05_09/

Palmisano S (2008). *A smarter planet: the next leadership agenda*. Speech by Sam Palmisano, Chairman and CEO of IBM, to The Council on Foreign Relations: New York City, 6 November. Available online at http://www.ibm.com/ibm/ideasfromibm/us/smartplanet/20081106/sjp_speech.shtml

Rayport JF & Sviokla JJ (1995). *Exploiting the virtual value chain*. Harvard Business Review **73**, 75–85

Rebonato R (2007). *Plight of the fortune tellers: why we need to manage financial risk differently*. Princeton

Richards A (2008). *Quality, talent and diversity in the UK university system*. Speech by Alison Richards, Vice-Chancellor of Cambridge University, to the Universities UK Annual Conference: Cambridge, 10 September. Available online at http://www.admin.cam.ac.uk/offices/v-c/speeches/20080910.html

Royal Society (2006a). *A degree of concern? First degrees in science, technology and mathematics*. The Royal Society: London. October 2006. Available online at http://royalsociety.org/document.asp?tip=0&id=5467

Royal Society (2006b). *Digital healthcare: the impact of information and communication technologies on healthcare*. The Royal Society: London. 08 December 2006. Available online at http://royalsociety.org/document.asp?tip=1&id=5684

Royal Society (2008a). *A higher degree of concern*. The Royal Society: London. January 2008. Available online at http://royalsociety.org/document.asp?tip=0&id=7403

Royal Society (2008b). *Royal Society submission to DIUS UK science and innovation strategy*. 29 February 2008. Available online at http://royalsociety.org/document.asp?tip=0&id=7484

Schrage M (2000). *Serious play: how the world's best companies simulate to innovate*. Harvard Business School Press: Boston, MA

Schultze U, Hiltz SR, Nardi B, Rennecker J & Stucky S (2008). *Using synthetic worlds for work and learning*. Communications of the Association for Information Systems **22**, 351–370. Available online at http://aisel.aisnet.org/cais/vol22/iss1/19

Siegele L (2008). *Let it rise: a special report on corporate IT*. The Economist **388**, 8603. 25 October. Available online at http://www.economist.com/specialreports/displayStory.cfm?STORY_ID=12411882

Slater SF & Narver JC (1998). *Customer-led and market-oriented: let's not confuse the two*. Strategic Management Journal **19**, 1001–1006. doi: 10.1002/(SICI)1097-0266(199810)19:10<1001::AID-SMJ996>3.0.CO;2-4

Tapscott D & Williams AD (2007). *Wikinomics: how mass collaboration changes everything*. Atlantic Books: London

Tether BS (2005). *Do services innovate (differently)? Insights from the European Innobarometer survey*. Industry and Innovation **12**, 153–184

Tett G (2009). *Fool's Gold: how unrestrained greed corrupted a dream*. Little, Brown: London

TfL (2009). *Skills and employment strategy*. Transport for London: London. March 2009. Available online at http://www.tfl.gov.uk/corporate/about-tfl/publications/1480.aspx

Thomas R & Walport M (2008). *Data sharing review*. Independent review for the Ministry of Justice. 11 July 2008. Available online at http://www.justice.gov.uk/reviews/datasharing-intro.htm

Thomke SH (2003). *Experimentation matters: unlocking the potential of new technologies for innovation*. Harvard Business School Press: Boston, MA

Tily G (2006). *Improvements to timely measures of service sector output*. Office for National Statistics. March 2006. Available online at http://www.statistics.gov.uk/cci/article.asp?ID=1470

Tufano P (2003). *Financial innovation*, 1st edition. In *Handbook of the Economics of Finance* eds Constantinides GM, Harris M & Stulz RM), 307–335. Elsevier

UUK (2008). *The future size and shape of the HE sector in the UK: threats and opportunities*. Research report. Universities UK: London. 10 July 2008. Available online at http://www.universitiesuk.ac.uk/Publications/Documents/Size_and_shape2.pdf

Varney SD (2006). *Service transformation: a better service for citizens and businesses, a better deal for the taxpayer*. December 2006. Available online at http://www.hm-treasury.gov.uk/d/pbr06_varney_review.pdf

Von Hippel E (2005). *Democratizing innovation*. MIT Press: Boston, MA

Yeandle M, Horne J, Danev N & Knapp A (2009). *Global Financial Centres Index 5*. City of London. March 2009. Available online at http://217.154.230.218/NR/rdonlyres/8D37DAE2-5937-4FC5-A004-C2FC4BED7742/0/BC_RS_GFCI5.pdf

Youngdahl WE & Loomba APS (2000). *Service-driven global supply chains*. International Journal of Services Industry Management **11**, 329–347. doi: 10.1108/09564230010355368

Zittrain J (2008). *The future of the Internet and how to stop it*. Allen Lane/Penguin: London

Annex 1 Glossary

ABI	Annual Business Inquiry: a statutory annual survey of employment information from businesses and other organisations in most industry sectors of the UK economy
absorptive capacity	the ability of an organisation to value, assimilate and apply new knowledge
AEK	acquisition of external knowledge—a type of 'innovation activity' recorded by the UK Innovation Survey
AIM	Advanced Institute of Management Research
AIM IPGC survey of EPSRC collaborators	A questionnaire sent to all industrial collaborators on EPSRC collaborative projects since 1999, asking about the nature and frequency of collaborators' interactions with HEIs, and drivers and perceived barriers to collaboration. There were surveys in 2004 (conducted by SPRU) and 2008 (conducted by AIM). The 2008 survey was sent to 3431 individuals at 3119 organisations, and had a 20% response rate. Organisations in the 'business services' sector (SIC(92) 72, 73, 74.1-3) made up 37% of respondents to the 2008 survey, with the majority of remaining organisations in the manufacturing sector.
AMES	acquisition of advanced machinery, equipment and software—a type of 'innovation activity' recorded by the UK Innovation Survey
APC	Air Pollution Control
API	Application Programming Interface
ATM	Automated Teller Machine (cash machine)
BAA	British Airports Authority
BERR	Department for Business, Enterprise & Regulatory Reform (disbanded in June 2009, and functions transferred to BIS)
BIS	Department for Business, Innovation and Skills
CASE studentships	Collaborative Awards in Science and Engineering: doctoral training grants for graduates to undertake research on a subject selected and supervised jointly by academic and industrial partners
CBI	formerly the Confederation of British Industry, the main lobbying organisation for UK business
CEO	Chief Executive Officer
CIO	Chief Information Officer
COPD	Chronic Obstructive Pulmonary Disease
core STEM	a category defined for the purposes of this report as biological, physical, computing and mathematical sciences, and engineering and technology; medicine and dentistry, subjects allied to medicine, veterinary science, and agriculture and related subjects are excluded
CRM	Catastrophe Risk Modelling
CST	Council for Science and Technology
DCM	Demand Chain Management
DCMS	Department for Culture Media and Sport
DfT	Department for Transport
DIUS	Department for Innovation, Universities and Skills (disbanded in June 2009, and functions transferred to BIS)
DTI	Department of Trade and Industry (disbanded in 2007, and functions transferred to BERR and DIUS)
EngD studentships	a PhD studentship leading to the award of an Engineering Doctorate Degree, during which the student conducts some research in an industrial context
EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
FSA	Financial Services Authority

Funding Councils	the Higher Education Funding Councils in England (HEFCE), Wales and Scotland, responsible for distributing public money for teaching and research to universities and colleges. In Northern Ireland this role is performed by the Department for Learning and Employment, which we include when using the phrase 'Funding Councils'
GDP	Gross Domestic Product—a measure of total economic activity
GIS	Geographical Information Systems: an information system that links together difference types of information link to a certain geographic area
GPS	Global Positioning System
grid computing	using several interconnected computers, sometimes distantly located from each other, simultaneously to solve a single problem
GVA	Gross Value Added: the contribution to the economy of each individual producer, industry or sector in the United Kingdom (or GDP minus taxes plus subsidies on products)
HEFCE	Higher Education Funding Council for England, responsible for distributing public money for teaching and research to universities and colleges in England
HEIF	Higher Education Innovation Fund: a funding mechanism administered by HEFCE designed to support knowledge exchange activities between HEIs and other organisations
HEIs	Higher Education Institutions
HESA	Higher Education Statistics Agency
IDeA	Improvement and Development Agency for local government
IoS	Index of Services: a statistic published by the ONS showing monthly changes in value added by 22 of 27 service sectors in the UK
IP	Intellectual property
IPGC	Innovation and Productivity Grand Challenge: one of four 'Grand Challenge' consortia funded by the EPSRC's 'Innovation Manufacturing' programme
IPPC	the International Plant Protection Convention: an international treaty to prevent the spread and introduction of pests of plants and plant products
ISIC	International Standard Industrial Classification of All Economic Activity (see SIC)
IT/ICT	Information Technology/Information and Communications Technology
IvT	Innovation Technology: a 'digital toolkit' comprising eScience, simulation, modelling and virtual prototyping software
KE(O)	Knowledge Exchange (Office)
KIBS	Knowledge Intensive Business Services—SIC(92) 64.2, 65 to 67, 72 to 73, 74.1 to 74.4
KTN	Knowledge Transfer Network
KTP	Knowledge Transfer Partnership
LINK	the main interbank ATM network in the UK
LSBU	London South Bank University
LTCM	Long Term Capital Management, a US hedge fund which failed in the late 1990s
MRI	Magnetic Resonance Imaging
NACE	Classification of Economic Activities in the European Community
NAO	National Audit Office
NATII	National Transport Information Incubator
NESTA	National Endowment for Science, Technology and the Arts
NHS	National Health Service
NIC	the NHS's National Innovation Centre
OECD	Organisation for Economic Co-operation and Development
ONS	Office for National Statistics
OS	Ordnance Survey

OSI	Office of Science and Innovation
PET	Positron emission tomography
R&D	Research and Development
RAE	Research Assessment Exercise
RCUK	Research Councils UK: a partnership of the UK's seven Research Councils
RFID	Radio-Frequency Identification: a tag attached to an object allowing it to be identified and tracked from a distance using radio waves
RNLI	Royal National Lifeboats Institution
services	Sections G to Q of the Standard Industrial Classification (SIC) 1992
SIC	Standard Industrial Classification, a system used by the Office for National Statistics to classify organisations according to the type of economic activity they engage in
SIPR	Scottish Institute for Policing Research
SMEs	Small and Medium Enterprises; defined in the UK as companies with fewer than 250 employees, a turnover of not more than £25.9 million and a balance sheet total of not more than £12.9 million
SNA	System of National Accounts
SPPI	Services Producer Price Index
SPRU	Science Policy Research Unit at the University of Sussex
SSME	Service Science, Management and Engineering: a term used to describe an interdisciplinary approach to studying, designing and implementing services systems, and associated university courses
STEM	Science, Technology, Engineering and Mathematics
TfL	Transport for London
Trading Funds	Trading funds were introduced by the UK Government under the Trading Funds Act 1973 as a 'means of financing trading operations of a government department'. There are over 20 UK Trading Funds and these are required to operate within a framework that includes supplementing, or fully funding, their operations from receipts of goods and services including licensing of data under delegated Crown copyright. Some of these Trading Funds also levy statutory charges. The business models and environments within which Trading Funds operate vary greatly. A continuum exists from those where data charges levied are a very small percentage of their recognised income to those that fully subsist from licensing their data
TSB	Technology Strategy Board
UKCES	UK Commission for Employment and Skills
UK Innovation Survey	The UK contribution to the Europe-wide Community Innovation Survey. The survey is sent to enterprises with ten or more employees in manufacturing and services sectors, and asks about organisations' innovation activity over the preceding three years. The survey was originally conducted every four years, but since 2005 has taken place every two years. The 2007 survey was sent to 28,000 UK enterprises, and had a 53% response rate
VAR	Value-at-risk

Annex 2 Acknowledgements and contributors

This study would have been impossible without contributions from a vast range of individuals and organisations. Those who wished to be acknowledged are set out below.

I am grateful to all of them and especially grateful to the members of the Working Group which produced the report; they are named on page vii.

Finally, it is a pleasure to acknowledge the financial support of both the Economic and Social Research Council and the Royal Bank of Scotland. This enabled us to commission various studies, especially many interviews of key business leaders conducted for us by SQW Consulting. We record their dispassionate help: they had no influence over the conclusions of this report.

David Rhind,

Chairman of the Royal Society *STEM in Services Innovation* Working Group

Data provision, analyses, interviews, and literature reviews

We commissioned researchers and consultants to conduct interviews, analyses, and literature reviews for us. Dr Ammon Salter and Dr Johan Bruneel (Imperial College Business School) analysed the AIM IPGC Survey of EPSRC Industrial Collaborators, Professor Bruce Tether (Imperial College Business School) analysed data from the UK Innovation Survey, Sally Gee (Manchester Business School, University of Manchester) did a case study analysis, Dr Alexander Frenzel (Imperial College Business School) reviewed the relevant academic literature, and David Lobley and Robin Brighton from SQW Consultants conducted the semi-structured interviews and wrote an initial report.

We received data from a number of public bodies for use in the report. We are grateful to Julia Bottomley and Debbie Buckley-Golder from the KTP Programme Office at AEA group for providing data on Knowledge Transfer Partnerships, Tomas Ulrichsen (Public and Corporate Economic Consultants Ltd.) for providing data from a review of HEFCE/OSI Third Stream Funding, Adrian Day (Higher Education Funding Council for England) for sending data from the Higher Education Business and Community Interactions Survey, and Stephanie Duff and Ainsley Smith (Office for National Statistics) for providing GDP time-series data.

Advice and discussion

The working group are very grateful to the following people who provided information or advice in informal discussions with members of the working group or the project secretariat:

Professor Christopher Allsop (University of Oxford)

Adrian Alsop (Economic and Social Research Council)

Peter Andrews (Financial Services Authority)

Andrew Bailey (Bank of England)

Barbara Beebee (The Actuarial Profession)

David Bolt (Serious Organised Crime Agency)

Tim Bradshaw (CBI)

Steve Bundred (Audit Commission)

Dolores Byrne (QinetiQ)

Tony Clayton (Office for National Statistics)

Professor Geoffrey Crossick (Goldsmiths University of London)

Partha Dasgupta (Pension Protection Fund)

Hamish Dibley (Improvement and Development Agency (IDeA))

Keith Dugmore (Demographic Decisions)

Professor Richard Durbin (Sanger Centre)

Jean-Noel Durvy (DG Enterprise and Industry, European Commission)

Dr David Evans

Helen Fleming (HM Treasury)

Stuart Fraser (City of London Corporation)

Alice Frost (Higher Education Funding Council for England)

Dr Dougal Goodman (Lighthill Risk Network)

Sandy Gordon (National Audit Office)

Iain Gray (Technology Strategy Board)

Richard Greaves (Meggit Aviation)

Philip Greenish (The Royal Academy of Engineering)

Katy Grundy (Transport for London)

Professor Steve Haberman (Cass Business School)

Sir Stelios Haji-Ioannou (easyGroup)

Jennifer Harris (Managing Director, JRBH Strategy & Management)

Javier Hernández-Ros (DG Information Society & Media, European Commission)

Professor Alan Hughes (University of Cambridge)

Toby Hutcherson (Environment Agency)

Nigel Jenkinson (Bank of England)

Alistair Johnston (KPMG)

Helen Joyce (The Economist)

Sir Paul Judge

Sir David King

Dr Ray Lambert (Department for Business, Innovation and Skills)

Professor Sir Alan Langlands (Higher Education Funding Council for England)

Roy Leighton (Financial Services Skills Council)

Fenella Maitland-Smith and Jil Matheson (Office for National Statistics)

Richard Max-Lino (Technology Strategy Board)

Trevor Maynard (Lloyd's)

Allan Mayo (Department for Business, Innovation and Skills)

Sir Callum McCarthy (former chairman of the Financial Services Authority)
Sir Richard Mottram
Adrian Penalver (Bank of England)
Vicky Pryce (Department for Business, Innovation and Skills)
Professor David Pym (HP Labs)
Stephanie Robson (Department for Business, Innovation and Skills)
Dr Sandy Scott (Chartered Insurance Institute)
Professor Robin Sibson (Higher Education Statistics Agency)
Aileen Simkins (Office for National Statistics)
Colin Singer (Watson Wyatt)
Malcolm Skingle (GlaxoSmithKline)
Richard Susskind (Director, Richard Susskind & Company)
Richard Taylor (HP Labs)
Chris Tofts (HP Labs)
Rolf Tolle (Lloyd's)
Rear Admiral John Trewby
Lord Adair Turner (Financial Services Authority)
Amanda Turner (QinetiQ)
Sir David Varney
Jonathan Waller (Higher Education Statistics Agency)
Dr Martin Weale (National Institute of Economic and Social Research)
Martin Whitworth (Environment Agency)
Sir Alan Wilson (University College London)
Robin Youll (Office for National Statistics)

Written evidence

The following organisations and individuals provided written submissions in response to our Call for Evidence. Organisations or individuals who asked not to be listed have been omitted from the list below. Asterisks indicate those who asked for their evidence not to be published.

Aberystwyth University
Academy of Medical Sciences
Aston University
Benfield UCL Hazard Research Centre
BMT Group Ltd
Bournemouth University
Brunel University
BT Centre for Major Programme Management
Cardiff University
Centre for Service Research (at University of Exeter)
CBI
Clifford Chance
Coventry University—Faculty of Engineering and Computing
De Montfort University
EDS*
Financial Services Authority
Financial Services Research Forum
Financial Services Skills Council
Guy Carpenter
IBM
IBM (Belgium)
Imperial College London*
Institute of Physics
King's College London
Legal & General
London Metropolitan University
Manchester Business School
Manchester Metropolitan University
Napier University
Newcastle University
Northumbria University
Oxford Institute of Retail Management
Oxford-Man Institute
Professor Neil Wrigley (University of Southampton—personal response)
Queen Mary University
Research Councils
Retail Research Group, University of Surrey
Robert Gordon University
Royal Bank of Scotland Group
Science and Technology Facilities Council
Steve Jewson (Risk Management Solutions—personal response)*
Technology Strategy Board
Trevor Maynard (Lloyd's—personal response)
UCL Department of Physics & Astronomy
University College London
University of Aberdeen
University of Bedfordshire
University of Chester
University of Cumbria
University of Exeter
University of Hertfordshire
University of Leeds
University of Leicester
University of Manchester
University of Plymouth
University of Portsmouth
University of Strathclyde
University of Surrey
University of Sussex*
University of the West of England
University of Wales Institute, Cardiff
University of Wolverhampton
University of York
Warwick University
Willis Re*

Semi-structured interviews

We are very grateful to individuals and representatives from the following organisations for agreeing to be interviewed for this project.

Accenture Technology Labs
Arup
Buro Happold
Butters Innovation Ltd
Credit Suisse and University College London
C-Tech Innovation Ltd
dunnhumby
EA Technology
EMB
Engine Service Design
Frazer Nash Consulting
Google
Gordon Edge
Halcrow
HSBC
Ipsos Mori
J.P. Morgan
Jane Tozer
KPMG
Laing O'Rourke
Live|work
Lloyd's
Lucid Group
Marks & Spencer
Martin Bontoft
Met Office
Monitise
NHS Direct
NHS Institute for Innovation
NHS London
Ordnance Survey
Oxford Asset Management
Peter Jones
Roke Manor Research
Science Business
Standard Life
Tesco
Tesco.com
Thinkpublic
Unilever
Unique Media
Wincanton
Yet2

Workshops

The following individuals attended the business or academic workshops held on 26 November 2008 at the Royal Society. Asterisks indicate members of the project working group.

Peter Andrews	Head of Department, Economics of Financial Regulation, Financial Services Authority
Professor John Burland FRS*	Emeritus Professor of Soil Mechanics, Imperial College London
Jonathan Butters	Butters Innovation Ltd
Christopher Clack	Director, Financial Computing, University College London
Nick Cooper	Director, Projects & Engineering, Meggit Sensing Systems
Dennis Curry	EMEA Innovation Director, EDS
Rowan Douglas	Chairman, Willis Research Network
Jerzy Graff	Director of Environment Systems, BMT Group Ltd
Dr John Henderson	Knowledge to Innovate, C-Tech
Michael Hume*	Bank of England
Steve Jewson	Risk Management Solutions (personal response)
Professor Michelle Lowe	Professor of Retail Management, University of Surrey
Michael Lyons*	Chief Researcher, Services and Systems Science, BT Group Chief Technology Office
Colin McKinnon	Innovation Director, Buro Happold Limited
Professor Andy Neely	Deputy Director, AIM Research, Cranfield School of Management
Professor Irene Ng	Director, Centre for Service Research (at University of Exeter)
Dr Paul Nightingale	Complex Product Systems (CoPS) Innovation Centre
Dr Shail Patel	Programme Director, Digital Consumers & Markets, Unilever

Professor Robert Paton	Professor of Management, Complex Services Innovation Research Network, University of Glasgow
Giles Pavey	dunnhumby
Chris Pearson	S4T Programme Coordinator, Institute for Manufacturing, University of Cambridge
Professor David Rhind FRS*	
Chris Sexton	Head of Engineering (Europe), Laing O'Rourke
Laura Smith	Research Assistant, Centre for Service Research (at University of Exeter)
Jon Stethridge	Managing Director, Unique Media
Paul Tasker	Programme Director, Support Solutions Research, BAE Systems
Sir John Taylor OBE FRS*	Chairman, Roke Manor Research
Professor Bruce Tether	Innovation Studies Centre, Imperial College London
Dr Kathy Tyler	Director, Service Sector Research Centre, University of Westminster
Mark Weatherhead	Guy Carpenter & Company Ltd
Ana Wheelock	Network Coordinator, Health and Care Infrastructure Research and Innovation Centre, Imperial College Business School
Stacy Williams	Head of Quantitative Strategy, HSBC
Peter Wrobel	Managing Editor, Science Business
Dr Alejandro Zalnieriunas	Senior Director, IT & Service Development, Vodafone

Annex 3 Treatment of the services sector and innovation by the Office for National Statistics

How services and innovation are measured by official statistics is critical in assessing how best to understand them and also what policy levers might usefully be employed to foster innovation based on STEM. This detailed note was kindly provided by Mr Tony Clayton, Divisional Director, Economic Analysis, in the Office for National Statistics (ONS): it illustrates the complexity of decision rules employed under international statistical standards.

Defining service firms

The agreed international System of National Accounts (SNA) defines the process.

One SIC code is associated to each unit recorded in statistical business registers (which, at the lowest level means a geographic or local unit), according to its principal economic activity. The principal activity is the activity which contributes most to the value added of the unit.

Under the rules on outsourcing, units which outsource all of their manufacturing and do not own the material inputs used in the manufacturing process will not be classified in manufacturing but in services. An example of the results of this rule is that Apple is classified by the US statistical system as a wholesaler of imported goods. Normally the units which supply them will be classified in manufacturing.

The description that businesses provide of their activities will not always indicate whether, under the outsourcing rules, they are classifiable in services rather than manufacture but such businesses can be identified using, within appropriate thresholds, ratios for variables collected by the Annual Business Inquiry (ABI):

- Purchases/sales;
- Purchases of goods for resale + sub-contracting/ purchases;
- Sub-contracting/sales;
- Turnover/employment (which needs different thresholds per industry).

Each reporting unit (which is the unit of homogeneous activity on which firms choose to report) is then classified on the basis of aggregating its local units by value added. If value added cannot be determined, substitutes such as gross output (sales) or employment are used.

The manufacturing/service split of the whole economy is defined in terms of industries as aggregated from firms, classified in this way.

Treatment of outsourcing/offshoring

Rules for determining how outsourcing is treated at firm level depend on who owns the inputs and outputs to the process.

Case 1) A principal who owns the main material inputs sub-contracts the complete manufacturing production process of products to another unit.

Codification rules: The principal who owns the main material inputs (eg textiles and buttons for the production of apparel, wood and metal accessories for the manufacture of furniture) and thereby owns the final outputs, but who has done the production by contractors, is classified in NACE Section C (Manufacturing), in the class that corresponds to the full production process. The contractor is classified with units producing the same goods for their own account.

Case 2) A principal who doesn't own the material inputs sub-contracts the complete manufacturing of products to another unit.

Codification rules: The principal who completely outsources the transformation process and doesn't own the material inputs is classified in accordance with the value added principle. The contractor is classified with units producing the same goods for their own account.

Rules for coding are included in the SIC 2007, which is on the ONS website (ONS 2008).

The rules are the same whether the outsourcing is undertaken in the UK (domestic outsourcing) or outside the UK (offshoring/importing). The ABI, through which the sales and value added data is gathered, does not distinguish between imported and domestically purchased goods—our information on these comes from administrative sources. However, it does collect data on imported and exported services, which has allowed the ONS to do useful work on patterns and trends of offshored services.

1.1 Turning survey data into estimates of manufacturing/services output

ONS produces short term (monthly and quarterly) and longer term (annual) estimates of economic output. The annual estimates of overall GDP are benchmarked to the ABI, which covers over 60,000 manufacturing and service firms. They also bring together a range of survey detail on purchases and sales by firms, on investment and consumption, which help to build a detailed picture of the structure of the economy. These are used to construct supply—use tables which show relationships between industries, how much output from each of 123 industries defined goes to each of the others, how much into investment, and how much into consumption.

The approach to short term output data is, in principle, the same for services and manufacturing—deflated turnover is taken to be the preferred indicator of changes in real value added. The service sector presents additional complexity due, mainly, to diversity of activities and the intangible nature of output. In some service industries it is necessary to use direct physical measures or input measures as proxies for output.

Service sector activity is measured from high frequency surveys of turnover and prices. The surveys include:

- Monthly Inquiry into the Distribution and Service Sector;
- Monthly Retail Sales Inquiry;
- Direct volume indicators.

To account for inflation, the figures are deflated using:

- Consumer prices index;
- Services Producer Price Index (SPPIs);
- Where SPPIs are not available, proxies based on earnings or consumer prices.

The accuracy of the deflation process depends on good estimates of product share within overall industry output. For the manufacturing sector this depends on a detailed (and very data intensive) survey of product outputs, (PRODCOM) required as part of EU regulation. A comparable services survey (SERVCOM), was recommended in the Allsopp review (Allsopp 2004).

The removal of price effects, and measurement of work in progress, are challenging for the service sector generally. These issues are strongest in sectors such as retail, finance and public sector which face specific challenges (for details, see Tily 2006).

The UK is a world leader in providing annual, quarterly, and monthly service sector estimates in response to user demands. It was the first country to develop a monthly indicator based on internationally agreed methods for the whole of the service sector.

Currently the Index of Services (IoS) covers 22 of the 27 service sector divisions, accounting for 94% of service sector activity. The IoS was launched in 2000 as an experimental statistic, and reclassified in 2007 as a National Statistic after significant improvements. Individually, over 80% of the IoS divisions are classified as National Statistics, and improvements have been made in five key areas: data sources and methods, seasonal adjustment, periodicity, level of detail, timeliness of publication. For more detail, see Drew and Morgan (2007).

One issue which challenges statistics offices round the world is dealing with substitution of domestically produced intermediate inputs by much lower priced goods or services from overseas. As lower cost imports increase, reported value added in firms increases. If value added measures of firm or industry output are deflated only by sales prices, then real growth will be overstated. There is a concern in the US that this has led to overstatement of manufacturing output. http://www.businessweek.com/magazine/content/07_25/b4039001.htm?chan=search

The ideal remedy is use of better price indices (for goods and services) to separately deflate inputs to and outputs from each industry. This is known as 'double deflation' and is one of the objectives of the national accounts reengineering, now underway.

ONS innovation surveys and treatment of services

ONS conducts three main surveys with regard to innovation, on R&D, ICT and innovation itself. All three are covered by EU Regulation, with UK variation to meet users' needs.

The Business Enterprise R&D Survey

The R&D survey is drawn from a universe of businesses that have previously reported R&D activity, either through inclusion in the survey or through signifying that they carry out R&D by responding to a question added biennially to our Annual Business Inquiry (which covers manufacturing and service firms). Businesses that have previously reported activity but now report that they have no plans to do so in the future are removed from the universe. Horizon scanning is also used to populate the universe, with specific effort to recruit to the banking and financial sector as the ABI excludes this sector. This process means that the whole economy is surveyed.

The questionnaire issued requests information about current and capital spend on R&D, with no specific questionnaire design arrangements to differentiate the service sector. The definition of R&D is internationally agreed, and covers activity to 'resolve technical uncertainty'; historically the interpretation of the definition has focused on physical products and processes. The survey is compulsory for selected firms.

The ICT use survey (also known as the e-Commerce survey)

This is a survey designed to assess the penetration and sophistication of ICT across business. It is an annual survey with a core of common questions, plus modules which change from year to year, and which are agreed across the EU.

From initial conception in 2001, when the survey was designed to assess how many firms used computers, the internet and e-commerce plus the value and distribution of electronic trading, the survey has developed to produce a broader picture of how firms use technology to link internal operations (process innovation) and link with customers and suppliers (service innovation). The survey is common across manufacturing and most service sectors—except for financial services where a specific format has been developed.

This survey has helped—along with estimates of demand for ICT investment—to show the importance of ICT for service innovation. Household surveys on the use of ICT also show where consumer behaviour consumption patterns are changing in response to innovation.

The Innovation Survey

The coverage of the UK Innovation Survey is laid down in EU Regulation, although we have extended coverage beyond the minimum to include some additional service sector businesses to meet UK policy users' needs. Some areas of the service sector are not included, for example, Public Administration, Education and Healthcare. The UK innovation survey is voluntary, and so achieves a lower response rate than the R&D and ICT surveys (but still well above the response rates in some other EU countries).

The survey covers both outputs from innovation (products and services, patents and know-how) and inputs to innovation (scientists and engineers, R&D activity, external sources of knowledge, and other activities required to turn knowledge into marketable outputs). Design of the survey is driven by policy colleagues in BIS and the UK version is ahead of some other countries in terms of its coverage of 'soft innovation' not directly related to technology.

Innovation is defined by international guidelines. This guidance changed in 2005 to include organisational and marketing innovation, in addition to the 'traditional' product and process innovations, acknowledging concern that these innovations were being overlooked. The change is a positive one as it increases the scope for identifying innovative businesses in the service sector, and helps to examine how technical and non-technical innovation complement each other.

New work on 'intangible' innovation investment, based on services

Over the last four years ONS has been working with Queen Mary, University of London, London School of Economics, HM Treasury, Bank of England and other stakeholders to improve data and understanding in those areas of innovation investment which depend on services. This means expenditure (by firms) which builds productive capacity for the future, but which is not classified as investment by accountants (either company accountants or in the National Accounts).

The programme's first big impact on ONS published statistics came last year, when we included fully 'own account' software as investment by firms, required by the System of National Accounts (SNA)—adding around £9 billion to GDP (see Chamberlin *et al.* 2007). The ONS is now working on the next SNA revision which requires R&D to be treated in the same way (Galindo-Rueda 2008).

Further work in this area, to quantify other intangible assets (non-technical innovation costs, work related human capital, organisation, reputation) has produced insights into the UK economy. It has shown the importance of intangible assets in the UK market economy (roughly equal to tangible investment), and a new view of UK productivity which challenges 'official' data. These were published in October 2007 as part of the Treasury pre-budget report (Marrano *et al.* 2007). Following this we are supporting work on distribution of intangible assets across industries in the UK economy, and initial results have been published by the National Endowment for Science, Technology and the Arts as part of their innovation index programme (Clayton, Dal Borgo and Haskel, 2008).

This work is of vital interest to the UK, because structural changes happening here mean we have one of the highest concentrations of intangible investment of the major world economies. It has increasing policy relevance, because:

- initial work (with Jonathan Haskel and others) shows some areas of intangible investment need better measures;
- some 'intangibles' will be included in National Accounts in the next few years, starting with R&D as a result of the new 2008 SNA;
- understanding the overall effect of intangibles, including parts which will not be covered by National Accounts changes, and being able to value their impacts, is important to Treasury, Bank, the Intellectual Property Office, BIS, the Department for Culture, Media and Sport and private sector analysts.

Annex 4 The evolution of Standard Industrial Classifications over time

Services are highlighted in grey

SIC 1992		SIC 2003		SIC 2007	
Section	Description	Section	Description	Section	Description
A	Agriculture and forestry	A	Agriculture, hunting and forestry	A	Agriculture, forestry and fishing
B	Fishing	B	Fishing		
C	Mining and quarrying	C	Mining and quarrying	B	Mining and quarrying
D	Manufacturing	D	Manufacturing	C	Manufacturing
E	Electricity, gas and water supply	E	Electricity, gas and water supply	D	Electricity, gas, steam and air conditioning supply
				E	Water supply, sewerage, waste management and remediation activities
F	Construction	F	Construction	F	Construction
G	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods	G	Wholesale and retail trade: repair of motor vehicles, motorcycles and personal and household goods	G	Wholesale and retail trade; repair of motor vehicles and motorcycles
H	Hotels and restaurants	H	Hotels and restaurants	I	Accommodation and food service activities
I	Transport, storage and communication	I	Transport, storage and communications	H	Transportation and storage
				J	Information and communication
J	Financial activities	J	Financial intermediation	K	Financial and insurance activities
K	Property development, renting, business and research activities	K	Real estate, renting and business activities	L	Real estate activities
				M	Professional, scientific and technical activities

				N	Administrative and support service activities
L	Public administration and defence; social security	L	Public administration and defence; compulsory social security	O	Public administration and defence; compulsory social security
M	Education	M	Education	P	Education
N	Health and social work	N	Health and social work	Q	Human health and social work activities
O	Other community, social and personal service activities	O	Other community, social and personal services activities	R	Arts, entertainment and recreation
				S	Other service activities
P	Private households with employed persons	P	Activities of private households as employers and undifferentiated production activities of private households	T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
Q	International organisations and bodies	Q	Extraterritorial organisations and bodies	U	Activities of extraterritorial organisations and bodies
R	Not known (field blank)				