HM TREASURY

Investing in Innovation

A strategy for science, engineering and technology

July 2002

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PREFACE

In an increasingly knowledge-driven global economy invention and innovation are critical to Britain's long-term competitiveness. This requires a virtuous circle of innovation: from the very best research in science, engineering and technology in universities and science labs to the successful exploitation of new ideas, new science and new technologies by businesses.

The 2002 Spending Review announced the largest sustained growth in science expenditure for a decade – £1.25 billion extra a year by 2005–06. This document – building on the commitments we made in the Science and Innovation white paper of 2000, *Excellence and Opportunity: A science and innovation policy for the 21st century* – sets out the strategy we will adopt to ensure that our science and engineering base grows and flourishes and makes an increasing contribution to national prosperity. Specifically, we will:

- Establish a substantial and dedicated stream of capital for universities, worth £500 million per year by 2004–05, to develop their science research infrastructure and to allow them to plan for the future with certainty;
- Provide substantial new resources to the Research Councils from 2005-06 to enable them to make a more realistic contribution to the full costs of the research that they sponsor in universities;
- Increase the money available to the Higher Education Funding Council for England for the research component of university block grants;
- Boost the volume of basic research through sustained real annual growth of 5 per cent in funding for Research Council programmes and equipment;
- Expand the Higher Education Innovation Fund, with funding to stimulate enterprise from research across the regions, to over £90 million per year by 2005–06;
- Invest an additional £50 million per year by 2005–06 to support collaborative research and development on key emerging and pervasive technologies such as nanotechnology; and
- Improve the pay and training of scientific postgraduate researchers, and enhance technology, mathematics and science education in our schools, colleges and universities.

And the Government, as a major user of research and scientific advice, will take action to ensure science in government departments is of the highest possible standard and is used effectively in the delivery of policy and public services.

For far too long British science has been denied the opportunity to develop. We now have the chance to turn this around: to make more British inventions become British manufactured products, creating jobs and prosperity for all.

The Rt Hon Gordon Brown, MP   The Rt Hon Patricia Hewitt, MP   The Rt Hon Estelle Morris, MP

EXECUTIVE SUMMARY

Science into innovation: realising the potential

0.1 Innovation is at the heart of productivity growth and social gain. Science makes an important contribution to providing the raw material for innovation – new knowledge and ways of understanding our world, new problem solving techniques, new technology and businesses, but above all highly educated people. Together, the generation and exploitation of science enable us to do more and to do it better: to deliver economic growth and enrich the quality of life, to widen choices for industry and individuals and improve the way we meet our current and future needs. Startling advances in communications, information, health and basic technologies are now converging to magnify the pace of scientific and technological change and the productivity of scientific research. Now more than ever before, investment in science accompanied by matching investments in technology and innovation offers the prospect of sustained social and economic dividends.

0.2 The potential of scientific and technological discoveries will only be realised, though, if they can be effectively translated into innovation – new products, processes, services and systems. A vibrant innovation system is the key to reaping the gains from research, connecting science and technology with developments in market demand and social needs. The individual entrepreneurs, businesses, and investors are the essential catalysts who convert science and technology into new ways of meeting economic and social needs. They translate ideas into commercial reality. Success in innovation can in turn provide the motivation for focused research, attract talented people and inspire public confidence in science and technology as well as providing the extra value added which can resource future increases in scientific research and business R&D. It is only through innovation that science and technology can benefit our economy and society.

0.3 The UK has a long tradition of scientific excellence and technological invention but has been much less successful in capitalising on earlier waves of scientific and technological breakthroughs. We must not allow this opportunity to elude us now. In previous decades, weak links throughout the innovation process have held back delivery of economic benefits. Excellence in scientific research had been insufficiently funded, weaknesses in education and training meant that many firms lacked people who could interface with the science base and exploit new technology. Too often, senior management failed to appreciate the importance of science and technology to their businesses. Firms were insufficiently committed to innovation and the exploitation of new markets, partly because the competitive spur to innovate was not as sharp as it should have been. Industry's own investment in technology and innovation was undermined by the instability of the economy as a whole, which damaged investment incentives. Early innovation gains were not diffused through the economy as rapidly as in other countries, contributing to the UK's relative productivity decline.

0.4 Investment in innovation is now embedded in a wider strategy for raising the sustainable growth rate of the economy through productivity gains. We have laid strong foundations of macroeconomic and structural reform. Improvements in the investment climate, the opportunities for enterprise, and the acquisition of skills provide a more supportive environment for the exploitation of science, the development of new technology and subsequent investment in innovation, which in turn will boost productivity growth. This document sets out how the science, engineering and technology research strategy is intimately connected to the Government's economic goals.

Investing in science capital and capacity

0.5 This strategy addresses the two key challenges facing UK science and technology: renewing, in a sustained manner, the physical and human capital stock which underpins our growing research endeavour; and investing in capacity to exploit the burgeoning opportunities for new science. It also addresses the way Government departments obtain and use research and scientific advice.

0.6 Because the benefits from innovation spread right across the economy and society, investment in this arena needs a collective input from all the major research funders: Government, business and research charities. The Government has the primary responsibility as lead investor in basic scientific research, and in sustaining the science education and training infrastructure. For this partnership to work well, there must also be greater clarity about the respective roles and contributions of companies and charities to research funding.

0.7 **The Government will therefore take the lead in providing a new dedicated capital stream and enhanced research funding to enable the science and engineering base to restore, maintain and grow the infrastructure for research.** Universities will be able to invest with greater certainty for the long term, but will at the same time have sharper responsibility to ensure that their research is sustainably funded. **The Government will establish clear principles on the contribution of public, private and charitable funding to maintaining the science infrastructure.** In return, universities will improve the transparency and accountability of their increasingly diverse funding streams, demonstrating clearly that, over time, the full economic costs of their research activities are covered.

0.8 The opportunities from investing in innovation are matched by imperatives to do so. Business and R&D are conducted in a global market, in which other countries are boosting their investment in science and technology. Without the body of highly educated and skilled manpower and the knowledge gained from past investments in R&D and innovation, business will not be able to exploit R&D and innovations generated elsewhere. The UK starts from a strong position of excellence in many areas, backed by good science education and training. But in key disciplines we are living off the human capital acquired in previous decades. The Government's strategy, therefore, responds positively to the findings and recommendations of Sir Gareth

Roberts' review of science skills[1]. We need to ensure that our scientific talent is continually refreshed and rejuvenated, and that the UK is an increasingly attractive location for individuals and business to engage in research.

0.9 **The Government will invest a further £100 million per year by 2005-06, through the Office of Science and Technology (OST) to improve the development of the UK's science and technology skills base. It will increase the basic support for Research Council funded PhD students to an average of over £13,000 per year, with the increases focused on subjects with recruitment difficulties. Training and career paths for researchers will be opened up. Universities will be able to invest in pay flexibility to meet skill shortages in key disciplines. Schools will gain resources to attract science graduates into the classroom, and the Government will fund science training to revitalise skills throughout teaching careers. This will include a partnership with the Wellcome Trust to deliver a National Centre for Excellence in Science Teaching. Schools and universities will also be given resources to modernise and upgrade their science engineering and technology laboratories.**

0.10 These reforms and funding should set the science and engineering base on course towards renewal over the coming decade. At the same time, the Government will boost the resources available for expansion of research, both to maintain the vibrancy of the UK's best research programmes and to enable growth in new priority areas. **By investing an extra £400 million per year by 2005-06 in science and engineering research programmes, and an additional £100 million per year by 2005-06 in equipment and capital infrastructure, the Government will fund real annual growth in research programmes of 5 per cent. This will finance the expansion of world class basic research – the life blood of scientific innovation – and allow a start to be made on new priority areas of research to tackle social challenges such as: brain science, regenerative medicine, proteomics (building on the foundation of genome sequencing in which the UK has played a key role), sustainable energy, and rural land use.**

0.11 **To complement these measures for the science base, the Government will also take steps to strengthen the use of science and management of research by Government departments.** This will help ensure that science priorities are carefully considered and given proper weight alongside other priorities in spending decisions. Arrangements for knowledge transfer will be enhanced. The Government's Chief Scientific Adviser, accountable for the quality of science in Government, will lead a new rolling programme of external scrutiny and benchmarking to reinforce best practice and high standards across departments. Improving the competence of departments to act as an intelligent customer for, and manager of, research and scientific advice, will be driven by a Chief Scientific Adviser in each of the major Government departments which perform or commission research.

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[1] ***SET for success:*** The supply of people with science, technology, engineering and mathematics skills.

Closing the innovation gap

0.12 Science and technology manifests itself in our lives through products and services, medical treatments and communications networks. The drive for this innovation must come from business. A key goal of the Government is increasing the productivity of industry and manufacturing in particular. If UK manufacturers matched the productivity levels of France, Germany and the US, and all else remained the same, the economy would be £70 billion per year better off, creating prosperity for all. Investment in innovation not only helps manufacturers retain a competitive edge in the face of growing global competition, but it is also a key driver of productivity improvements. The Government's strategy for manufacturing[2] provides a comprehensive framework for taking forward the manufacturing agenda in partnership with key stakeholders. This will be achieved, not least, by joining up Government activities and polices which underpin manufacturing success. The Government has now put in place the necessary framework of macroeconomic stability and structural reforms to create a better climate for investment. Of itself, this should encourage R&D investment by business, which by the late 1990s had shown the first signs of reversing several decades of relative decline.

0.13 The UK's strongest innovative industries are global leaders, but too many of our sectors are significantly lagging behind international investment levels in R&D. In 2000, the Government started to tackle this, through introducing tax incentives for R&D among smaller technology-based firms. This year, the Government has widened these fiscal reforms to encompass all UK-based business R&D. The Government is now investing through the tax system around £500 million per year across the full range of British manufacturing and services to underpin more than £11 billion of business R&D.

0.14 Industry's own efforts to exploit the ideas and skills emerging from the UK science base will be buttressed by continued and growing investment by the Government in knowledge transfer from the science base. Government resources will be sharply focussed on identified gaps in the transfer of scientific knowledge to industry, enabling collaboration between business and universities and forward-looking investment in future 'disruptive' technologies.

0.15 To complement this, the universities and publicly-funded research establishments need to build on their recent progress in linking with business to create value for the regional and national economy. **The Government will consolidate the Higher Education Innovation Fund (HEIF) as a permanent third stream of funding for universities, with investment rising to £90 million per year by 2005-06.** This will provide pump-priming resources for technology transfer, entrepreneurship training, corporate spin-outs and seed venture funding. The **Regional Development Agencies** will play an enhanced role in helping to direct resources from HEIF and other knowledge transfer programmes, so that they contribute most effectively to regional growth strategies.

[2] DTI (May 2002), The Government's Manufacturing Strategy.

Science and innovation in the Devolved Countries and English regions

This science strategy covers policy areas that are reserved to the UK Government such as science funding by the OST and tax credits, and those areas where policies are devolved such as higher education funding. In areas which are reserved to the UK Government, the coverage of this science strategy, and increases in funding associated with it, are UK wide. In areas that are devolved it will be for the devolved administrations to decide what policies they wish to implement; they will receive their share of increases in comparable programmes in the spending review in the normal way.

The Government intends to work closely with the devolved administrations in implementing this science strategy to ensure that the partnership between the Government and the devolved administrations delivers improved prosperity and productivity across the UK.

The Government will similarly work closely with the RDAs to strengthen the science base in the English regions, with the aim of strengthening innovation as a key driver of improved regional productivity.

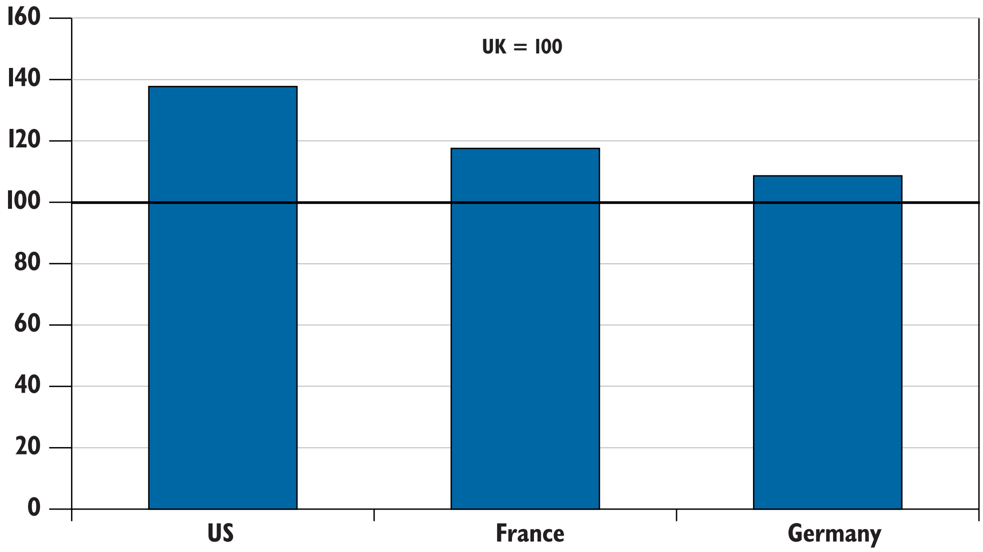
1 THE VALUE OF SCIENCE AND INNOVATION

Introduction

1.1 The Government's central economic objective is to achieve high and sustainable levels of growth and employment. To succeed, the Government is committed to increasing productivity in the UK[3].

1.2 The UK currently has a substantial productivity gap with other major industrialised economies. This gap exists with France, Germany and particularly the US, however productivity is measured. Chart 1.1 below shows that the gap, expressed as output per worker, is just under 40 per cent with the US, and that there is also a significant gap with France and Germany.

Chart 1.1: Output per worker, 2000



Source: ONS

1.3 The Government has made it clear that improving economic performance over the long term requires action across a range of areas: competition, enterprise, innovation, skills and investment. A strategy for science, engineering and technology focuses inevitably on the role of innovation. But innovation depends on enterprising companies and individuals, the supply of skills, and the opportunities and pressures created by a competitive environment. These factors are linked, and what is proposed here needs to be seen in the context of the Government's comprehensive approach to productivity enhancement.

[3] See, for example, HM Treasury (2000), Productivity in UK: the evidence and the Government's approach.

1.4 Innovation has been shown to be one of the most significant explanations of differences in GDP across countries and over time. Evidence shows that innovating companies sustain a higher performance, grow faster than non-innovators, and are much more profitable[4,5]. An economy's ability to undertake and exploit innovation is therefore central to its prospects for improving standards of living and prosperity. Despite the advances in electronic communications, research and development (R&D) activity is often concentrated in particular locations and regions, benefiting from the range of interactions which occur in and around research clusters. Business R&D is similarly drawn to specific locations, partly to benefit from regional pools of skilled labour. So national capacity for innovation matters.

1.5 To reap the economic benefits of innovation, it is therefore necessary for Government and business to invest fully in the necessary infrastructure: simply borrowing the fruits of overseas research is unlikely to be a successful long term strategy. Conversely, by creating a favourable climate for research and innovation, the UK can attract internationally mobile science and technology personnel and financial capital to this country, bringing wider productivity benefits. Encouraging scientific research and innovations flowing from them must play a major role in the Government's strategy for raising productivity.

1.6 The Government's approach to increasing innovation recognises the complexity of the environment in which firms operate and the incentives they face. It sees successful innovation as a system operating across the economy. This requires a constant stream of new ideas arising at the interface between science and technology and economic and social needs, and in which the knowledge arising from basic scientific research plays a major role. Firms must have the knowledge base, highly trained personnel and the incentives to develop these ideas into commercially successful innovations. Firms must also be able to access and absorb relevant science and technology from all sources, academic and industrial, domestic and international, in order to benefit from them. UK universities play an important role both as the primary source of scientific knowledge and as intermediaries between UK firms and science and technology worldwide. This interactive process requires sustained investment by business, but also by Government, as funder of the science base and user of research for public policy and service delivery.

The value of innovation

What is innovation?

1.7 Innovation is the generic term for the successful exploitation of new ideas. Although innovation is often viewed as, and quantified by, R&D activity, it is much more than that. Innovation can result from new science and technology, from changes in skills or business processes, or from the exploitation of new markets. Typically all or most of these are involved. New technology can

[4] Geroski and Machin (1993), The Profitability of Innovating Firms, RAND Journal of Economics.

[5] Cameron (1998), Innovation and Growth: a survey of the empirical evidence, Mimeo Nuffield College; Cameron (2000), R&D and Growth at the Industry level, Nuffield College, Discussion Paper. No 2000-W4; OECD (2000), The impact of Public R&D on Business R&D.

result from scientific research (particularly in science-based sectors), from R&D carried out by the firm concerned, from customers, suppliers and competitors, from engineering development, and from 'learning by doing'. Although attention tends to focus on the initial introduction of a new product, process or system, it is its subsequent diffusion through the economy which yields the benefits to productivity and economic and social well-being. This may take decades and usually involves the innovation being improved out of all recognition from its original appearance.

1.8 Innovation itself can take many different forms including: process innovations, product innovations and innovations in business processes and models. One type of innovation often needs to be linked with others if it is to be successful. For example, a manufacturer may generate a product innovation, which then becomes an input into a process innovation. Organisational innovation will often accompany the new process in order for the user to maximise the benefit from the technological change.

1.9 Historically, the bulk of R&D has been carried out by the industrial sector. In the face of growing global competition, the most successful industrial companies invest in continuous innovation in order to add value in production and customer services and to ensure that, in product and service development, they can remain ahead of what will often be lower cost competition from overseas.

1.10 Industry's contribution to the UK's R&D activity remains vital, particularly in leading edge product innovations in high-tech sectors. But it is no longer enough to encourage R&D in manufacturing and industry alone. As the service sector has expanded in industrial economies, improving overall economic performance means more widespread increased attention to technology. This may not require such firms to spend heavily on R&D to increase innovation. Rather, the emphasis may be on firms having the ability to absorb, adopt and adapt technological improvements and to organise their processes and functions more innovatively to make productivity gains.

1.11 Increasing innovation therefore requires a multi-faceted approach that recognises the different circumstances of different firms and sectors, appreciates the regional dimension, and recognises that firms do not innovate in isolation. Interaction with different institutions and the incentives created by the microeconomic climate are crucial to a country's innovation performance.

The importance of R&D and innovation to economic growth

1.12 Work by the OECD and others has demonstrated that R&D carried out by businesses across different sectors has had a large impact on productivity[6,7]. Estimates of the contribution of a firms' own R&D effort to productivity

[6] E.g. OECD (2000), Knowledge technology and economic growth: recent evidence from OECD countries; OECD (2001), R&D and productivity growth: a panel data analysis of 16 OECD countries.

[7] E.g. Coe and Helpman (1993), International R&D Spillovers; Englander and Gurney (1994), OECD Productivity Growth: Medium Term Trends.

growth are typically high – estimates of private annual rates of return to R&D tend to be around 10 to 15 per cent, although some studies have estimated them to be as high as 30 per cent[8]. Further recent analysis of returns in the UK puts this figure at between 10 and 20 per cent. To set this in context, the average net rate of return on capital employed for UK manufacturers over the period 1970 to 2001 was 5.7 per cent per year.

1.13 Furthermore, there are also significant positive spillover effects from private R&D activity, which increase the benefit of the R&D to the economy as a whole (the social return). Spillovers can occur through a number of sources, for example through the transmission of knowledge through scientific journals, via engineering understanding of the product itself and the movement of skilled workers between firms. These can create difficulties in capturing the full economic benefits of innovation via the price of a product or service. Spillovers are generally largest between firms in the same industry, although sizeable spillovers may occur across industries and across countries.

1.14 The effect of these spillovers is seen in estimates for social rates of return, which are consistently found to be higher than private returns. Research indicates the private rate of return may constitute as little as a quarter of the social returns to R&D as a result of technology spillovers. This means that society as a whole would benefit from firms undertaking more R&D than they would individually choose to do. This divergence between private returns and social returns implies that firms left to their own devices will generally face insufficient incentives to invest in R&D from society's point of view[9].

1.15 The end result is that, left to itself, the private market will tend to under-invest in R&D. This provides a clear rationale for Government intervention to create incentives for firms to increase the level of privately funded R&D to the optimal level by capturing more of the benefits associated with spillovers, which firms are unable to appropriate directly. Basic scientific research is likely to be particularly subject to under-provision, owing to its broad nature and the high-risks associated with investment.

The innovation system

1.16 This strategy sets out in detail how the UK can encourage increased innovation to help drive up productivity through investment in R&D. Successful technological innovation needs to be seen as a system operating across the economy. A variety of conditions need to be met for such a system to work effectively. In some, Government's role is direct and obvious – the funding, for example, of education to generate a skilled workforce. In others, the role is indirect, but still important. Tax policy, for example, can help to strengthen the incentives for innovation by increasing post-tax returns to investment. Competition policy can create incentives for innovation by encouraging the entry of new providers and new services. Striking the right balance in these

[8] Hall (1996), The Private and Social Returns to Research and Development, in [eds] B Smith and C Barfield, Technology, R&D and the Economy, Brooking Institution and American Enterprise Institute: Washington DC.

[9] Griliches (1992), The Search for R&D Spillovers, Scandinavian Journal of Economics, Vol. 94.

relationships can be complex. Intellectual property rights, for example, restrict competition, but are essential to give innovators the incentives they need to take risks.

1.17 National policies provide the framework within which the innovation system operates at a local and regional level. The collaborative and interactive nature of much research and its exploitation in the economy roots much of this activity in specific locations, based on localised linkages between researchers, institutions and business. This human and social dimension provides the drive towards the clustering of innovation and the persistence of activity in specific regions over time.

1.18 Clustering is a well-known phenomenon: Silicon Valley, Cambridge and the Thames Valley are familiar examples for the 'new economy'; recent studies[10] have identified many other innovation-based clusters across the UK. The main drivers behind such concentration include 'thick' labour markets, particularly in highly skilled personnel with technical and commercial expertise. Universities can be a major source of supply into these labour markets – particularly of the highest-quality graduates and academics. Supply linkages between firms can also be important, and also between firms, university departments and other research organisations. Another element seen in many innovation clusters is the supply of high-quality professional and financial services. Local access to capital can be particularly important, especially when firms are too small to access national and international markets. Financing of technology firms is a specialist activity, and brings not just financial capital but access to networks and expertise in building businesses and markets.

1.19 Persistence effects can be seen in innovation performance at both the level of individual firms and regions. Once a firm or region has established itself on a successful trajectory, it is more likely to stay there. A firm that has assembled the resources needed to fund and manage successful innovation – the access to intellectual and financial capital, the expertise to undertake R&D and the management skills involved in commercialising technology successfully – is more likely to be able to continue attracting these resources, whether by recruiting good quality graduates or extra financial capital.

1.20 This said, innovation is not a smooth or linear process. Much innovation is characterised by incremental change. But other changes can be more dramatic – like the emergence of wholly new technologies which disrupt existing products and processes. Firms will have different capabilities to adopt and implement different types of change. But the larger the technological change, the more radical the change that is likely to be required in organisational form. This may mean the rise of wholly new markets and industries, populated by new entrant firms, or the transformation of existing firms so that they have a different character. Science, technology and customer needs influence one another in the innovation process.

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[10] For example, DTI (2001), UK Business clusters in the UK.

1.21 These characteristics of innovation have implications for policy. They stress the importance of building on success at the regional and national level, to strengthen conditions for growth. They also point to creating an environment that supports the widest variety of innovations across firms and technologies, and to reducing barriers to entry to new enterprises. Creating such a system will require action in many areas.

1.22 Successful innovation requires a continual stream of new scientific, technological and business ideas on which entrepreneurs and firms can draw to develop new and commercially successful innovations. These in turn require:

- strong basic research capability to provide the new knowledge and research methods;
- strong technological capability within firms to undertake R&D and other forms of technology development and to seek out, absorb and adapt science and technology from elsewhere;
- business capabilities to adapt new technology to the needs of customers, to produce, market and service products successfully and to manage the innovation process generally; and
- sufficient supply of high level skills in scientists and engineers and trained managers to support the above.

1.23 The UK has produced high volumes of high quality basic scientific research for many years. Much of this is performed in university science and engineering departments. Since 1997, the Government has consistently invested in university research because it produces successful outcomes. In the 1998 Spending Review, the Science Budget was increased by 15 per cent in real terms between 1999-2000 and 2001-02. Following the 2000 Spending Review, it has been increasing at 7 per cent per year in real terms. Combined annual DTI and DfES spending on science research now stands at some £3 billion. Chapter 3 deals with the detailed issues that need to be addressed to ensure that universities can continue to provide world-class research on a sustainable basis in the face of increased global competition for talent and ideas.

1.24 To understand better the supply of scientists and engineers to the UK economy, in the 2001 Budget the Government commissioned Sir Gareth Roberts, President of Wolfson College Oxford, to carry out a review of this issue. The review published its findings in April 2002, and has set out recommendations for ensuring that the UK has adequate scientific skills in the economy[11]. The Government's formal response to the Roberts report is included at Annex A. Chapter 4 of this strategy sets out how the Government will act to ensure that the UK trains and develops enough highly skilled scientists and technologists to support a vibrant innovation system.

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[11] ***SET for success:*** The supply of people with science, technology, engineering and mathematics skills.

1.25 Addressing these areas will help to ensure that the UK has the capacity to produce, absorb and develop new ideas and inventions. To encourage their dissemination throughout the economy, the Government can help to reduce barriers to knowledge transfer between higher education and public sector research establishments and firms, and between different firms. The same spillover rationale behind Government support for university and business R&D research also supports many knowledge transfer activities. Well-targeted Government action can therefore help to improve incentives for this activity, by:

- encouraging strong links between the private sector and universities and other research establishments; and
- reducing informational and other barriers that reduce knowledge transfer between firms.

1.26 Chapter 5 looks in detail at what the Government can do to increase activity in knowledge transfer.

1.27 Business innovation requires the private sector to invest in R&D and to develop the capacity to absorb new technologies. This in turn needs a supportive economic environment to provide the incentives for them to do so, through:

- stable macroeconomic climate in which firms can invest for the future;
- strongly competitive regime to provide incentives for firms to innovate and reduce the costs and barriers to new entrants to markets;
- reduced barriers to entrepreneurship to encourage new innovative businesses to emerge, thus increasing competitive pressures on incumbents;
- incentives, via tax measures and patent protection, to encourage private sector investment in R&D and skills; and
- efficient and sophisticated capital markets that are attuned to the needs of research-intensive companies.

1.28 Chapter 6 sets out the Government's approach to creating the right framework conditions to support investment across the UK economy as a whole. In particular, it highlights the measures taken to foster the demand for innovation investment among firms, and the supply of the finance necessary to fund this, most notably through the introduction of new tax credits on R&D spending by all businesses.

1.29 Action in all these areas will produce an environment that is conducive to increasing innovation and encouraging technological progress. The Government has an important role to play and is committed to doing so. Ultimately, however, the challenge is to firms to respond to that environment and to make best use of the opportunities presented to improve their performance.

The challenge to industry

1.30 The need to adapt and stay ahead of competitors both domestically and internationally drives innovation at the firm level – continually seeking new products, services, processes and markets that will lead to sustained profitability. Innovation surveys for 12 European countries indicate that, on average, more than 30 per cent of annual revenues in the manufacturing sector derive from new or improved products i.e. the result of innovation[12]. In the UK this figure is 23 per cent.

1.31 At the firm level, spending on R&D can be an important determinant of growth. Furthermore, firms tend to spend more on R&D when several of the factors in the system described above come together. For example, there is evidence that there are strong complementarities between the rate at which firms adopt new technologies, higher levels of capital investment and workforce skills[13]. There is a strong persistence effect. Firms that have been successful innovators in the past tend to build on that success and outperform competitors.

1.32 Notwithstanding the positive benefits from R&D investment, UK business performance in this area declined over much of the 1990s. UK business R&D declined from 1.5 per cent of GDP in 1990 to 1.2 per cent by 1997. Since then, there have been signs of a gradual improvement in investment levels. But as a share of overall economic activity, R&D spending in the UK remains below most other industrialised economies. At the same time, other countries have increasingly recognised the importance of R&D and innovation to growth and have seen increases in investment in the private sector.

1.33 The challenge is therefore clear. Firms need, themselves, to invest to maximise their productive potential through innovation. This requires management to make such choices. Failing to invest in R&D and the skills needed to exploit innovation through improved products or services reduces a firm's ability to grow, succeed and perhaps survive. In an increasingly competitive global economy, the ability to keep on innovating becomes increasingly important to a firm's long term health and viability.

[12] DTI (2001), Competitiveness Indicators, Second Edition.

[13] HM Treasury (2000), Productivity in the UK: The evidence and the Government's approach.

Box 1.1: Innovation in Europe and internationally

The Lisbon agenda: Enhancing R&D and innovation across the European Union

The Government recognises that the innovation potential of the UK is closely linked to the research and innovation capacity of the rest of Europe. It strongly supports the strategy adopted at Lisbon European Council in March 2000, which aims to enhance Europe's capacity in this area as a means to becoming 'the most competitive and dynamic knowledge-based economy in the world by 2010'.

Since Lisbon, the UK has been at the forefront of calls for the reforms needed to raise the level of European performance. Currently European businesses spend less on R&D and take out less intellectual property protection than those in the US. In particular, many European countries fail to fully translate a relatively strong research base into the inventions and innovations which yield tangible economic outcomes: the so-called 'European paradox'.

The Government played a key role in drawing up a report on R&D and innovation which was agreed by EU economic and finance ministers (ECOFIN Council) in January 2002[14]. This report emphasises the importance of getting the broad economic framework conditions right if innovation is to thrive. Focusing on the importance of the intricate links and feedback loops within innovation systems, the report also identifies several key barriers to innovation in EU countries, for example:

- ineffective intellectual property regimes (including the need for an affordable EU patent system);
- weak science-industry links;
- a lack of risk capital; and
- the effectiveness of public research spending.

This was followed up by a joint letter from the Prime Minister and his Dutch counterpart to the Spanish Prime Minister, ahead of the Barcelona Spring Council in March 2002[15]. This letter reiterated the UK's support for the recommendations of the report agreed at ECOFIN.

The Barcelona Council conclusions themselves reflect this renewed importance placed on R&D and innovation. The Council called on the European Commission to come forward (by Spring 2003) with proposals on how to integrate innovation into a 'European Knowledge Area', which would encompass both education and research policies. A core part of these proposals will look in detail at the European weaknesses identified in the ECOFIN report.

In addition, the Barcelona Council set an ambition for the EU to increase spending on R&D to 3 per cent of GDP by 2010, with two-thirds of this investment coming from the private sector. This is triggering further analysis of the ways that the EU can best improve both the amount of R&D undertaken, but also the effectiveness of that spending. The Government welcomes an extensive exchange of best practice between EU Member States on this issue.

[14] http://europa.eu.int/comm/economy_finance/epc_en.htm
[15] http://www.number-10.gov.uk/output/page4481.asp

At the same time, the EU is currently finalising negotiations on the 6th Research Framework Programme, which has a total budget of 17.5bn over four years. This latest Framework Programme aims to focus down on key areas of European research excellence, consolidate and add value to existing research projects, and enhance researcher mobility.

Promoting UK science and technology on the global stage

The Government recognises that there are many advantages to the UK from engaging fully and actively in international research collaboration beyond Europe. The UK has many strengths to offer as a partner in international research endeavours: the top rated research excellence generated by many UK institutions, the successful track record of multilateral programmes, and the ease of communicating (via English and the UK's global transport links) with UK-based researchers. These assets are to be more vigorously promoted with increased support overseas for wealth creation by UK industry and research community, through the expansion of the networks of Foreign and Commonwealth Office science attachés and DTI International Technology Promoters.

Conclusions

1.34 R&D and innovation are important to increasing economic growth and productivity. However, raising the UK's innovation performance requires an approach that recognises the complexity of the forces that contribute to technological progress.

1.35 Chapter 2 looks at the UK's past record on R&D and innovation to provide a context for this strategy. It shows that over the last 20 years, businesses in the UK have invested less in R&D than our major competitors and that our innovation performance is relatively weak.

1.36 The remainder of the strategy explains what the Government and others need to do to develop a technological innovation system in the UK to improve this record. A strong scientific research system has a vital role to play in this. In the UK, the bulk of basic scientific research is carried out in universities; and chapter 3 explores the issues that must be addressed to ensure that universities can sustain their current output in the long-term and move into new areas of research.

1.37 Chapter 4 then analyses the current supply of highly skilled scientists into the economy and shows that the UK is facing potential problems. It sets out how the Government, universities and business together can prevent these occurring.

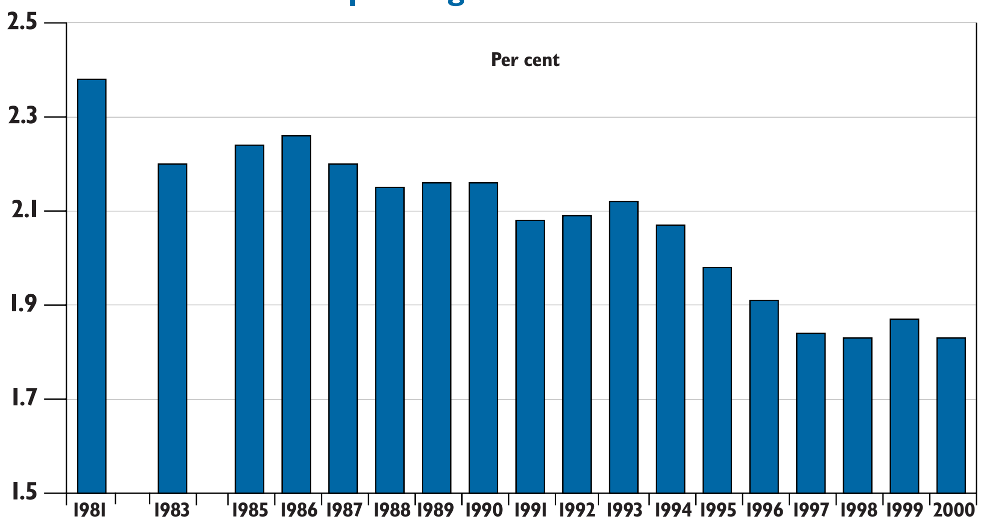
1.38 Chapter 5 then covers knowledge transfer, before chapter 6 looks in more detail at the wider innovation system and the challenge to business to increase investment in innovation. Chapter 7 sets out how the Government intends to strengthen its own research effort to improve the delivery of public services.

2 THE UK'S RECORD ON R&D AND INNOVATION

2.1 This chapter sets out the context for the Government's strategy for increasing R&D and innovation in the economy. It examines the evidence on the UK's record over the last 20 years. It draws on the available data describing the quantity of research inputs by business, Government and higher education, as well as the more limited evidence on the quality and quantity of the innovation outputs from these activities.

2.2 Chart 2.1 presents total UK R&D expenditure as a percentage of GDP over the 1980s and 1990s. It shows clearly the progressive trend decline in R&D spending as a share of GDP in the UK. UK gross R&D spending has in fact fallen from 2.38 per cent to 1.83 per cent of GDP between 1981 and 2000 – a fall of 23 per cent. There are, however, some signs that this downward trend has been arrested and may be starting to reverse.

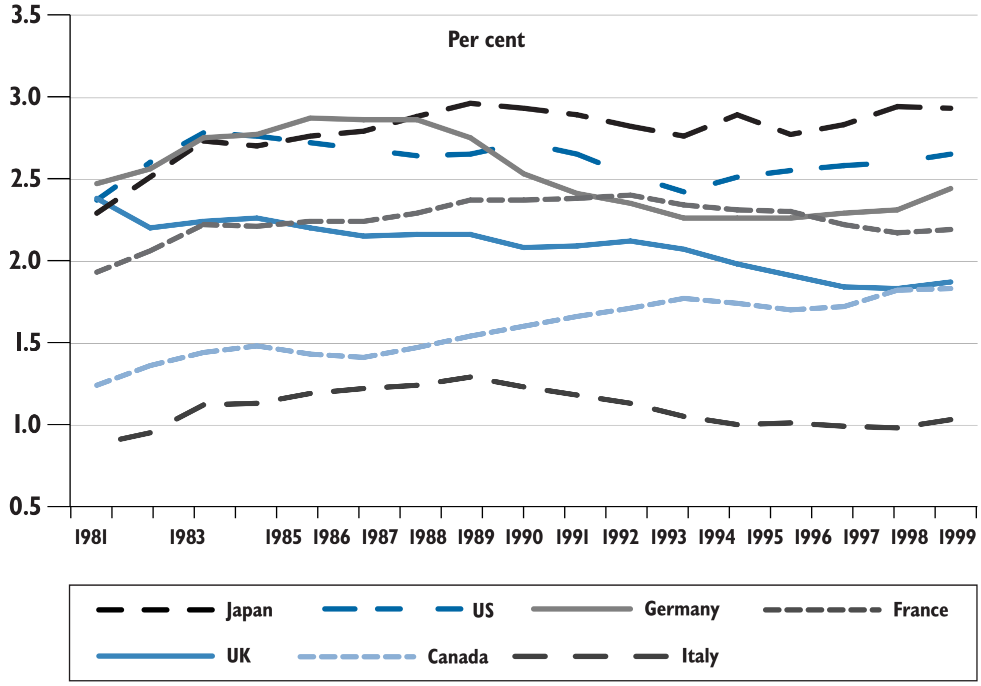
Chart 2.1: UK R&D spending as a share of GDP



Source: OECD

2.3 Chart 2.2 shows total R&D spending as a proportion of GDP for the G7 countries over the same period, placing the declining level of investment in the UK in the context of international trends. This demonstrates that, while the UK invested more than the rest of the G7 except Germany in 1981, by 1999 the US, France, Germany and Japan all spent more on R&D as a percentage of GDP. Part of the UK's absolute decline can be accounted for by a sharp downturn in defence R&D over the 1990s, from 0.5 per cent of GDP in 1989 to 0.2 per cent in 1999. Although similar falls in defence spending were also experienced in most other G7 countries, in nearly all the proportion spent on civil R&D increased, more than offsetting the fall in defence R&D expenditure. Large increases in the level of investment will now be required for the UK to catch up and converge with the leaders, whose investment levels are also rising.

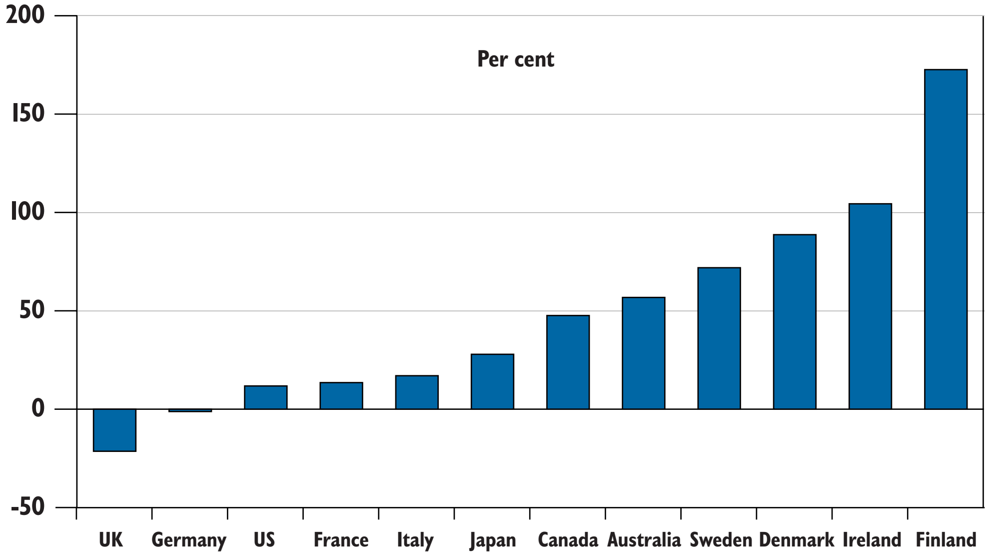
Chart 2.2: R&D expenditure as a proportion of GDP in G7 countries



Source: OECD

2.4 Furthermore, as chart 2.3 shows, the UK was the only country to experience a significant decline in total R&D spending as a share of GDP compared with its competitors.

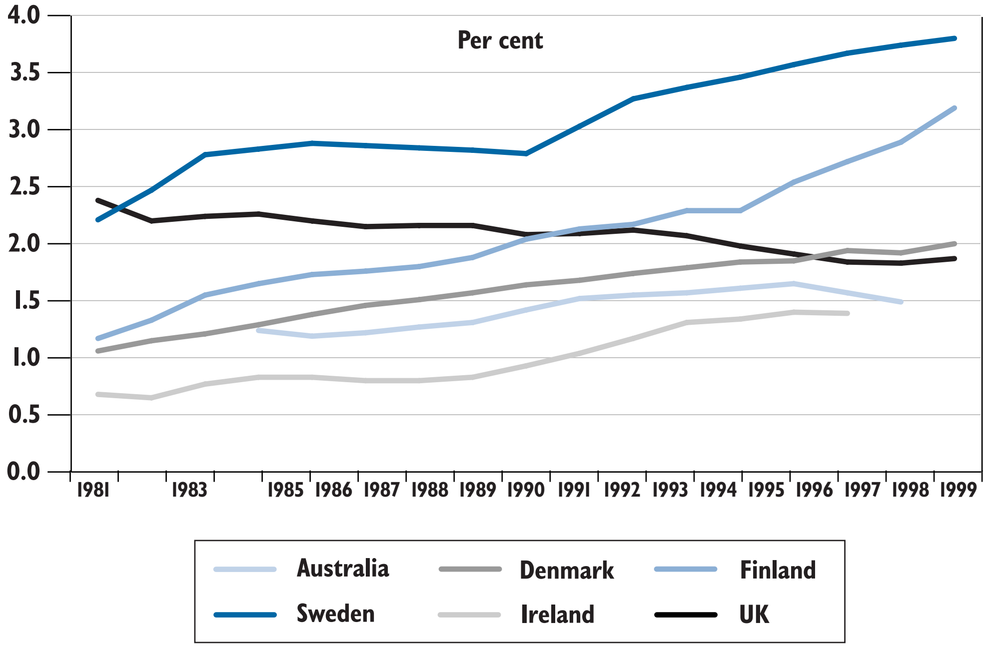
Chart 2.3: Growth in R&D spending as a share of GDP, 1981 to 1999



Source: OECD

2.5 Chart 2.4 shows that many smaller economies have significantly increased spending on R&D. For example, Sweden, Finland, Denmark and Ireland have accelerated spending as a share of output in the last twenty years by 72 per cent, 172 per cent, 88 per cent and 104 per cent respectively. As a result, the UK now invests a lower percentage of GDP in R&D than many OECD countries. The high levels of investment in R&D by many smaller nations suggest that there is a widespread acceptance that it is not enough for economies to 'free ride' on R&D investment by others. There is some evidence that in smaller economies, R&D investment primarily facilitates technology transfer from other economies, while in large economies it directly increases the rate of innovation[16]. Nevertheless, these high investment levels by even small, open economies support the view that spillovers often occur within countries. This suggests that all economies benefit directly from their own R&D investment.

Chart 2.4: R&D expenditure as a proportion of GDP

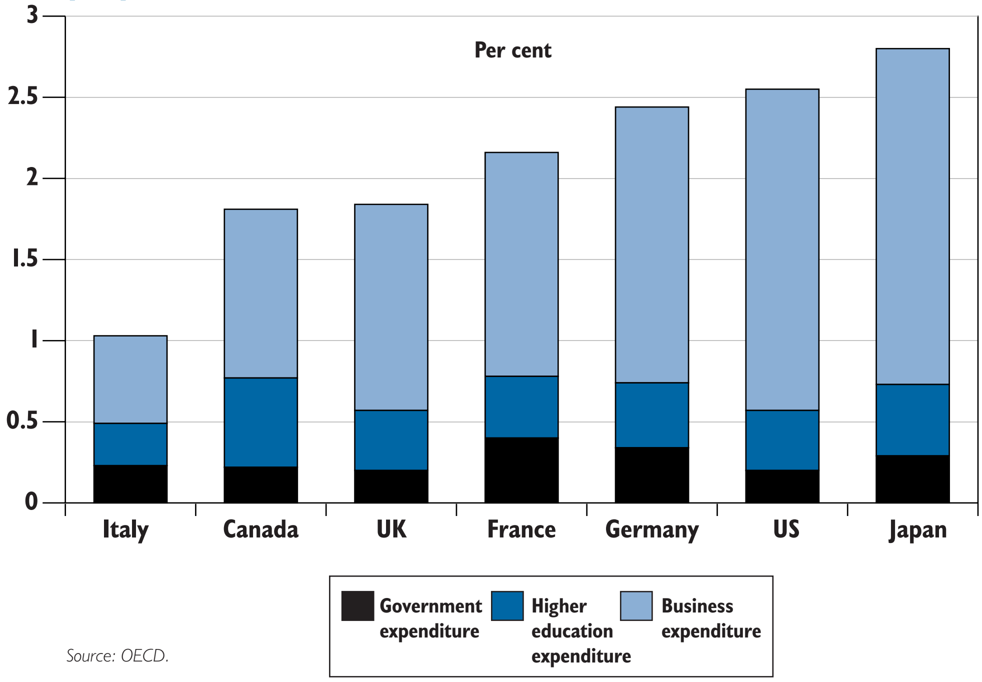


Source: OECD.

2.6 In all countries, the largest component of R&D investment is that performed by business – accounting for between 52 per cent and 77 per cent among the G7 in 1999. This is shown in chart 2.5. Given the prominence of business R&D within the total, variability in this element will have a significant impact on the R&D investment levels of a country as a whole.

[16] OECD (2000), A New Economy? – The role of innovation and information technology in recent OECD economic growth.

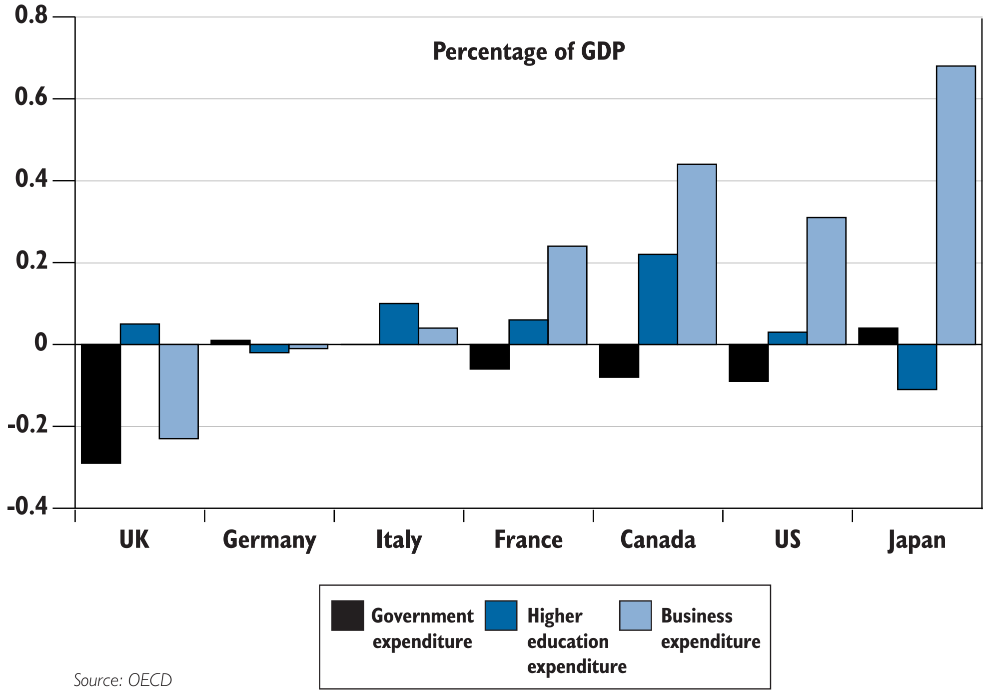
Chart 2.5: R&D expenditure by principal performer as a proportion of GDP, 1999



Source: OECD.

2.7 Chart 2.6 shows the impact of changes in components of R&D. The decline in spending in the UK relative to other countries between 1981 and 1999 can be mainly accounted for by a reduction in spending by business. Although R&D performed by government in the UK decreased in the period by more than other G7 countries, business R&D as a percentage of GDP also declined here while in other countries it mainly rose – and often substantially.

Chart 2.6: Change in composition of R&D expenditure, 1981 to 1999



Source: OECD

Sectoral patterns of innovation

2.8 The UK excels in innovation and R&D in some sectors, giving it world-leading industries. In others, though, the UK's research intensive sectors fall some way short of international benchmarks in R&D investment. Chapter 6 explores the sectoral patterns of UK business R&D and sets out the Government's approach to improving the climate for business investment in innovation.

Indicators of innovation

2.9 This analysis has reviewed comparative performance in terms of R&D expenditure. While useful as a measure of the UK's commitment to innovation, it is only an input to the innovation process and does not show the effectiveness of the spending[17]. Critical to the success of R&D research is the ability of firms to transform research initiatives into commercially viable new processes and products.

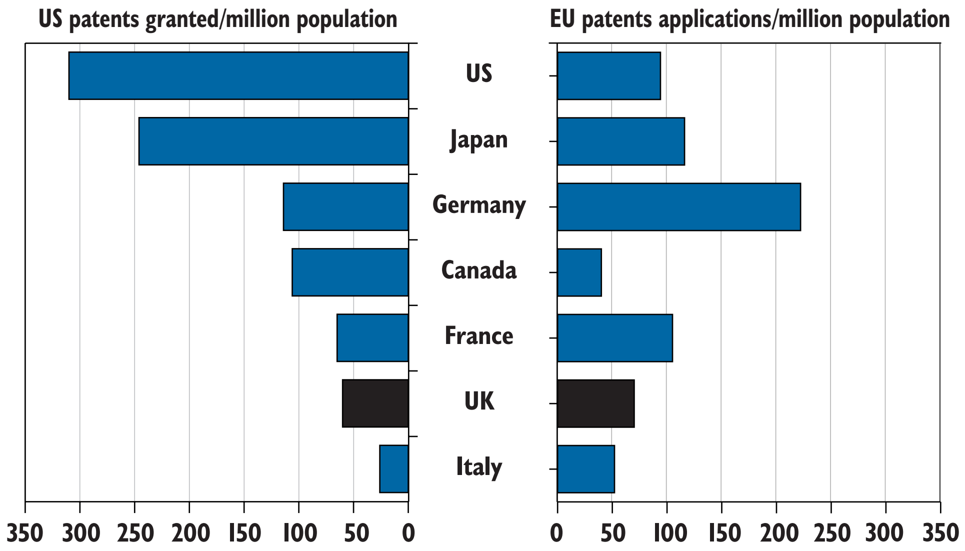
2.10 International comparison of patents applied for or granted to firms can be used as a proxy indicator of success in converting knowledge spending into new products or processes (although there are limitations to such comparisons). Problems include the fact that firms follow different policies for patenting products. Some inventions are not patented as firms find other ways of protecting them. Equally, not all patented products become a commercial success. Differences between countries' patenting systems also cause difficulties. For example, some countries and regions tend to focus on patenting finished products; others tend to patent all the intermediate stages and a number of variations of the final product. Nevertheless, patents are a useful indicator of innovation potential and capacity.

2.11 Chart 2.7 provides information on European Patent Office (EPO) and United States Patent and Trademark Office (USPTO) patents[18]. The data suggest that the UK lags behind the US, France, Japan, and Germany in both the EU and US markets. The predominance of US firms in holding US patents reflects a home advantage as it is generally more expensive to patent abroad. However, the US records a relatively strong performance in the EU market as well. When a comparison is made within the EU, the UK record on patent numbers is nearly a third the level of Germany, and less than France, Japan and the US.

[17] DTI (2000), UK Competitiveness Indicators: Second Edition

[18] The USPTO only publish data on patents granted, whereas the EPO only publish data on patent applications

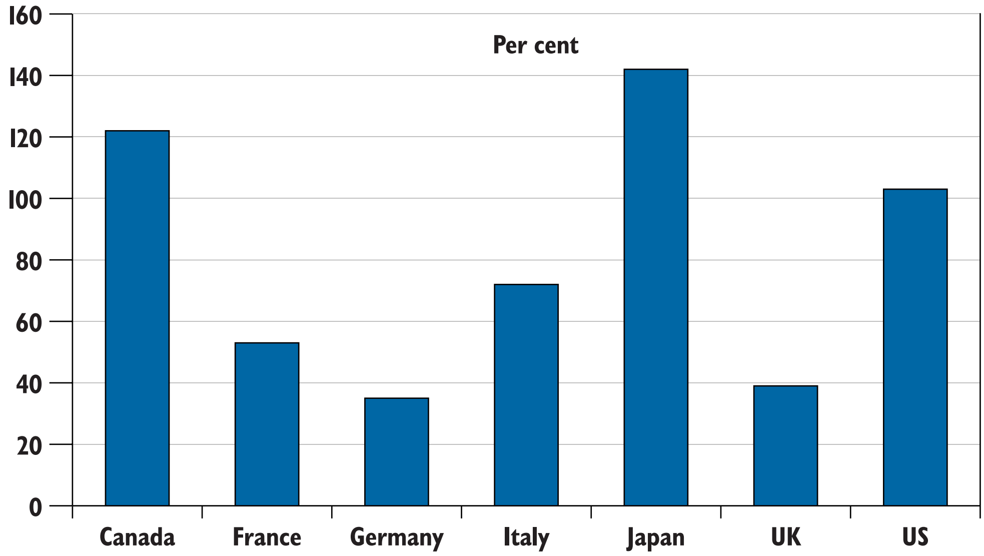
Chart 2.7: Patents granted and applications, 1999



Source: US Patent and Trademark Office; European Patent Office.

2.12 This therefore suggests that the UK has some way to go to catch up with German, Japanese and US innovative capacity. Chart 2.8 shows the percentage change in US patent grants between 1985 and 1998 as a measure of the pace of change of UK performance versus our international peers. This indicates that the UK has experienced a slower increase in its innovative performance than most other G7 countries.

Chart 2.8: Change in US patents granted, 1985 to 1998



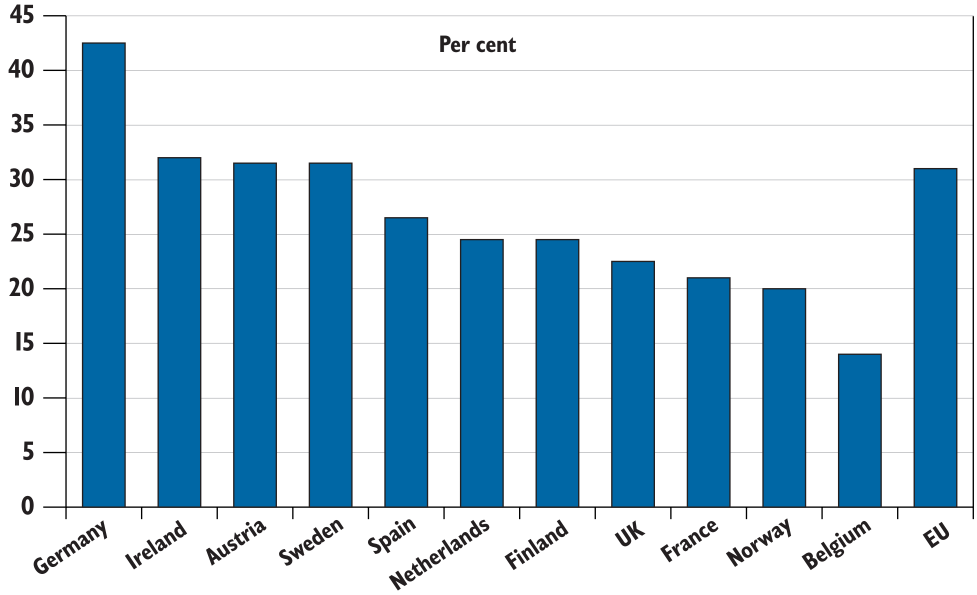
Source: OECD.

2.13 Comparison of the UK's performance on other output indicators of innovation show a similar pattern. For example, the revenue generated by firms from new or improved products is an indicator of the effectiveness of R&D spending, showing the commercial success or viability of new products, processes and services.

2.14 Chart 2.9 highlights that UK manufacturers are in the bottom half of the EU league in terms of revenue generated from new or improved products. Only 23 per cent of turnover is derived from new and improved products compared to an EU average of 31 per cent. This is consistent with the relative decline in investment levels in R&D in the UK.

2.15 This decline is largely a phenomenon of the last two decades. Even in 1981, the UK's total spend on R&D was the second highest in the G7 as a share of GDP, reflecting in part the combined focus of Government and business on defence research and product development. However, this investment did not translate into outstanding economic performance. As Chapter 1 argued, what is needed to link R&D with economic growth is an effective system for driving innovation through the economy, so that new ideas are turned successfully into new products. When UK businesses were investing heavily in R&D, the framework conditions, including a weak competition regime, an unstable macroeconomic climate, lack of commercial focus and poor access to risk capital, did not provide the right incentives to foster innovation.

Chart 2.9: Manufacturing revenues from new or improved products, 1996



Source: European Community Innovation Survey.

Conclusion

2.16 The UK's productivity performance has been weak over recent decades, allowing a considerable productivity gap to open up with other countries such as the US, France and Germany. One driver of improved productivity performance is innovation and technological progress, which is driven in part by investment in R&D. This chapter has shown that the UK's record on R&D is relatively weak and that, in contrast to other developed countries, the private sector has reduced R&D investment over the last 20 years.

2.17 This creates a challenge for industry to remain internationally competitive. But, as Chapter 1 argues, it also places the onus on Government to ensure that the innovation system is functioning well. This requires delivery of complementary policies. The Government will invest where it is best placed to do so in basic research, involving research partners in business and charities in sustainable financing for the long term. Chapter 3 sets out the Government's approach to ensuring that universities (which conduct the bulk of basic research in the UK) are able to produce sustainable high quality research output and to move into new areas of science. The Government will also work to ensure that the national and regional innovation systems operate well to diffuse ideas and skills generated in business and the science and engineering base. Chapters 4 and 5 set out the Government's approach to the creation and deployment of research and technology skills in the economy, and the transfer of knowledge across business and the science base.

3 STRENGTHENING UNIVERSITY RESEARCH

Introduction

3.1 Chapters 1 and 2 have shown that it is the private sector that drives much of the economic exploitation of science and innovation, but that there is much the Government can do to provide the incentives for businesses to invest in such activities. Underpinning the innovation system, though, and providing the feedstock of research outputs and skilled personnel, is the UK's science and engineering base. This chapter looks at how the Government can work with other partners to ensure that the UK has the capability to produce world-leading scientific ideas and inventions into the future.

University research

3.2 Scientific research is a diverse activity, producing outputs with a range of social and economic benefits. The closer these are to the commercial objectives of firms, on the one hand, or the policy objectives of Government departments and agencies, on the other, then the more those commissioning the research should themselves have the incentives and responsibility for funding this activity. Beyond this, there will remain a core of basic research activity, providing dispersed benefits throughout society and the economy as a whole, through both the ideas generated and the training of skilled personnel. The Government's responsibility is to ensure that this science and engineering research base (the universities along with the Research Council Institutes) is maintained and developed, so that it continues to deliver flows of new basic scientific research and associated skills to support the rest of the innovation system. At the same time, the research base for the arts and humanities, which also contributes to economic and social benefits, should continue to be supported.

3.3 UK universities perform well compared to institutions in other countries, producing relatively high volumes of top quality research. Although the UK only has 1 per cent of the world's population, it carries out 4.5 per cent of world science and produces 8 per cent of science papers. These papers receive 9 per cent of citations[19]. Furthermore, on average, UK scientists receive about 10 per cent of internationally recognised science prizes.

3.4 The overall research performance of universities is on an improving trend. In recent years, the outcomes from the Research Assessment Exercise (RAE) have shown the quantity of high quality research coming out of UK universities has increased substantially. At the same time, helped by Government initiatives such as the Higher Education Innovation Fund (HEIF), universities are building more and stronger relationships with business and other users of research. The numbers of spin-out companies created have reached record levels. All this has improved the prospects for publicly funded science being transferred into productive use.

[19] DTI (2000), Excellence and opportunity: a science and innovation policy for the 21st century

3.5 The Government has already invested significantly to support university research. Between 1996-97 and 1999-2000, research funding available to universities from the Funding and Research Councils has increased in real terms. This has enabled universities to increase the volume of research undertaken, to move into new areas of research, and to increase the quality of the outputs (as demonstrated by the 2001 Research Assessment Exercise (RAE)).

3.6 Overall, the story is one of growing success. However, for this to continue, three key issues must be addressed.

- First, the market for science and research has become increasingly global in recent years. UK universities have to compete with the USA, Europe and elsewhere for talent and research contracts if their departments are to maintain or improve their world ranking. This means universities - particularly those which are recognised leaders in their fields - being able to offer competitive salaries to potential staff, and having facilities and equipment conducive to top class research.

- Second, universities must be able to sustain and improve their current output. Past under-investment in universities has put at risk the current high levels of research output. Despite previous Government initiatives, there remains much to do to modernise university infrastructure. Furthermore, much research does not cover its costs let alone allow universities to compete in the international labour market.

- Third, universities must have the resources and dynamism to move into new areas of scientific research and to ensure their work remains at the cutting edge. This means universities being able to fund such investments but also having the institutional flexibility to cross traditional disciplinary boundaries.

3.7 This chapter describes how the Government intends to play its part in addressing these three issues through:

- a more sustainable system of university research funding, with the onus on universities to deliver change at the institutional level;

- improved mechanisms for universities to engage with all the users of the science base, including Government, the research charities and business; and

- resources to enable the science base to respond to the demands of new science.

3.8 While this chapter sets out the Government's intentions with respect to the first two of these and commits substantial new funding for the third, much of the detail will remain to be developed in due course. It is intended that a cross-departmental group will be established, reporting to the Minister for Science and Innovation, Lord Sainsbury, and convened by the Treasury, to co-ordinate the implementation of the package of measures proposed.

Ensuring scientific research is sustainable

3.9 There has been much public debate about research 'funding gaps'. However, increasing the resources provided by Government will not alone be sufficient to ensure that that the volume and quality of scientific research carried out in UK universities is sustainable in the long term. Rather, there are structural issues that need to be addressed by Government, the universities and other users of the science and engineering base together. They require all funders and users of the university research base to recognise a shared interest in its long term viability and to work in partnership to sustain it.

Funding of university research

3.10 University research is now resourced from a range of sources, including the Government, charities and industry. This diversity has increased in recent years as bodies outside Government have funded, and contracted with, universities to carry out greater volumes of research. The Government welcomes this diversity: it maximises the chances of fruitful outcomes given the uncertainty inherent in scientific research.

Dual support system

3.11 The Government itself provides two streams of funding known as the dual support system. The first stream from the Funding Councils[20] (known as Quality Related or QR funding) provides an underpinning research capability for universities. Support from the Funding Councils is intended to provide research departments with:

- the base from which permanent academic staff can make credible proposals for research project funding from the Research Council and other project funders;
- the costs of training new researchers;
- the resources to build research capabilities; and
- the freedom to pursue a certain amount of their own blue-skies research.

3.12 The Funding Councils reward excellence as measured by the RAE. Funding is skewed sharply towards the best rated departments, giving those most likely to produce results the resources to do so. This incentive structure has been successful both in driving up the quality of university research and in encouraging universities to focus on their strengths. The improvement in the quality of research assessed in the RAE has been dramatic. In 1992, 23 per cent of researchers were in a 5 or 5* rated department, the two highest ratings. That figure rose to 31 per cent in 1996 and in the 2001 RAE was 55 per cent. Nearly two thirds of all universities now have at least one 5 or 5* rated department.

[20] The Higher Education Funding Council for England (HEFCE), the Scottish Higher Education Funding Council (SHEFC), the Higher Education Funding Council for Wales (HEFCW) and the Department for Employment and Learning, Northern Ireland (DELNI)

3.13 HEFCE announced on 27 June 2002 that it would be conducting a review of the RAE in partnership with the other UK higher education funding bodies. The review will investigate different approaches to the definition and assessment of research quality, drawing on the lessons both of the recent RAE and of other models of research assessment, and will advise on the future of research assessment. Sir Gareth Roberts, President of Wolfson College, Oxford, will lead the review, which will begin in autumn 2002. There are concerns that the RAE does not give proper weight to applied research and favours basic research, which results in conventional research outputs, such as articles in peer reviewed journals. There are also concerns that the RAE, as a subject based exercise, does not give proper weight to inter-disciplinary research. Both these areas were given attention in the 2001 exercise. The review will need to consider, among other things, to what extent existing steps have been successful and what should be put in place to tackle these issues in future. From the Government's viewpoint, it also will be important to ensure that any modifications reinforce incentives for excellence – increasingly measured by world class standards – and maintain a dynamic research system by enabling newcomers to challenge research leaders. The review must also take account of developments in the dual support system set out in this strategy, and of the implications of these for the future allocation and management of QR funding within the dual support system.

3.14 The second Government funding stream is delivered by the Research Councils funded by the Office of Science and Technology (OST). It provides money for specific peer reviewed purposes. The Research Councils are listed in table 3.1 below. The Council for the Central Laboratory of the Research Councils (CCLRC) provides facilities and technical expertise in support of basic, strategic and applied research programmes for the Research Councils and other users. In total, the Research Councils are, at present, investing £1.6 billion per year in scientific research.

Table 3.1: Research Council budgets 2002-03

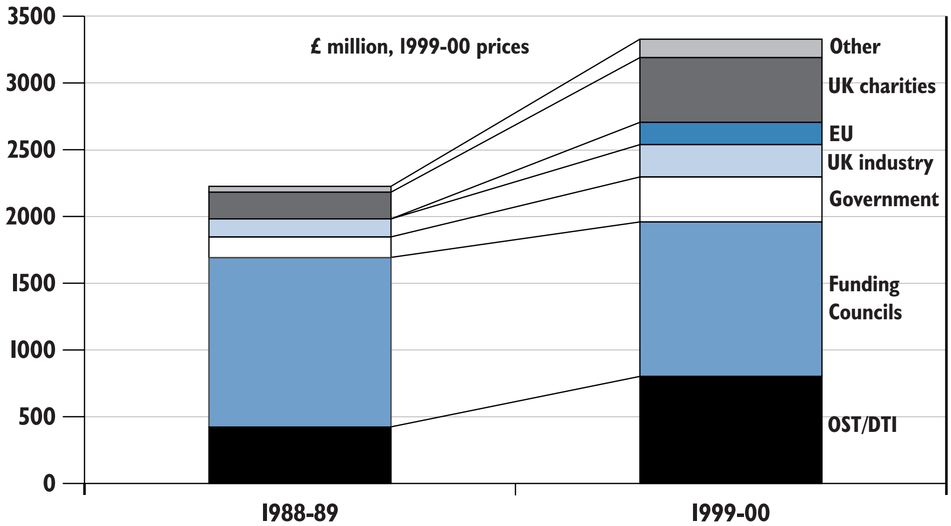
Research Council	Budget (£m) total
Medical Research Council (MRC)	374
Biotechnology and Biological Sciences Research Council (BBSRC)	239
Natural Environment Research Council (NERC)	203
Engineering and Physical Sciences Research Council (EPSRC)	498
Particle Physics and Astronomy Research Council (PPARC)	228
Economic and Social Research Council (ESRC)	84
Council for the Central Laboratory of the Research Councils (CCLRC)	11
Total	1,638

3.15 The Research Councils are not obliged to fund research and training in any particular type of institution, but are free to decide upon the best means to deliver their Royal Charter objectives, which include the need to promote and support high quality basic, strategic and applied research. In 1999-2000, 49 per cent of Research Council funding was spent in universities, with the remainder being spent largely in Research Council Institutes and on subscriptions to international facilities.

3.16 The Government continues to believe that the dual support system is the most effective way to fund university research. It sustains a dynamic balance in research funding which underpins the vitality of UK research. The precise mechanisms will need to adjust; this strategy itself proposes changes. But the principle remains valid and has become even more crucial as it now underpins an even more diverse – and potentially productive – system.

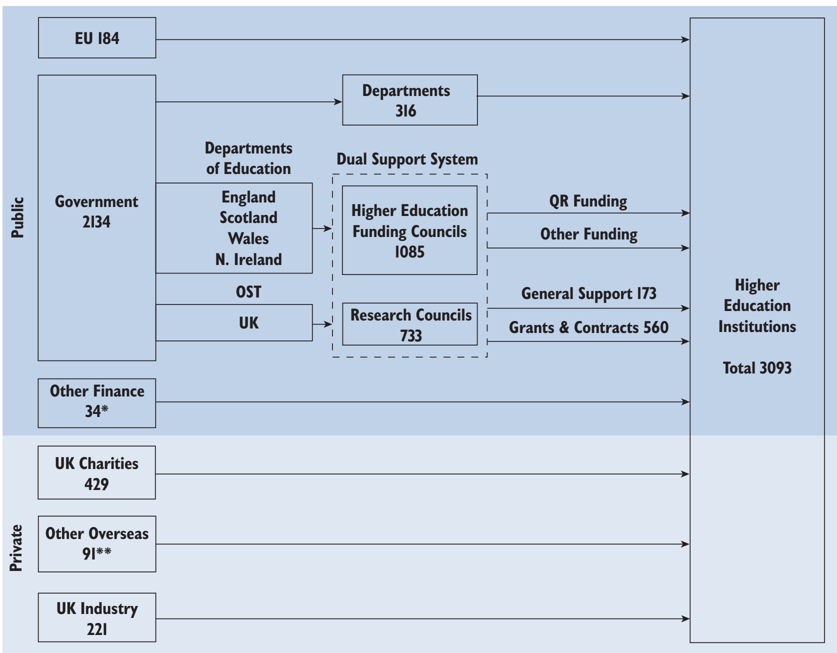
3.17 Chart 3.1 below shows that third parties now provide universities with over 40 per cent of their funding for research, compared to less than 25 per cent in 1988-89. It also shows that over little more than a decade total research income in universities has risen by around 50 per cent. This dramatic increase has been driven mainly by the growth of third party income, especially from research charities. Chart 3.2 shows how all the different funders of university research now contribute.

Chart 3.1: Sources of university research funding



Source: Office of Science and Technology.

Chart 3.2: How universities receive funds, 1998-99 (£million)



* Universities own funding, other universities, local authorities **Non-EU funding including overseas charities and firms

Charities

3.18 Research charities are now major funders of the UK science and engineering base, spending over £600 million a year on scientific research. In 1999-2000, the Wellcome Trust spent around £350 million on science research. Other medical research charities spent a further £288 million. In the last five years, medical research charities have contributed £2.7 billion to the science base. In particular, Cancer Research UK has an annual scientific spend of more than £130 million per year, and in 2001 the British Heart Foundation spent £40 million on research. Much of this money is effectively spent in partnership – with universities and the Government. For example, in addition to the research projects it funds through the universities, the Wellcome Trust provided £525 million towards the recent Joint Infrastructure Fund and the Science Research Infrastructure Fund in partnership with the Government. They have also, alongside the Medical Research Council and the Department of Health, provided an initial £45 million for the UK Biobank project – a study of genes, environment and health that will capitalise on the knowledge from the Human Genome Project. In addition, the Wellcome Trust has committed £110 million to the Diamond Synchrotron project, and £360 million over five years for genomic research at the Wellcome Trust Sanger Institute.

3.19 Charities, in general, are increasingly making a distinctive contribution to research by supporting different types of partnerships. These have enabled charities to work with others to develop more focused, strategic and sustainable research programmes which meet the objectives of both the charity and the research institutions.

Industry

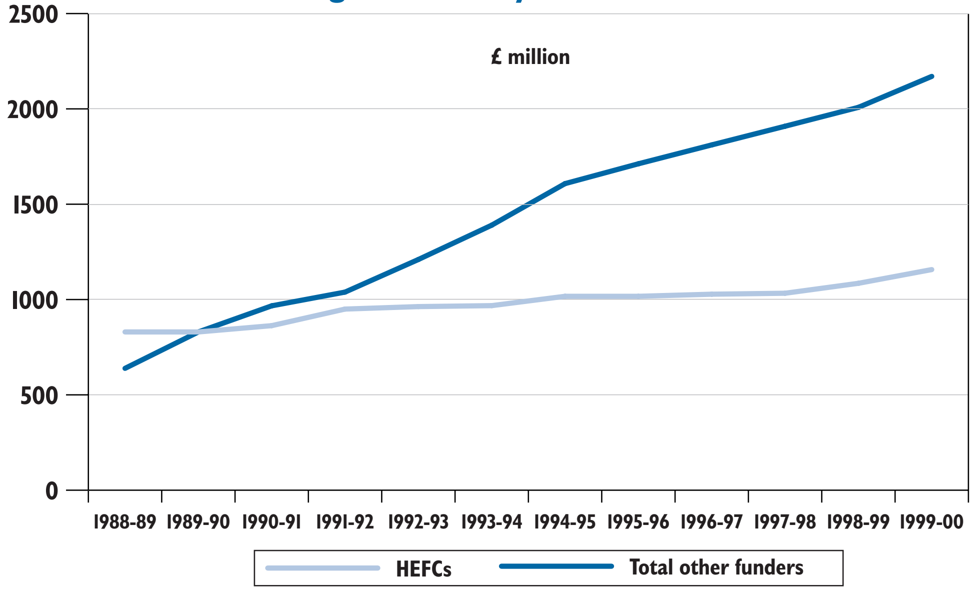
3.20 In parallel, industry collaboration with, and use of, university research has grown in real terms from £135 million to £242 million (in 1999-00 prices) between 1988-89 and 1999-2000. Building such relationships with business is crucial to successful scientific research relevant to the wider economy. The Government, through the Higher Education Innovation Fund and other measures, has encouraged this growth.

Government departments

3.21 Government Departments are also major users of university research, though their role is distinct from that of the Funding and Research Councils. Departments' concerns are usually with particular policy objectives, rather than more general scientific enquiry. The NHS, however, is an important funder of the science and engineering base, now spending more than £500 million per year in total on clinical and other health-related research in NHS Trusts, universities and research institutes. Its position is, therefore, closer to that of the Research Councils.

3.22 The differential growth rates of different funding streams have changed the balance of university research funding. From a position in the late 1980s where Funding Council resources were intended to complement Research Council grants and were basically in balance with all other sources of research funding, they are now dwarfed by the latter, as Chart 3.3 shows. As a result, Funding Council resources have been increasingly thinly spread.

Chart 3.3: Funding of university research



Source: Office of Science and Technology.

3.23 This situation has enormously increased the apparent productivity of the research base but in a way which now risks its sustainability. As a result, some key issues now need to be addressed to ensure the future of scientific research in UK universities. These are:

- a lack of clarity over what level of support (if any) Funding Council money is intended to provide to specific projects and programmes funded by others;
- the accumulated under-investment in the university research infrastructure;
- the incentives which exist at present for universities to take on increasing volumes of research without sufficient regard for their long term viability; and
- the need for universities to manage their research and finances to match the increased complexity and demands of diverse funding sources.

Principles for the public funding of research

3.24 The increased volume and diversity of university research funding makes it imperative that there is greater clarity about the purpose and scope of Funding Council support for research. **The Government is therefore proposing a set of principles to which universities should have regard when considering how to manage and price the research they take on.** These are set out in box 3.1 below. The basic proposition is that money from the Funding Councils should be used to support research which is intended to, or otherwise likely to generate, a public good.

3.25 These principles recognise that basic research is highly speculative and long term in nature. Many avenues of research will prove unfruitful, while others will unlock huge wealth-generating potential quite unexpectedly. It is therefore unlikely that industry, left to itself, would fund this form of research. Nevertheless, such research is clearly beneficial to the economy, to individuals and to society. Government therefore funds this research and, by doing so (and thereby lowering the risk), also leverages in research funds from others. Where research is near market and the rationale for it is directly related to the user's core business, universities should ensure that the price paid covers at least the full costs of the project.

3.26 In summary, there is a distinction between *funders* of the research base, motivated by the health of science and acquisition and diffusion of knowledge, and *users* of it who are motivated more by their own, more circumscribed, interests.

Box 3.1: Principles for using QR funding to support a research project

i. Research should demonstrably contribute to the enhancement of the UK Science and Engineering Base (SEB) or in some other way provide a net public good. An indicator of this may be that the results will be published openly in the academic literature and that any intellectual property generated by virtue of the research will vest in the university rather than with the commercial funder (so that revenues generated by licensing or spin-outs benefit the university). Charity funders may, with the agreement of the university, choose to hold and exploit intellectual property themselves, or allow the university to do so.

ii. The funder will have a research strategy, which, while recognising the advantages of having a plural funding system, nevertheless takes account of the strategy and priorities of other key funders, most notably the Research Councils and charities.

iii. Research supported will be only of the highest quality. Funders wishing to benefit from public support will need to be able to demonstrate that they have project appraisal systems in place which seek to ensure that only high quality research is funded

iv. Access to research funds should not systematically be restricted to any specific research performers or group of performers. In principle, anyone with an idea for excellent research and the means to carry it out should be eligible for funding.

3.27 The exercise of these principles will differentially impact different organisations who may in different situations be funders or users. The precise impact will need to be determined by individual universities in the light of their financial positions, the value to them of particular pieces of research, and the need to move their research activity towards long-term sustainability. But even where the research conducted demonstrably meets the principles for support there may need to be some greater contribution from funders. In recognition of this, **the Government has provided an additional £120 million per year from 2005-06 to increase the Research Councils' contribution in respect of existing levels of research**. The precise form this will take will need further discussion. But it is a very clear signal of the Government's intention to start to redress the imbalance identified and to put research financing on a long term sustainable basis. It will be looking to other partners similarly to recognise that the long run viability of the system is in the interests of all.

3.28 The future health of university research will be increasingly dependent on an open partnership between the major stakeholders. **The Government will set up a Science and Engineering Base funders' forum, to allow major research sponsors to share strategic information about research plans, to consider the financial impact of their plans on the system overall, and to make sure there is a shared understanding of how all the funding streams for research fit together.** Key partners include the charities, Government departments and industry.

3.29 The Government recognises the important role that charities play in UK research and the enormous value of the research they sponsor. The goal of the research charities – especially in the biomedical field – is clearly to generate knowledge that will benefit the public. This makes them funders rather than users of university research. They provide an independent stream of research funding which should complement that of the Research Councils and NHS. This argues for explicit recognition of what has up to now only been implicit – that in principle charity funding of research in universities is entitled to support from public funds provided by the Funding Councils. What this means in practice will need to be decided, case by case, by universities in discussion with charities, against the background that – taking all sources of funding together - research should be fully funded. But the Government believes that charities accept that they should at least pay the full directly attributable costs of the research they fund, looking to universities to provide supporting physical and human infrastructure. Beyond that, many charities have shown themselves willing and able to make specific investments in university buildings and equipment where they see the specific need, or wish, for example to exercise greater influence, for their own strategic purposes, over a research programme.

3.30 The Government welcomes the continuing development or such partnerships between charities and universities. It hopes that the explicit recognition of the national role that charities play in funding UK research will lay the foundations for a long term strategic partnership, under which there is a shared appreciation of a mutual interest in a financially healthy science and engineering base and a joint sharing of expenditure plans and research priorities. The publication by the Wellcome Trust of its five-year forward funding strategy, enshrined in its corporate plan, is a positive move down this road.

3.31 Government departments are major users of the research base. In 1999-2000, they accounted for around 10 per cent of university research income. They will need to recognise that the context in which they are using universities to procure evidence to support policy making is changing. They often commission research to meet their own objectives, rather than to advance the science and engineering base *per se*. In the light of the Government's principles, Government departments must therefore increasingly expect to pay nearer to the full costs of much of their research. And in common with other users who depend upon the existence of specialised infrastructure within which they can commission the applied work they need, they will need to be prepared to enter into strategic partnerships with universities, Research Councils and charities and other funders if they are to be sure of the continuing provision of this infrastructure.

3.32 The Government welcomes the increased interactions between industry and universities. It also recognises that these are complex, varying from near market applied research to basic, high risk research that can have significant knowledge spill-over benefits. Only universities can determine in discussion with industry what should be charged for individual projects, but in general the nearer to the market the research and the more focussed it is on financial benefit for business, the fuller the economic cost the customer should expect to pay. In return, industry should expect a high quality, timely service. The funding proposals contained in this strategy should also ensure a research base which is increasingly up to date, well equipped, able to attract the best talent and therefore more capable of responding to industry's demands.

Improving research infrastructure

3.33 The imbalance in university research funding has manifested itself in a growing and persistent failure to invest in research infrastructure. Two particular issues have exacerbated this:

- universities have been incentivised to increase volumes of research above other priorities such as investing in and maintaining their capital infrastructure; and
- resources from the Funding Councils have risen more slowly than Research Council grants.

3.34 The RAE provides a strong incentive for universities to take on increasing volumes of research as the funding they receive is based on a formula that rewards such behaviour. Equally, the RAE , as the driver of the Quality Related allocation formula, has provided the clearest route for universities to increase discretionary funding from Government in recent years.

3.35 The Research Councils' funding has grown substantially faster than that for the Funding Councils over the past decade. This has allowed the Research Councils to fund more projects than universities could support with money from the Funding Councils. Given, also, increased demands from charities and industry, Funding Council money has fallen short of providing sufficient infrastructure spending. These funding issues have been exacerbated by management and cultural factors including annual cash-based budgeting and too little attention to long term asset management.

3.36 A modern and well maintained capital infrastructure in universities is important to the health of scientific research in the UK because:

- the quality and age of the facilities and equipment determine the quality of the science that an institution can do. Failure to invest will progressively put the UK at a competitive disadvantage given the increasingly global nature of the science research market; and
- universities with older laboratories and outdated equipment will find it increasingly difficult to attract and retain the best research talent.

3.37 The poor state of infrastructure in UK universities featured in Lord Dearing's report on higher education in 1997 and, more recently, in Sir Gareth Roberts' report on the supply of scientists and engineers (see chapter 4). There have been estimates of the extent of the investment needed to bring the research capital stock in UK universities up to the required level to compete internationally. One, in the run-up to the 2002 Spending Review, estimated a required spend of £3.5 billion on infrastructure (including equipment)[21]. Such estimates depend on the assumptions made. And, of course, the backlog cannot always be distinguished from forward looking investment needs and priorities. Nevertheless, there is a clear need for significant investment, particularly given how much of the estate comprises buildings erected in the 1960s, which are now reaching the end of their useful lives.

3.38 In the last two Spending Reviews the Government recognised this problem and, in partnership with the Wellcome Trust, launched the Joint Infrastructure Fund (JIF) and the Science Research Investment Fund (SRIF) to provide £1.75 billion for investment in research infrastructure. While JIF and SRIF have been successful in increasing investment in research infrastructure, they only run to 2003-4 and do not therefore provide the certainty to enable universities to deal with their long term capital requirements on an efficient and planned basis. SRIF also included a requirement for universities to raise their own or third party resources amounting to 25 per cent of projected spend. This has the advantage of encouraging partnership and of buttressing financial discipline in choice of projects. The longer planning horizon implied by a permanent capital stream should help to attract third-party partners. On the other hand, a contribution as high as 25 per cent has caused problems for some universities through distorting their higher level priority setting.

3.39 The Government has now concluded that it should:

- **institute a dedicated earmarked capital stream for science research infrastructure. It will build up from £400 million in 2003-04 to some £500 million by 2004-05[22];** and

[21] JM Consulting (2002), Study of science research infrastructure (www.ost.gov.uk/research/funding/underinvest/index.htm)

[22] These figures aggregate DfES resources (for England only) and OST resources (for the UK as a whole). It will be for the devolved administrations to determine how far to allocate their share of the England only funding for research capital to these purposes.

- given the scale and likely timescale for righting the problem, **reduce the contribution that universities have themselves to make to new infrastructure projects.** It will therefore reduce the contribution that universities have to make from own or third party resources from 25 per cent to 10 per cent.

3.40 Capital funding will be distributed, as SRIF has been, on the basis of research excellence and volume, with higher education institutions drawing down their allocation in exchange for an infrastructure investment strategy. Separately, increased capital for higher education will also allow arts and humanities investment to increase. Under SRIF, a separate capital stream was earmarked for the modernisation of Research Council Institutes and the development of large national facilities. This line will continue, alongside the capital for university science research infrastructure. **Furthermore, an element of the capital stream will be retained centrally to support strategic rationalisation and restructuring of the university science base.** Funds will only be available where it can be demonstrated that the restructuring would produce a critical mass of international research excellence that could not be achieved by the institutions using their individual funding allocations. This might be as part of institutional mergers. This funding should only support the research element of such restructuring; the teaching and regional benefits should be funded from other relevant sources.

Increasing Funding Council resources

3.41 The measures outlined in this chapter to increase capital resources for research, increase the cost contribution from Research Councils, and the new framework for other partners, should all contribute to larger and better balanced funding streams. It will also be important that reforms to the RAE buttress the measures in this strategy to improve long term sustainability, and make provision for the very best research to be rewarded properly. In the meantime the Government recognises that existing levels of excellent research will be jeopardised without further Funding Council resources, when at the same time the outcome of the 2001 RAE shows there is now more high quality research undertaken than ever before. The scale of the assessed improvements following the 2001 RAE outstripped the available resources. **The Government will therefore significantly increase real terms spending on recurrent spending on research, with extra resources for HEFCE[23] starting in 2003-04 and rising to an additional £244m in 2005-06, compared with 2002-03 levels.** The major part of these increases could be expected to be spent on science, which has historically accounted for around 80 per cent of DfES' recurrent funding of university research. Precise arrangements for distribution of this funding will be announced in due course. This will help to restore balance in the dual support arrangements.

[23] The devolved administrations will receive their share of the additional funding in the normal way, and will, if they so decide, be able to use it to fund recurrent research in their univerisities.

3.42 These increases in research funding will be made in the context of a balanced overall funding settlement for higher education, which recognises the strong linkages between teaching and research. The 2002 Spending Review will ensure a real terms rise in total institutional funding per student in the three years to 2005-06, providing additional resources for teaching, access, pay and capital investment in teaching infrastructure and estates, which will benefit arts and humanities disciplines as well as science. The Government will set out its broader strategy for higher education in a strategy paper this autumn.

The challenge for universities

3.43 The Government believes that the changes outlined above represent a solid contribution to a more sustainable research base. However, decisions about which projects to accept and how to fund them are taken at the university level. Universities themselves must therefore be ultimately responsible for ensuring that science and engineering research output in the UK is sustainable in the long term.

3.44 The increase in the volume of research that universities carry out and the increasingly diverse range of funding they receive means that they now need more and better information than previously to enable them to manage their businesses effectively. They need to ensure they are investing enough for long term needs as well as covering their current costs. Equally, the principles set out here about the use of Funding Council resources will require them to think more strategically about the work they do and how they fund it.

3.45 The implementation in universities of TRAC[24], a management system for tracking the costs of research, was required following the 1998 spending review. For the first time, it provides universities with the financial data they need to meet the demands of managing research in the current climate and has enabled them to understand better the true costs of the research they carry out. This must now be used to create sustainable research businesses, so that the full economic costs devoted to research are covered from the range of public and private funding available to universities. This cannot be achieved immediately. But the Government expects universities progressively to put in place the necessary systems and policies, with a view to their individually achieving a sustainable position. Progress will be reviewed before the next Spending Review. Given the importance of transparency to research customers and Government, and the importance of setting the right financial context for university decision-making, **the Government will ask the Funding Councils to review, via an independent evaluation, how best to improve further universities' financial reporting and activity costing, building on the progress to date and balancing reporting requirements against the benefits to funders and universities.**

[24] Transparent Approach to Costing, a new regime for improving the public accountability of research and other publicly funded activities, and for improving information for management within institutions. This was introduced following the Comprehensive Spending Review in 1998, and has now been implemented across the higher education sector.

Maintaining cutting-edge research

3.46 This chapter has shown how the Government, working in partnership with the universities, research charities and business, is prepared to put university research onto a sustainable basis. This is intended to create the foundations for a continuing growth in research activity.

3.47 In the last spending review, the Government made available an additional £350 million for science and engineering research over the three years to 2003-04. £250 million of this total was earmarked for investment in three specific new cross-Research Council programmes: e-science, genomics, and basic technology. This boost to spending enabled UK researchers to move rapidly into expanding new areas of major importance.

3.48 Two years on, the UK is well placed to build on this, especially after the formation of Research Councils UK (RCUK) in May 2002, following the Quinquennial Review of the Research Councils. One of RCUK's early tasks will be to develop a Research Council investment strategy which will, in turn, enhance the quality of research investment prioritisation in the future. A start has already been made down this road. OST and the Research Councils have developed and published a long term road map for investment in large scale science facilities and, in the course of the last year, the Councils developed a range of priorities for new areas of science research which hold great promise for the future.

3.49 **To ensure that the UK can remain in the forefront of scientific research, the Government will increase the resources available to the Research Councils – above and beyond the increases described above to enable the Councils to make a larger increase to universities' indirect research costs – by £136 million in 2004-05 and £300 million in 2005-06.** This will enable the Councils to maintain growth in the volume of science which they fund, building further on the significant new resources made available in 1998 and 2000. Details of how these new funds will be invested through the Research Councils will be announced later this year, but some early indications of areas of interest are described below. This investment provides for growth in funding of research programmes of 5 per cent per year in real terms from 2002-03 to 2005-06.

3.50 To remain internationally competitive in science, it is important to accompany investment in front line research by making investments in a carefully constructed portfolio of large instruments and facilities which are crucial to the performance of world class science. The Government has recently confirmed its intention, through the formation of a joint venture with the Wellcome Trust, to build the Diamond Synchrotron. **This has now been fully costed and the Government is committing a further £122 million from 2002-03 to 2005-06 to ensure the project is built to time and specification. Additional resources rising to £30 million per year by 2005-06 will also be made available to allow new investments to be made in other large facilities and in renewal of infrastructure at the Research Councils' own Institutes.**

Future Research Council investments

3.51 A key issue for the Research Councils in the period ahead will be to consolidate their existing core programmes following a period in which increases in research funding have tended to be directed more towards specific new programmes.

3.52 Beyond this, the Councils have identified a wide range of fertile new areas for research investment. RCUK will advise on the prioritisation of these areas to be funded as resources allow. The new money made available for investment in such programmes will be augmented by contributions from the Councils' existing budgets as lower priority areas are phased out over the next three years. Examples of the opportunities for outstanding new areas of investment which will be considered by RCUK in drawing up its advice include:

- **Brain science:** recent advances in molecular biology and imaging, coupled with an influx of multi-disciplinary scientists into this arena, should enable UK basic science to become better aligned to serve clinical need and lead to the development of preventative strategies.
- **Regenerative medicine:** the UK recently became the first country in the world to approve properly conducted research into the use of embryonic stem cells. There is now an opportunity to develop the potential of stem cell based therapies for repair and replacement of tissues and organs.
- **Proteomics:** research into what proteins do, and how they do it, building on the foundation created by the recent genome sequencing programmes. Proteomics work will enable the UK to benefit fully from the investment to date in genomics, and move towards targeted development of drugs and plant and animal breeding.
- **Sustainable energy:** to support the UK's goal of access to secure, safe and reliable energy at competitive prices, while meeting the challenges of global warming, requires significant scientific underpinning from across the research disciplines. This programme aims to build on the UK's existing research strengths to address the technological and societal challenges of sustainable energy supply.
- **Rural economy and land use:** the UK rural economy faces significant shifts in economic, political and environmental drivers. Against a background of agricultural policy reform, growing land pressures, and climate change, inter-disciplinary research can help generate viable options for land use: delivering safe and efficient food production, in a manner which enhances biodiversity and sustains a healthy rural economy.

Box 3.2: University Veterinary Teaching and Research

The health and welfare of farm animals is vital to the well-being of the countryside, the performance of the economy, and a safe food chain. Veterinarians play a crucial role in clinical practice and research. Their effectiveness can only be sustained by ensuring that veterinary science has sufficient teaching capacity and access to research funds. Historically, however, the costs of clinical veterinary training in universities have not been fully funded. There has been no equivalent to the resource available from the NHS for the clinical training of doctors. This deficiency has impacted on both teaching and research.

The Government is therefore planning to inject £15m of funding over the Spending Review period into a new strategic partnership with The Wellcome Trust to strengthen clinical veterinary teaching and research in universities. The Government will consider the need for additional resources in the light of the review of exotic farm animal infectious disease conducted by the Royal Society. The Trust will be making an associated investment of £25m over five years into animal diseases in developing countries that will complement this initiative. Strategic arrangements for managing and co-ordinating these new resources will be developed in the light of the review. DEFRA will lead the co-ordination with key roles played by HEFCE and the Biotechnology and Biological Sciences Research Council and with the participation of the Royal College of Veterinary Surgeons.

Conclusions

3.53 University research in the UK is a key source of the ideas and inventions that are necessary for the UK to create the innovative new products and services needed to increase productivity and economic growth. It is already a world leader in terms of research outputs. However, the increasing diversity of the funding system, the changing balance within it, along with incentive and management issues, mean that funding has had to be enhanced and restructured. This chapter has set out reforms affecting all stakeholders in the research community, against a shared interest they all have in a healthy, well functioning research base.

3.54 These reforms should ensure that the UK continues to produce the ideas and research that are needed to support innovation. To benefit from them, however, requires highly skilled individuals, who can develop them and turn them into products and services that the private sector can take into new markets. Ensuring that the UK has the skills base to achieve this is the subject of the next chapter.

Box 3.3: Scientific Research and the British Library

The British Library has an important role to play in supporting scientific research in the UK, by providing access to its scientific reading rooms, and through its document supply service. In 2001, the Library provided over one million scientific, technology, medicine and engineering documents to higher education institutions and industry in the UK. In addition, five million scientific journals, monographs and patents are consulted each year in the reading rooms. The Library estimates that the opportunity cost saving to universities of its provision is £50m per year. It has potential to provide particular benefit to smaller firms which are less able than large companies to hold substantial collections of scientific journals and other publications.

The Library is facing pressures from increases in publishing output (running at 10 per cent per year) and from inflation in the cost of publications (around 7 per cent per year). It is also considering how best to meet increasing requests for information to be supplied electronically and has identified priorities for digitisation to focus on the most useful and relevant parts of its collection.

The Library is funded by the Department for Culture, Media and Sport and receives an annual grant of around £86 million. It also receives around £28 million per year from provision of services, largely the document supply service, which charges at cost for its standard service, but offers value added services such as express delivery for a premium charge. The work of the library is also of relevance to the work of both DfES and DTI/OST; HEFCE and the Library launched a strategic alliance in March 2002.

Recognising the value placed on the British Library as a resource to scientific researchers in the UK, both public and private, the Government will be reviewing the Library's resource plans for the coming years. This should allow the Library, among other things, to step up the level of digitisation of its collection, enabling more researchers to have quicker access to its collection, and to search the Library's databases more effectively.

4 SKILLS

Introduction

4.1 The previous chapter set out the Government's strategy for sustaining and enhancing scientific research in UK universities. Putting their funding on a more sustainable basis ensures that they can operate at the cutting edge of science and create the new ideas that, alongside business investment, generate innovation. The need for human ingenuity both in making new discoveries and – in industry – in developing new products and services, means that innovation is also critically dependent upon the availability of skilled scientists and engineers, as well as technicians and other R&D support staff.

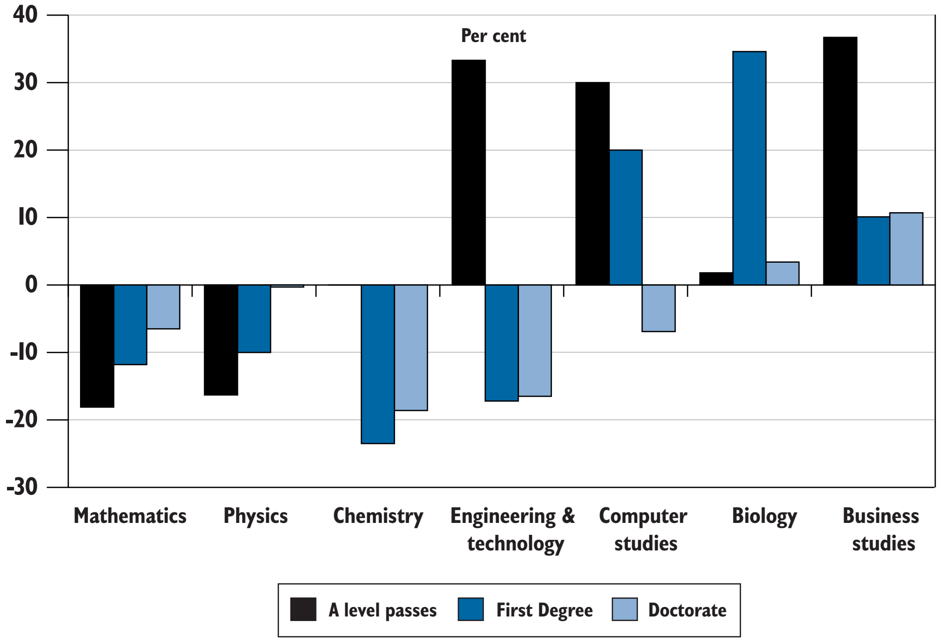
4.2 At the time of the 2001 Budget the Government asked Sir Gareth Roberts, President of Wolfson College, Oxford, to lead a review to determine whether the UK has an adequate supply of people with science, technology, engineering and mathematics skills. The Review's final report was published in April 2002[25]. It found that fewer students in the UK are choosing to study many science and engineering disciplines – particularly physical sciences, mathematics and engineering (see chart 4.1). As a result of these trends, and increasingly attractive opportunities for skilled scientists and engineers to work outside R&D, the Review found evidence of emerging shortages in their supply to R&D employers. The Review concluded that these emerging shortages will act to constrain R&D and innovation in the UK, not just in these disciplines but also more widely, since much cutting edge research is multi-disciplinary.

4.3 The Review also concluded that securing a strong future supply of scientists and engineers will require co-ordinated action from the Government, employers and universities to ensure that:

- those individuals gaining graduate and postgraduate qualifications and training in science and engineering are given attractive options to work in university and private sector research and development; and
- there is a strong supply of students at every stage of the education system both able, and wanting to study and work in science and engineering.

[25] ***SET for success:*** The supply of people with science, technology, engineering and mathematics skills.

Chart 4.1: Change in numbers taking science and engineering courses, 1994-95 to 1999-2000



Source: Data from DFES, HESA and Govt Actuary's Dept, as presented in the Roberts Review.

4.4 To ensure this, the Review identified responsibilities and challenges for the Government, R&D employers and others with an interest in science, engineering and innovation in the UK. Together with schools, colleges and universities, the Government has a role in ensuring that sufficiently attractive opportunities exist for individuals to study science and engineering subjects. (This includes the need for schools, colleges, universities and related organisations to be responsive to the requirements of employers). The Government has a role, again in partnership with universities, in offering attractive employment opportunities in scientific research in universities and the public sector. Furthermore, the Government has a role in creating a favourable environment for scientific research and development, through improving the public's understanding and perception of science, engineering and technology.

4.5 However, the Review was clear that ultimate responsibility for an appropriate flow of scientists and engineers into private sector R&D rests primarily with employers, and with their ability and willingness to offer opportunities that are competitive with the other sources of employment open to highly-skilled scientists and engineers.

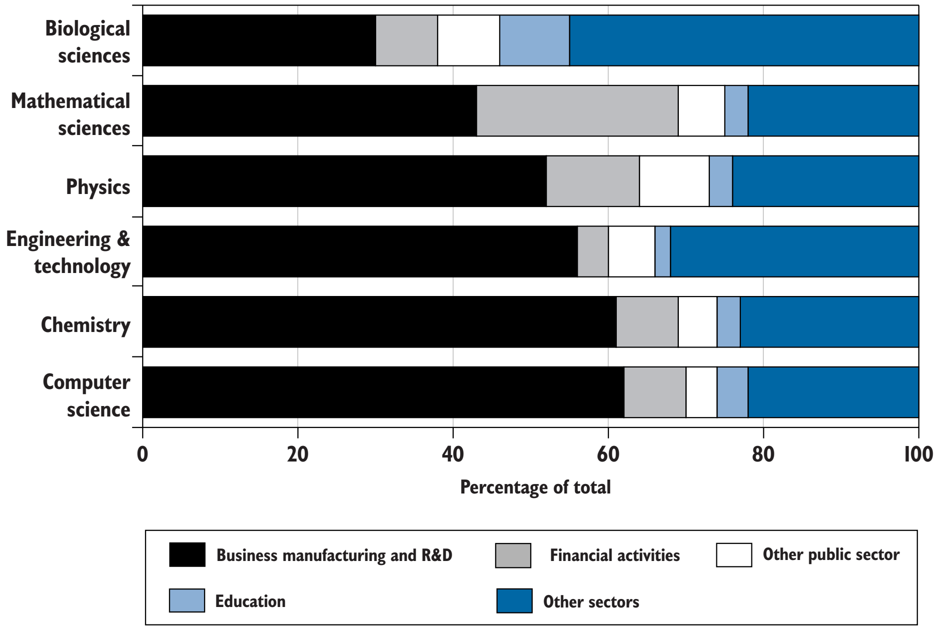
4.6 The Government's detailed response to each of the Review's recommendations is at Annex A. This chapter sets out in broader terms how the Government intends to address the issues that Sir Gareth Roberts raised in his report.

Creating attractive careers in science and engineering

4.7 The most highly skilled scientists and engineers have many career options on completing their studies. Crucially, they have a choice of whether to stay in scientific research and development in either the public or private sectors, to work in other areas related to science and engineering (for example, teaching), or to leave science and engineering altogether. It is important that enough choose to remain in science and engineering not only to produce research and innovative output itself but also, in schools, colleges and universities, to train future generations.

4.8 Chart 4.2 shows the first destinations of graduates with science and engineering degrees. This shows that the majority currently go on to careers in private sector R&D, although the financial services sector is an important employer for mathematics (and, to a lesser extent, physics) graduates.

Chart 4.2: First destination of science and engineering graduates, 1999–2000



Source: Data from Higher Education Statistics Agency, as presented in the Roberts Review.

Improving the attractiveness of careers in business R&D

4.9 The number of scientists and engineers employed in R&D[26] in business has declined by around 20 per cent since the mid 1980s[27], although there has been an upturn more recently. These trends reflect overall levels of R&D expenditure in the UK. If the UK is to continue to improve its innovation performance the numbers of scientists and engineers available, and wanting, to work in R&D must keep pace with increasing levels of R&D. To ensure

[26] Business manufacturing and R&D includes a few other small areas of employment. See the Roberts Review for further details.

[27] Data is from OECD and OST, presented in the Roberts Review report

this it is crucial that businesses undertaking R&D offer competitive career packages attractive to the best scientists. (Similar challenges face universities and public sector research institutions recruiting scientific research staff, as discussed later).

4.10 However, the Roberts Review found that many highly skilled scientists and engineers are not attracted to careers in scientific research and development. The Review concluded that this lack of attractiveness was contributing significantly to the recruitment difficulties experienced by R&D employers, evidenced by employers surveys. Overall shortages of skills commonly possessed by skilled scientists and engineers were also seen to lead to some businesses, principally in the financial services sector, using differential salary premia to attract science and engineering graduates in certain disciplines.

4.11 In his final report Sir Gareth Roberts identified insufficiently competitive remuneration packages as a significant factor in R&D employers' difficulties in trying to recruit the most talented scientists and engineers. Evidence presented in the report showed that despite limited salary differentiation by some R&D employers, technical graduates working in the electronics, pharmaceuticals and R&D services sectors still typically earn significantly less than their counterparts in the financial services and computer services sectors[28]. Furthermore, this difference is more pronounced at the top end of the salary range. For example, those in the top decile of earnings in R&D employment receive around 20 per cent less than their counterparts in financial services. This suggests financial services and computer services companies are targeting financial rewards to recruit and retain the very best people. Data from the Labour Force Survey and the Institute of Physics supports this analysis.

4.12 The Roberts Review also found that non-salary factors may deter people from careers in R&D in the private sector. These include relatively weak career structures and insufficient opportunities to keep in touch with subject developments. The Government agrees with the Review that employers need to recognise these weaknesses and to address them to improve the attractiveness of jobs in scientific R&D for the most able scientists.

4.13 The Government is also committed to improving opportunities in science, engineering and technology for groups that are currently under-represented in this area (for example, women and certain ethnic minority groups). The Government notes the concern expressed in the Roberts Review on this issue, and agrees that a number of the Review's recommendations, coupled with existing measures, should help to improve participation from these groups. Furthermore, the Government has asked Baroness Greenfield to advise on a stronger and more strategic approach to increasing the participation of women in particular.

[28] Mason (1999), The labour market for engineering, science and IT graduates: are there mismatches between supply and demand, NIESR.

Improving the attractiveness of careers in higher education

4.14 Universities are also facing stiff competition for the most talented scientific staff – from overseas as well as from other UK employers. They are reacting to this changing environment, as are their counterparts abroad. There is increasing differentiation of salaries at senior levels to reflect market forces. However, universities report significantly less variation in pay amongst junior and middle-ranking academic staff. Instead, many appear to be promoting more staff to professorships and other senior posts, or offering staff other benefits such as fewer teaching hours. Such approaches can be effective in attracting and retaining individuals. However, they are less visible to those considering careers in scientific research and are therefore less effective (compared to more visible and explicit salary increases) in promoting careers in these areas where competitive pressures are greatest.

4.15 The Government recognises that universities need to respond to the challenges of an increasingly competitive labour market and that this implies more differentiation in pay than previously at all levels. In the 2000 Spending Review, £50 million was allocated in 2001-02, followed by £110 million and £170 million in the two subsequent years, to support higher education institutions' human resource strategies, which include measures to recruit and retain the best staff.

4.16 **The Government agrees with Sir Gareth's conclusion that more, permanent, funding is needed and will therefore allocate further resources in the 2002 Spending Review for pay increases targeted on the recruitment and retention of permanent staff in all disciplines (including, but not only, those in science and technology) where there is the greatest competition.** These increases will be based on priorities identified in universities' human resource strategies.

4.17 Improving pay and conditions for the most talented researchers will enable R&D businesses, universities and public sector research establishments (PSREs) to compete in a global marketplace. It can be a powerful signal to potential researchers. But it is only part of the answer. It is also essential to address shortcomings and difficulties at every stage of the education process, to improve the flow of highly skilled scientists and engineers from which universities and R&D businesses have to recruit.

Fostering scientific talent

Improving the attractiveness of scientific PhDs

4.18 Postgraduate study is fundamental to the development of the highest level of science and engineering skills. It develops specialist knowledge and, particularly at the PhD level, trains students in the techniques and methods of scientific research. With the increasing sophistication of much R&D activity, the majority of the UK's future scientific researchers need to have postgraduate qualifications. Yet as with students at A-level and degree level, there is concern at the falling numbers of postgraduate students in some subjects. For example, there was a 9 per cent reduction in the number of PhDs in the physical sciences awarded to UK-domiciled students between 1995 and 2000. Of concern, too, is the attractiveness of PhDs to the best students – for example, in chemistry the proportion of PhD students with a degree class of 2:1 or higher fell in the late 1990s.

4.19 If UK universities and businesses are to undertake the cutting-edge research necessary to lift the UK's innovation performance, they need to work with Government to ensure that the most able undergraduate scientists are attracted to postgraduate study. To achieve this, two sets of issues need to be addressed:

- the immediate attractiveness of a PhD compared to other options; and
- the options opened up as a result of gaining a PhD.

4.20 The Roberts Review found features of science PhDs deterring too many of the most able students, and concluded that two in particular should be addressed:

- the level of the PhD stipend and that many PhDs continue beyond the time for which funding is available; and
- the nature of a science PhD in the UK and how far it confers the balance of skills required to conduct high quality R&D in business.

Ensuring the PhD stipend is attractive to the best graduates

4.21 Until 1998 the basic stipend for most Research Council PhDs had been unchanged in real terms since 1966. Since 1998, the Government has raised the level of Research Council PhD stipends significantly, from under £5,500 to a planned £9,000 in 2003-04[29]. Despite these rises, PhD stipends remain far below what able graduates can earn elsewhere: the mean post-tax graduate salary expected for a first job in 2000 was over £12,000. They are also below typical PhD stipends in the US.

4.22 It would be unreasonable to expect PhD stipends to compete with top graduate salaries as there are other benefits from carrying out research and gaining a PhD. However, in an increasingly competitive labour market, where there is a premium on the most talented, the Government accepts that PhD stipends should rise further.

4.23 **The Government will therefore provide resources in the Spending Review to increase the minimum PhD stipend to £12,000 a year by 2005-06. Additional funding will be provided for the Research Councils to increase the stipend still further in areas where recruitment is difficult. As a result, the Government expects that the average PhD stipend will increase to**

[29] DTI (2000), Excellence and opportunity: a science and innovation policy for the 21st century.

over £13,000 by 2005–06. The Government also accepts that it is necessary to provide the flexibility to permit a longer time for PhDs. Funding will therefore be provided to extend the average length of funding to 3½ years. Research Councils UK will consult later this year on detailed implementation issues, including the issue of any additional costs incurred by universities.

Improving the training given to PhD students

4.24 Students need to know that a science PhD will equip them with the skills relevant to their future careers. In many areas over half of PhD graduates go into jobs in business. So such skills must be relevant to that environment as well as to university and public sector employment. The Roberts Review concluded that PhD programmes do not deliver the quality of training required by industry. The most significant weakness is in the level of training provided in transferable skills, such as management and project planning.[30]

4.25 The Government agrees that there needs to be a new impetus to improve standards of PhD training. **To encourage universities to address the skills acquired by PhD students, and to ensure they are relevant to business, the Government expects all universities to meet high quality minimum training standards on their PhD programmes, and agrees that all funding from HEFCE and the Research Councils in respect of PhD students should be made conditional on meeting these standards. The Government has also provided additional funding to the Research Councils in the Spending Review to enable enhanced training for their PhD students, as recommended in the Roberts Report.**

4.26 The Government believes that a combination of increased stipends and better training content will improve the attractiveness of PhD study to the most talented undergraduate scientists. However, PhD study is not an end in itself. Its importance is that it is the route into many careers in scientific R&D. As set out above, the Government will provide funding to enable universities to improve the pay of key academic researchers. Just as importantly, industry must rise to the challenge of providing attractive career packages for R&D work in industry.

4.27 It is also necessary to ensure that there are clear routes into careers in business and academia following postgraduate study.

Ensuring postdoctoral research is attractive to the best PhD graduates

4.28 A third of PhD graduates in the UK go on to spend time as postdoctoral researchers where they learn how to run research projects – skills that are vital as academic staff or researchers in the private sector. There are currently some 10,000 postdoctoral researchers in the UK funded by the Research Councils, with many more funded from other sources. However, the position

[30] The New Route PhD, which is being developed in 23 English universities, begins to address this issue. It aims to allow students to develop a fuller and individually-tailored range of skills, including in general areas such as management and enterprise, alongside a major piece of research in their chosen discipline.

of postdoctoral researcher is unattractive to many PhD graduates. The Roberts Review identified poor pay and conditions, including short-term contracts that rarely provide security beyond the current project, as particular problems. Furthermore, there is little career advice and only around 20 per cent of postdoctoral researchers become full time academics. The rest leave for jobs outside, in R&D in business, in teaching, or often outside science and engineering altogether, despite as much as ten years training in their discipline.

4.29 The Research Careers Initiative has made progress in addressing these problems. However, the Government believes there needs to be further and faster progress to ensure that:

- salaries for postdoctoral researchers are more attractive to the best scientists and engineers;
- there are clear career paths into business R&D and academia for postdoctoral researchers; and
- conditions of employment are significantly improved, including job security and training opportunities relevant to both business and academia.

4.30 To address these issues, the Government will provide funding in the Spending Review to:

- **increase the average Research Council postdoctoral salary by around £4,000 by 2005-06.** As with the PhD stipend, the Government also believes that salaries should be varied better to reflect labour market pressures;
- **improve the training opportunities available to postdoctoral researchers.** The Government will provide additional funding to the Research Councils to deliver additional training for contract researchers and will work with RCUK and HEFCE to ensure that this is put into practice. The Government will ask HEFCE to make clear that support for postdoctoral researchers will be expected to feature in institutions' human resources strategies. This will help ensure that researchers are prepared for future careers in higher education or industry; and
- **create 1,000 new academic fellowships over five years to provide more stable and attractive routes into academia, working with organisers of similar existing fellowships, such as the Wellcome Trust and The Royal Society.** Further details will be announced later this year.

4.31 Taken together, the changes above should encourage more of the best emerging scientists at undergraduate level to continue their studies and pursue careers in research and development in both the private and public sectors. The changes are necessary because without them these people will pursue careers in other areas or will go abroad to continue working in science. Both outcomes would have negative effects on the capacity of the UK to produce world-class science and innovation.

Accessing scientific talent from abroad

4.32 The UK can also seek scientific expertise from abroad. As the market for top scientists has become increasingly global, countries have sought to attract skills from other countries. Most developed nations, including Germany, the US and Canada have introduced schemes to attract skilled individuals. In Canada one scheme has been targeted specifically at research positions in universities.

4.33 UK employers need to be able to access scientific talent from abroad. Recognising this, the Government has reformed the work permit and immigration systems to make it easier for employers to recruit staff from abroad. Work permits now last for five years, rather than four, and processing times have fallen significantly. Applications are typically now processed within 24 hours of receipt. It is also easier for overseas students to obtain permission to work in the UK after graduating. This is crucial as increasing numbers of students from abroad come to study in UK universities – for example, nearly half of all engineering and technology doctorates are awarded to non-UK students.

4.34 To increase further the numbers of highly skilled people who come to work in the UK, a new Highly Skilled Migrant Scheme was launched on 28 January 2002. The scheme enables highly skilled individuals to come to the UK and look for work without the need for a specific job offer. Applicants can demonstrate their eligibility for the scheme through educational qualifications, work experience, achievements in their field or past income.

4.35 The Roberts Review found that awareness of these changes amongst employers and universities was poor, particularly amongst small and medium sized businesses. **To address this the Government will step up the provision of information about these changes. In particular, Work Permits UK will develop concise and tailored information for smaller employers, and will work with the Small Business Service and employers groups to target the advice towards those who might benefit. Work Permits UK will also consult employers and others on the merits of adding more fields of science and engineering to the list of areas of national skills shortage.** This would further ease recruitment of scientists and engineers from abroad. Furthermore, the Government will take steps to improve awareness of the options and routes into employment available to foreign students in UK universities.

Inspiring young people to study science and engineering

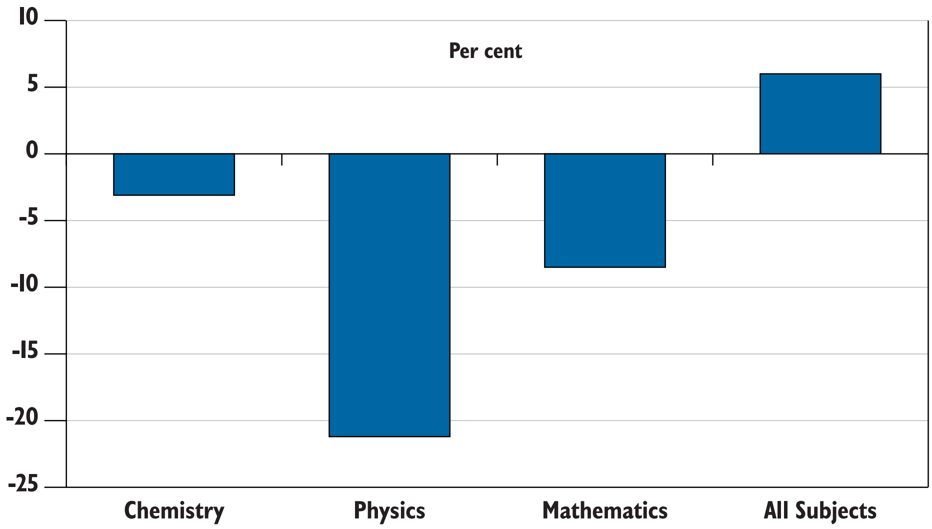
4.36 Assisting universities and other employers to access scientific and technical talent from across the world will help to improve the supply of scientific and technical expertise in the UK. However, the domestic supply of people wanting, and able to, study science and engineering will always be critical to ensuring that there are adequate numbers of skilled scientists and engineers in the UK. It is therefore vital that young people at school find science and engineering subjects stimulating and are keen to study them beyond GCSE and A-level.

Enthusing pupils at school to study science, mathematics and technology

4.37 The experiences that students gain in school are crucial to their subsequent education and training and to their careers. Since 1997, standards in primary and secondary schools have risen considerably, as a result of the Government's emphasis on, and investment in, school education. Nevertheless, the Government is concerned that fewer pupils are choosing to study areas of science, technology, engineering and mathematics at A-level and beyond.

4.38 The Government's concern is based on analysis from the Roberts Review, which found that numbers taking A-levels and degrees in many scientific subjects are decreasing. For example, between 1991-92 and 1999-00 the numbers of people taking A-level physics fell by 21 per cent. In the same period there was a 9 per cent reduction in students taking A-level mathematics, and a 3 per cent reduction in chemistry, despite rises in life sciences, computer sciences and an overall rise of 6 per cent in all subjects (see chart 4.3).[31]

Chart 4.3: Percentage change in pupils taking selected A levels, 1991–92 to 1999-00



Source: Data from DfES, as presented in the Roberts Review

[31] Furthermore, proportionately fewer female and ethnic minority pupils study science beyond 16.

4.39 The Roberts Review identified several reasons for these trends, including:

- shortages in the supply of appropriately trained science and mathematics teachers in schools;
- that many school laboratories are out of date; and
- the need for curricula to keep up with the fast pace at which modern science is developing and to appeal positively to pupils.

4.40 Addressing these issues should help increase the number of students choosing to take further courses in these subjects and improve their numeracy and scientific ability. Critically, given the increasing dependence of many sectors of the economy on science and technology, it will also improve the scientific and technical literacy of the general population.

Increasing teacher numbers in science and mathematics

4.41 Vacancy rates for teachers of the physical sciences, mathematics and IT are higher than for teachers of most other subjects, and it has been consistently difficult to recruit adequate numbers of graduates to teacher training programmes in these subjects. Furthermore, the Roberts Review showed that significant numbers of science teachers are required to teach areas of science outside their expertise.

4.42 The Government presented a new vision and direction for the teaching workforce in the Secretary of State for Education's speech to the Social Market Foundation last autumn. The vision involves remodelling the school workforce to drive up standards and free teachers to teach. This will lead to new models of organising teaching and learning, including in science and mathematics. And it should also have a positive impact on recruitment and retention of teachers in these and other subjects.

4.43 In the meantime, there are still recruitment and retention problems that the Government is determined to address. Part of the current problem is that graduate numbers in mathematics and the physical sciences are declining and there is therefore a smaller pool from which teachers can be drawn. The Government has also recognised the financial disadvantage that new graduates can suffer as a result of choosing to undertake the further year's training needed to become a teacher, rather than going straight into salaried employment. It is addressing this through the introduction of teacher training bursaries. For those training as, and becoming, teachers in shortage subjects, including mathematics, the physical sciences and IT, Golden Hellos and the writing-off of student loans provide even more financial support during the early years of teaching.

4.44 Although these measures have begun to have a positive effect, difficulties remain. **Over the Spending Review period, the Government is determined to enhance pupils' science, mathematics and technology education by improving prospects for the recruitment and retention of science and mathematics teachers, including through paying more to good science**

and mathematics teachers. Therefore, the Government will consider further targeted incentives, building on student loan write-offs and the flexibilities already available to schools, and will be asking the School Teachers' Review Body to consider how the teachers' pay and conditions system might be adapted over the Spending Review period to enable schools to offer more targeted incentive packages to tackle problems with the recruitment and retention of science and mathematics teachers. Further details will be announced later this year.

4.45 To further improve schools' ability to provide high-quality teaching in science, the Government is providing resources in the Spending Review to:

- **introduce a major programme that will pay science, mathematics, IT and engineering undergraduates and postgraduates to return to schools during their studies and support teachers in the classroom and laboratory, with appropriate support and training to equip them to be effective.** This will operate as part of an initiative covering other subjects as well and will act to improve the support to teachers and pupils – particularly in practical classes – and provide pupils with excellent role models. The Government will build on the teacher associate scheme – which pays participants up to £40 a day – to deliver this programme. The Government's aim is to ensure that, as quickly as possible, all secondary schools within easy reach of a university are covered by the programme; and
- **improve the science-related training and development available to science teachers, both in their initial teacher training and throughout their careers to ensure that their skills and knowledge are relevant and up to date. The Government and the Wellcome Trust will launch a joint initiative to establish a national centre for excellence in science teaching.** Together with supporting networks, including a number of regional centres, this will enable teachers to enhance their professional skills through engaging with contemporary scientific ideas and training in effective teaching approaches and modern scientific techniques. The aim is to bring about changed teaching practice, to inspire pupils by providing them with a more exciting and intellectually stimulating and relevant science education, and to raise morale in the profession. It will be funded jointly by the Wellcome Trust and the Government, with the Trust contributing up to £25 million and the Government providing additional funds to support the initiative. Teachers and schools will be encouraged to take advantage of this initiative through, amongst other measures, having participants' travel costs and the related costs of supply teaching cover subsidised.

Improving teaching facilities

4.46 The environments in which science and related subjects are taught is crucial to pupils' quality of education. However, reports from Ofsted show that science laboratories in secondary schools are generally in a worse state than the school estate overall. Only a third are estimated to be of a 'good' standard or better. The Government is clear that, as in universities, this situation must be improved. Capital spending in schools has increased by over £2 billion since 1996-97, following many decades of under-investment. Some has been spent on science facilities, and an additional £60 million has been targeted specifically at schools science laboratories. However, the Government agrees with the Roberts Review that there is a need for such investment to be given higher priority.

4.47 **In this Spending Review, therefore, the Government will provide funds within the overall increase of over £1 billion for capital investment in education to improve significantly the quality of school science and technology laboratories and equipment. The Government will also prioritise investment in school laboratories from all sources of capital funding, and will include progress on improving the quality of science laboratories in its appraisal of local education authorities' Asset Management Plans. The Government's aim is to meet the initial modernisation target set in the Roberts report by the end of the Spending Review period, and to be on track to meet the 2010 modernisation target set in the report.**

Box 4.1: Specialist science and technology schools

The White Paper, *Schools achieving success*, published in September 2001, extended the range of specialisms under the Specialist Schools Programme to include science. The first 24 secondary schools to be designated as Science Colleges will become operational from September 2002. These will join the growing network of 992 specialist schools, including 443 Technology Colleges. Secondary schools that place a special emphasis on teaching science and technology promote an ethos which is scientific, technological, enterprising and vocational. Science and Technology Colleges extend learning opportunities in their chosen specialisms, for example, by providing a wider range of courses in their specialist subjects. They raise standards of achievement for pupils across the ability range by broadening their understanding of technology, science and mathematics and the relationships between these subjects. Science Colleges and Technology Colleges also play an important role in encouraging increased take-up and interest in science, mathematics and technology more generally, particularly post-16, through the links they are required to have with other schools and the wider community.

Creating exciting and relevant science curricula

4.48 Finally, the science curricula studied at GCSE and post-16 need to be relevant to pupils, and encourage a wider range of pupils to continue study in this area. The Government agrees with the Roberts Review that this will be crucial in increasing interest in the physical sciences, especially among girls and ethnic minorities, who are often under-represented in such subjects. The Government is piloting a new GCSE science programme and will review it in this context as soon as possible.

4.49 **As part of the summer 2003 review of the Curriculum 2000 reforms, the Government will ask the QCA to advise on how effective the recent changes to A-level science have been, and on whether further changes are needed to ease the transition. The Government is also launching an inquiry into post-14 mathematics, with the aim of ensuring that the UK has enough young people with good mathematical skills and knowledge that meets the needs of employers and of further and higher education.**

4.50 **The Government will also seek a step change in the relevance of science curricula to employers through making SETNET and the Education Business Link Partnerships work together to improve the interaction between schools and businesses and others.**

Encouraging the study of science and engineering in further and higher education

4.51 The measures described above should help improve the knowledge and skills of pupils studying science in schools and encourage more students to continue their study of science beyond school into further and higher study. Further and higher education play a vital role in training the next generation of scientists and engineers, as well as technicians and other support staff.

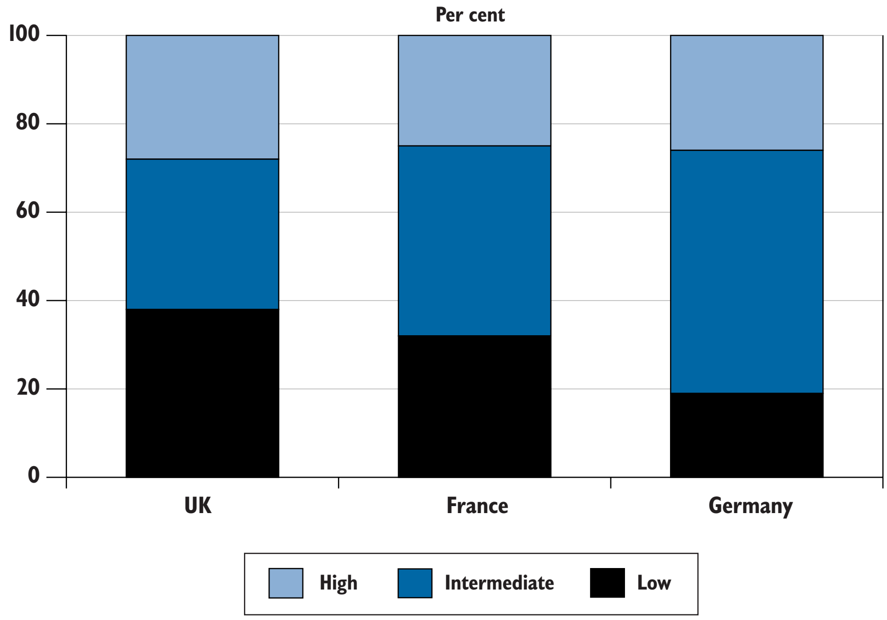
Improving the supply of scientific technicians and other support workers

4.52 Workers with intermediate skills are vital to the overall success of the UK economy. They are particularly important in the fields of science, engineering and technology, through their role as technicians and other support staff. It is important that both young people and adults are encouraged to develop their skills, and that vocational opportunities in science, engineering and technology help to create a pool of skilled workers for the sector.

4.53 Overall, the UK faces a significant skills gap at the intermediate level (see chart 4.4 below). Over a third of the UK workforce (over 8 million people) lack level 2 qualifications, equivalent to 5 good GCSEs. This problem both reduces productivity and leads to social exclusion. The Government is supporting the skills development of young people and helping the adult population improve their skills. Increased spending on education, alongside reforms to ensure that standards in schools and colleges are raised, and the development of new vocational routes for young people, is seen to be having an impact on the skills of young people in the UK.

4.54 The Government is also implementing policies to support adults to improve their skills. Over 1 in 4 UK adults do not have the levels of numeracy expected of an 11 year old. The Skills for Life policy has already helped improve adults' basic skills, and the Government will continue to support this through allocations in this Spending Review. New pilot schemes to test a possible new policy approach to raising the demand for training among low-skilled adults in the workforce, as outlined in the 2002 Budget, will help the Government to develop further policy measures in this area.

Chart 4.4: Employees by skill level, 1999



Source: OECD.

4.55 The Government is developing an education and training system that includes high quality vocational routes to allow young people to develop the kinds of skills required in the science and engineering sectors. Young people are demonstrating a great interest in vocational training in this area – for example, around 16 per cent of young people on Advanced Modern Apprenticeships (AMAs) are on courses related to science and engineering. The Government will continue to promote Modern Apprenticeships with the aim of increasing participation so that by 2004 at least 28 per cent of young people enter a Modern Apprenticeship before the age of 22.

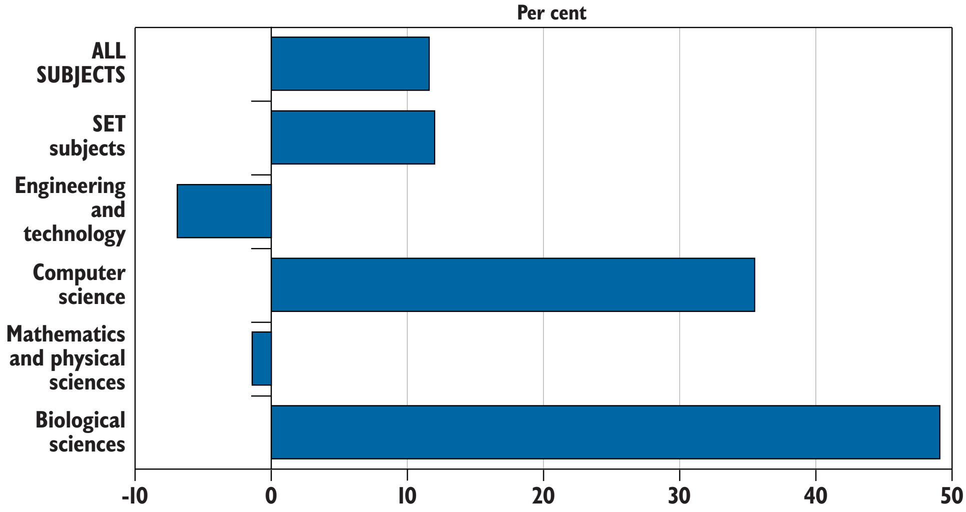
Increasing the attraction of science and engineering degrees

4.56 The Roberts Review found that the rise in the overall supply of graduate scientists and engineers in the UK in recent years masks significant falls in the numbers of graduates in the physical sciences, mathematics and engineering (see chart 4.5). This will have increasingly serious consequences for the UK as it reduces the capability of universities and the private sector to carry out the R&D necessary to increase innovation. Aside from the direct impact from R&D capability in these areas, there will be a read-across to other disciplines, since R&D is increasingly multi-disciplinary in nature.

4.57 In order to reverse these trends and ensure a strong supply of science and engineering graduates across the disciplines, the Government agrees with the Roberts Review that it is necessary to:

- improve science and engineering teaching facilities in universities;

Chart 4.5: Percentage change in first degree graduate numbers, 1995 to 2000



Source: Data from HESA, as presented in the Roberts Review.

- encourage more students to study science at undergraduate level by improving the links between schools and universities and addressing the current perception among prospective students that degrees in these subjects are relatively hard and expensive to succeed in; and

- ensure that science degrees provide graduates with the skills that employers need and value and that rewarding career paths are open into further study and academia.

4.58 Chapter 3 showed that the university research estate is in need of maintenance and refurbishment. There are also significant problems with the teaching estate, and the equipment used in science laboratories is often outdated. This not only impairs the teaching of science and engineering in universities, but also means that graduates are often not familiar with equipment used in R&D in business. As well as the dedicated capital funding stream for research (see Chapter 3) the Government is therefore introducing in the Spending Review significant additional resources for universities to use to maintain and upgrade their science teaching infrastructure. **The Government agrees with the aim of the Roberts report that by 2010 all university science and engineering teaching laboratories should be of a good standard or better (as measured by HEFCE). Resources to start to improve laboratories and move towards this target are included within the overall increase of capital funding for higher education.**

4.59 Improved facilities should have a positive impact on the performance of students learning science at university and will attract more people to undertake such degrees, as well as giving graduates valuable experience working with equipment more similar to equipment used in business R&D.

4.60 Furthermore, as recommended by the Roberts Review, HEFCE is examining the detailed funding formulae for teaching different subjects. Through this review the Government and HEFCE can ensure that in the longer-term teaching funding for different subjects accurately reflects the costs involved in modernising their teaching environments (for example, science and engineering teaching laboratories) in line with technological progress. The Human Resources strategies and associated funding provide a mechanism for institutions to recruit and retain teaching staff in competitive markets, but HEFCE will also consider whether and, if so, how, the teaching funding for different subjects should reflect differing recruitment and retention costs.

4.61 The Roberts Review also concluded that other factors, are important. Some were seen to related to perception: for example, degrees in these subjects are often seen as harder than degrees in arts subjects.

4.62 The perception that science degrees are harder than other subjects is to some extent linked with weak outcomes at school level in the physical sciences and mathematics. The Government is determined to address these perception issues through, amongst other measures, improving staffing and the teaching environment in these subjects at school.

4.63 However, the Roberts Review also identified more tangible issues that could act as deterrents to studying science and engineering. For example, there have been concerns that the greater likelihood of four-year degrees and more structured study in science degrees could act as a disincentive for students, particularly those from disadvantaged backgrounds. The main reason for this is the extra expense of a four-year course and the reduction in free time (or time available for part-time work) available to science students.

4.64 **The Government will ensure that the guidance for allocations of hardship funds by universities recommends that universities take account of contact hours as one of the factors to consider in making these funds available. The Government will also monitor the issue of four-year courses to ensure that their length, when combined with other factors such as student funding arrangements, does not act as a deterrent to students considering pursuing science and engineering courses at degree level.**

4.65 Responsibility for designing and delivering courses lies with institutions and it is ultimately for them to make sure that they teach students what they need to know in order to progress in science, engineering and mathematics courses. The Roberts Review identified though that the variation in the prior knowledge and skills of students can be a challenge to institutions in delivering science and engineering degrees in particular, and institutions already put a good deal of effort into supporting new students. **Mathematics skills can be a particular issue and, as mentioned earlier in this chapter, the Government is launching an inquiry into post-14 mathematics. Furthermore, in order to improve the transition into science and engineering at higher education the Government will work with the higher education sector to pilot and evaluate different approaches to bridging the gap between students' prior knowledge and the requirements of higher education study.**

4.66 Finally, universities must work with business to ensure that their courses are teaching skills relevant to employers. This requires higher levels of interaction between business and universities, which the Government will continue to encourage through its teaching and 'third-stream' funding. Students need to see that they will be rewarded for studying science. So businesses and other employers need to ensure that salaries post graduation are sufficiently competitive and businesses and universities also need to work together to ensure that more information is made available to students, for example through school and university career services, about the rewards of science and engineering degrees. The Government agrees with Sir Gareth Roberts' suggestion that RDAs may well have a role in brokering these relationships in their regions, particularly on behalf of SMEs. The Government also believes that the employers group, referred to in Annex A, should play an important role in encouraging this sort of interaction.

Conclusion

4.67 The need for human ingenuity in making discoveries and creating new products, processes and services means that the UK's innovation performance is critically dependent on a strong supply of scientists and engineers. The Roberts Review set out the challenges that face Government, businesses and others in improving this supply. The policy announcements in this chapter, and also in Annex A, demonstrate the Government's determination to respond to these challenges by improving the teaching available to young people; the prospects for undergraduate and post-graduate study; and the career opportunities for our best researchers.

4.68 Sir Gareth Roberts made clear in his report that action by businesses and other employers is vital role in encouraging more science and engineering graduates to work in research and development. The Government agrees with Sir Gareth Roberts that its resources and efforts in delivering the changes will be less effective if they are not accompanied with action by employers. Therefore, the Government will re-examine, before the next spending review, the response of employers to the challenge set out above – in order to ensure that taxpayers' money continues to be used to best effect.

4.69 Together with the initiatives described in chapter 3, this action will ensure that the UK has a strong research and development capability in the long-term. With a constant flow of leading-edge ideas and highly skilled scientists to develop them, the UK will be in a good position to increase its innovation record and to benefit from technological progress.

4.70 It is crucial, however, that the research that occurs in universities and the public sector can lead to R&D opportunities in the private sector. It is therefore necessary to foster further links between the two and for business to rise to the challenge to improve its performance. The next chapter explores the issue of knowledge transfer, while chapter 6 sets out the challenge to business in detail.

5 KNOWLEDGE TRANSFER

Introduction

5.1 Investment in research provides much of the foundation for innovation and the new products and services that result. However, such exploitation depends on ideas and skills transferring between universities, other research organisations and businesses, a process which has not always worked well in the UK. So it is imperative that, as we renew the research base, enhance the flow of skilled scientists, and invest in further growth for new science, we also ensure that there are effective two way links between research and the market.

5.2 As shown in Chapter 2, the track record of UK business in producing commercially successful new products and services is poor relative to our major competitors. For example, according to the Second European Community Innovation Survey, the percentage of UK business revenues generated from new and improved products was 23 per cent compared with an European Community average of 31 per cent.

5.3 This chapter describes the importance of knowledge transfer and accelerated diffusion as a means of capitalising on the wider potential benefits of publicly funded R&D, to ensure that they are developed into successful products and services. Chapter 6 then sets out the Government's approach to establishing a supportive yet challenging environment which enables and stimulates business to invest in innovation to deliver productivity growth.

5.4 Innovation involves intricate connections between research and business. Simple linear models, which assume that investment in the supply side (knowledge creation) will automatically result in marketable innovations, do not fully capture this complexity. Innovation is far more interactive. The major drive for this must come from the private sector, responding to competitive challenges and market opportunities. Leading edge businesses are not just passive recipients of science and technology – they actively explore new fields, helping to generate new solutions to innovation challenges, and also play a role in shaping agendas of academic research. An important role for Government, though, is to remove artificial blockages within the innovation system, and to create the right framework conditions for the efficient functioning and development of the system.

5.5 There is no single model of what an innovation system should look like – this will vary from country to country and sector to sector. Further, there is an increasingly international dimension to the process of innovation. R&D knowledge and human capital are mobile across borders. But to exploit these assets here, UK business needs to be able to deploy the skills and financial capital to attract, absorb and develop them into commercially successful products, processes and services. As the Roberts Review highlighted, the UK may be enjoying a 'brain gain' rather than a 'brain drain' at present, but both Government and business must do more to recruit and retain the UK's best scientists and engineers to support innovation here. Multinational businesses will often assess the quality of the science base in deciding on the location of their European research facilities. So the climate for business innovation in the UK is closely linked to the depth and breadth of knowledge transfer from the science base.

5.6 Perhaps the most significant forms of transfer from the science and engineering base to business and the community are through the supply of highly skilled people. Chapter 4 describes how the Government intends to address the issue of people and skills.

5.7 Knowledge transfer between the research base and business depends on:

- the capabilities of the research base and the extent to which it is orientated towards the needs of business;
- the technological capabilities of business and its propensity to innovate; and
- the coverage and strength of the links between them.

5.8 Action by both the public and private sectors is therefore needed if publicly funded research is to be effectively translated into marketable products and services. The role of business is crucial, and any measures which strengthen the technological and innovation performance of business will tend to support knowledge transfer from the research base. The private sector also needs to have easy access to university research and to understand how universities operate. Equally, universities and the public sector must have a realistic awareness of the possibilities for the commercial exploitation of their research, and an understanding of the priorities and needs of the private sector.

5.9 Knowledge transfer requires the right economic environment to support and stimulate business to link with suppliers, customers and the research base. These linkages will primarily be created and financed by industry. But there is a key role for Government to help redress identified market failures in particular activities or regions, and to invest strategically in new strands of science and technology and its exploitation. This chapter considers how the Government can work with both research and business organisations to stimulate knowledge transfer.

Increasing knowledge transfer

Encouraging industry to build on publicly funded research

5.10 Companies whose competitive advantage derives from technological innovation should spontaneously seek out the skills and research knowledge they need, pulling through ideas from the UK's science and engineering base. But there are potential barriers to this process operating efficiently. From the point of view of the individual firm, the results of long term research are uncertain in terms of their relevance to the firm's business, their timing and the commercial returns they eventually yield. Often the results of research carried out by the firm benefit other organisations. For these reasons, firms may undertake less long term research than is desirable from the point of view of the economy as a whole.

5.11 There are three main reasons for Government financial support to encourage long term R&D and knowledge transfer. As elsewhere, any particular intervention needs to ensure that Government resources and activity are truly supplementing the private sector's own efforts and are likely to deliver net economic benefits:

Collaborative research

- Collaboration between firms can help solve barriers to innovation. For the same amount of money per firm, a coalition can undertake a much wider range of research increasing the chances of a successful technological and commercial outcome. A group of firms may be able to capture a much greater proportion of the results of their joint research than an individual firm acting alone. However, research collaborations between firms are not always easy to arrange. Firms may encounter difficulties in identifying partners, problems over intellectual property rights, and the process may involve heavy use of the scarce time of senior management. Government can help to bring firms together, acting as an impartial co-ordinator and intermediary. Government support for collaborative R&D also allows a combination of the scientific excellence of the science base with the greater understanding of potential commercial applications of the private sector.

Lowering risks

- For large firms the vast majority of R&D projects involve only modest financial risk; the bulk of expenditure on innovation comes later. However small and medium sized enterprises (SMEs), particularly high technology SMEs who wish or need to grow quickly, often have to undertake R&D projects which are relatively large in relation to the financial value of the company. Raising external finance against uncertain future assets generated by technology investment may be difficult. Potential lenders may lack understanding of both the technology and market involved. Government co-finance can lower the financial risk to the firm and to potential private sector sources of funds. Project appraisal by DTI can ease the burden of due diligence for private investors.

Diffusion of technology and best practice

- Government can provide information on how adopting new technologies can improve a business, drawn from business best practice and exploiting economies of scale not available to private providers. Firms are having to incorporate an increasing number of technologies into their products and processes, and to keep up with an increasing number of changes in business practice. Combined with the quickening pace of technological change, this imposes a burden on the firm, particularly heavy on SMEs, to monitor and evaluate an increasing range of technologies and business practices which may be relevant to their business. As a result, many SMEs do not adopt new technologies or business practices as soon as they should.

Government interventions to encourage knowledge transfer

5.12 DTI is giving greater priority to innovation and has established a new Innovation Group headed by a Director General for innovation and technology. This, together with DTI's current review of its business support functions, provides the opportunity to direct resources most effectively to those interventions which truly augment the private sector's own efforts and contribute effectively to the UK's growth potential. The Department will in future have a better informed and more sharply focused objective of driving innovation, including knowledge transfer from the science base, into the business sector. One of its aims will be to increase the exploitation of the knowledge created in the UK's world class science base as well as from abroad. Improving the UK's innovation performance is also one of the pillars for supporting manufacturing success here.

5.13 DTI's current portfolio of programmes to encourage knowledge transfer between the science base and industry includes:

- Support for collaboration through the **LINK** programme and **Faraday Partnerships** which together currently provide £52 million annually of Government support, and cover a very wide range of technologies from textiles through food processing, polymers chemical measurements to nano-composites. Around a thousand firms of varying sizes are involved, many of which would not have otherwise taken part in collaborative projects. Working with the Research Councils facilitates the participation of universities and Research and Technology Organisations (RTOs), at the interface between the science base and business. This helps strengthen the technological knowledge outputs of the research, capture the additional scientific knowledge that the research will yield, and disseminate any advances in research methodology and 'know how' to the wider research community.

- Lowering the commercial and technological risks of investment in R&D and innovation, especially for SMEs, through programmes such as **SMART** and **TCS** (formerly the Teaching Company Scheme). SMART provides grants for R&D in technologically innovative products, amounting to £27 million in 2001-02 for 800 projects. TCS provided £22 million of support in 2001-02 to businesses (up to 900 at any one time) for employing high quality graduates on two year projects and giving firms the opportunity to take direct advantage of the science and engineering base, thus reducing the risk of expanding their technological range or even of doing R&D for the first time.

- Support for spreading information on technology developments abroad through the **International Technology Service** and the spread of best practice through **Industrial Forums**. For example, in 2002-03, ITS will have organised some 40 missions to other countries; and there are currently eight Industrial Forums in areas such as aerospace, oil and gas, and chemicals.

5.14 An increasingly important element of DTI's knowledge transfer activities has been investing in the diffusion and development of new or emerging technologies with the potential to have pervasive impacts and to disrupt traditional businesses and markets. Examples to date are biotechnology, genomics and e-science, where there is also a high degree of complementarity with the Government's investment in science. Prospectively, nanotechnology now holds out major potential to influence products and processes across many sectors (see box below).The current budget for DTI's overall portfolio of knowledge transfer activities (including the space sector) has increased in recent years to some £250 million in 2002-03.

5.15 The Government recognises that well targeted and evaluated interventions which address market failures can help stimulate valuable collaboration between the public and private sectors, and can lead to long term benefits for the economy. **In this Spending Review, therefore, the Government will increase the resources available to DTI for knowledge transfer activities to £300 million by 2005-06**. With additional resources and a sharper DTI focus on innovation, there is an opportunity now to re-evaluate the current portfolio of programmes to ensure that resources are allocated to complement the private sector's own efforts, in as efficient and effective manner as possible. DTI will take this forward.

Box 5.1: Nanotechnology – redefining products and processes

Nanotechnology – the application of science at the atomic and molecular level – is set to redefine our lifestyles and the way we manufacture products – from pharmaceuticals that are formulated for individuals to tiny computers based on biotechnology and groups of molecules. Nanotechnology is disruptive and pervasive – it forces rapid change and will make many accepted products redundant as well as making more efficient use of natural resources (for example, digital cameras do not need photographic film).

A recent report[1] by the UK Advisory Group on Nanotechnology Applications, chaired by the Director-General of Research Councils, indicates that although the UK possesses a strong basic research capability in nanotechnologies, it is not achieving critical mass or securing adequate industrial engagement. Too many in UK industry still believe that nanotechnology is some way over the horizon. The reality is otherwise. The report proposes a five year strategy based on increasing industrial capability to turn research into new products and processes with clear and effective routes to market, including establishing new national nanotechnology fabrication facilities to offer firms – especially leading edge SMEs – high quality equipment and expertise where they can test ideas practically.

Industry itself also needs to be alert to the threats and opportunities that nanotechnology brings. This means working closely with the Government and the research and education sectors to ensure that public and private investment can be made with confidence and with sufficient critical mass to deliver commercially successful new technological applications in an ever more demanding market place.

[1] DTI/OST (2002), New dimensions in manufacturing: a UK strategy for nanotechnology

Encouraging links between the research base and business

5.16 Knowledge transfer takes place naturally through the movement of trained researchers between the science base and business, and from the publication and patenting of research results. The investment in research output described in Chapter 3 should strengthen the flow of ideas into the economy, augmented by the measures to improve the supply of scientists and engineers highlighted in Chapter 4. Beyond these steps, the quality and volume of knowledge transfer can be improved by tackling a range of factors which would otherwise impede this process:

- Capacity building in universities and public sector research establishments (PSREs) so that they can develop better relationships with industry, create networks and exploit intellectual property. There may be barriers to establishing this activity initially: once overcome through public intervention, the resulting links with business could become self sustaining.

- Relationships between SMEs and the science base, where many smaller firms do not readily have the means, information or incentives to invest in engaging with universities, despite the commercial and wider benefits which this could bring.

- Support for collaborative research into technologies at a very early stage of development or which mainly benefit society as a whole. Examples of the latter include technologies yielding environmental, health or regeneration benefits, while the former include disruptive technologies, which may have wide applicability to new and growing industries but may be less immediately relevant to today's companies.

Support for these technologies will be decided in the light of the potential for long term economic, social and environmental benefits and the extent to which these benefits are expected to be widely distributed.

5.17 There are thus clear rationales for well targeted Government intervention to counteract the tendency for sub-optimal interactions between business and the research base and for business itself to undertake too little research. The main purpose of Government interventions to assist universities and the public sector in improving relations with, and relevance to, the private sector – detailed in table 5.1 below – has been to generate new capacity for commercially focused innovation in universities and PSREs.

Table 5.1: Government programmes to increase knowledge transfer

Scheme	Objective	Outcomes
University Challenge – first round (1999)	To close the funding gap between basic research and private sector investment by overcoming difficulties faced in trying to fund proof of concept and prototype development work, to demonstrate sufficient success so private investment will follow.	37 institutions (28 universities and 9 Research Council institutes) have access to £65 million (£45 million from Government and charity sources, and £20 million from universities).
University Challenge – second round (2001)	As above.	Five funds established in which 17 institutions are involved. Each consortium received £3 million of Government funding to establish the fund, or in some cases to add to funds in the first round.
Science Enterprise Challenge – first round (1999)	To encourage the emergence of a culture that is open to entrepreneurship, which is required for successful knowledge transfer from the science base.	12 centres of excellence were established with £29 million of Government funding. Following external contributions, the centres have access to around £57 million funding.
Science Enterprise Challenge – second round (2001)	As above.	7 consortia (involving more than 30 institutions) were successful and £15 million of Government investment was made. The majority of awards provided additional funding to centres established by the first round.
Higher Education Innovation Fund (2001)	Third stream of funding for universities (additional to teaching and research) building on Higher Education Reach Out to Business and the Community Fund.	Government allocated £140 million over three years from 2001-02.
PSRE Fund (2001)	To enable bodies carrying out research in the public sector to support commercialisation and access seed capital funding.	£10 million was awarded in 2001-02, £4 million in establishing a seed fund, and the remaining £6 million to enable 14 consortia, comprising PSREs and more than 30 NHS Trusts, to develop capacity in knowledge transfer.

5.18 Institutions have responded positively to the measures introduced and as a result the capacity for, and the amount of, knowledge transfer occurring between universities and business has increased considerably. There is clear evidence[32] of this improvement. For example:

- 199 spin off firms were created in 1999-2000 compared with 26 in 1997, and an average of under 70 per year over the previous five years;
- in 1999-2000, total patents filed by universities rose by 22 per cent from the previous year to 1,534;

[32] HEFCE (2001), Higher education business interaction survey

- more than 90 per cent of universities employed specialist staff to support commercial work; and
- one spin off firm was identified for every £8.6 million of research expenditure in UK universities in 1999-2000, compared to one for every £53.1 million in the US.

5.19 Schemes such as the Higher Education Innovation Fund (HEIF), University Challenge and Science Enterprise Centres are enabling universities to generate capacity for knowledge transfer. The £10 million commercialisation fund for PSREs was launched with the aim of stimulating a similar culture change in those institutions.

Higher Education Innovation Fund

5.20 HEIF was introduced in 2001-02 and will be worth £60 million a year by 2003-04. The funding has been allocated to universities by an advisory board chaired by the Director General of Research Councils and the programme managed by HEFCE on behalf of OST and DfES, with the aim of building on universities' potential as drivers of growth in the knowledge economy. It has supported more than 70 universities in activities such as the employment of specialist staff, establishing business incubators, improving the intellectual property infrastructure, and providing enterprise training for staff. Much of this funding has gone to non-research intensive higher education institutions, which adds valuable diversity to the range of knowledge transfer activities across the UK.

5.21 University Challenge, to which the Government has allocated £60 million over the last two Spending Reviews (including £18 million from the Wellcome Trust and £2 million from the Gatsby Charitable Foundation), provides seed capital funding for the development of new commercial initiatives. Science Enterprise Challenge has provided £44 million over the last two Spending Reviews to allow universities to teach science, engineering and technology students business and entrepreneurial skills. These measures have been extremely successful in stimulating activity from a low base and improving the awareness and experience of knowledge transfer within universities. These specific initiatives have helped catalyse new innovation activities across a wide range of institutions.

5.22 It is important to ensure that there is continued support to overcome persistent barriers to efficient market driven innovation. To do this, the Government will continue to support knowledge transfer between universities and business through the Higher Education Innovation Fund (HEIF). The Government is also restating its commitment that HEIF should form the basis of the permanent third stream of funding (in addition to teaching and research).

5.23 **In this Spending Review, the Government will increase the funds available through OST and DfES for HEIF, combining funding previously allocated to University Challenge and Science Enterprise Challenge into the new HEIF budget[33]. A total of £170 million will be allocated to universities via another round to fund two further years of activity to 2005-06.** In this way, the Government will be supporting knowledge transfer in universities and research institutes through a single stream of funding. This funding will aim both to build on success which has been demonstrated so far in knowledge transfer, and to broaden the reach of these activities through support for non-research intensive university departments.

5.24 Having developed momentum in the higher education sector in support of knowledge transfer activities, universities can now play a greater role in targeting available resources at identified priority areas, be it capacity building, seed funding or other activities. Universities will, if they choose, be free to bid for HEIF funding to support the type of activities that were previously supported by other schemes, for example to top up venture capital funds which are now proving themselves or to build on their earlier investments in entrepreneurship education. In order to remove the constraints on funding imposed by ring fenced schemes, there will therefore be no further separate rounds of University Challenge or Science Enterprise Challenge.

5.25 The new expanded HEIF should support:

- work to promote enterprise in universities and to promote networking between the university, business and other user communities for the outputs of research;
- the infrastructure and capability to transfer knowledge from universities into business and the community through applied research, technology and knowledge development, and consultancy, linking with all types and sizes of business; and
- the formation, through seedcorn funding, of companies to spin out new knowledge, or the development of commercial enterprises to pursue the activities above.

5.26 HEIF will be awarded for a two year period beginning in 2004-05, based on a programme of work proposed by universities, building on their earlier successes. Universities will also have to propose measures by which their progress and success can be judged. These should over time provide a basis for establishing measures to ensure that this money increasingly follows success. Stakeholders should continue working to identify what these measures might be. As part of their proposals for using HEIF, universities must consider how they can better engage businesses in knowledge transfer activities. To ensure that HEIF proposals are relevant to the needs of local and

[33] HEIF is currently an England only (devolved) scheme, while Science Enterprise Challenge and University Challenge are UK (reserved) schemes. The new HEIF will be a devolved scheme. The devolved administrations will receive their share of the additional funding in the normal way, and will, if they so decide, be able to continue to use it to fund knowledge transfer schemes.

regional economic development, Regional Development Agencies (RDAs) should be involved in the development and prioritisation of universities' proposals for use of HEIF.

5.27 Through this approach, the Government is increasing both the amount of funding for these activities, and the flexibilities for universities to determine the best ways in which to stimulate knowledge transfer activities.

Public Sector Research Establishments (PSREs)

5.28 Research Council and departmental PSREs have also begun to embrace the commercialisation opportunities arising from their research. They have recruited specialist technology transfer staff, and are identifying opportunities for exploitation of their research. To provide further support and guidance, Partnerships UK have established a dedicated science and innovation unit, focused on developing and spreading best practice in commercialisation amongst PSREs.

5.29 Those PSREs for which exploitation is a relatively new concept are beginning to respond positively to the commercialisation opportunities. **To create parallel incentive mechanisms for knowledge transfer from the Government's own research organisations, to those provided for universities, the Government will provide a further £15 million over two years to support increasing commercialisation among PSREs**. This will increase by 50 per cent the amount of funding devoted centrally to knowledge transfer from PSREs since the last Spending Review. This recognises the opportunities that exist, and the significant potential that these organisations hold.

5.30 Universities and PSREs should be incentivised to step up their activities in knowledge transfer by the rewards of income from successful development of research ideas, and from enhanced and more user relevant research. Government support for these activities is, except when addressing clear market failures, largely stimulating activity which can be taken forward in the medium term by universities and PSREs.

Cambridge-MIT Institute

5.31 The Cambridge MIT Institute (CMI) provides an international dimension to the UK's knowledge transfer programme. This project brings together the expertise of two of the world's leading research universities to provide joint educational and research initiatives aimed at improving entrepreneurship and productivity in the UK economy, sharing the results with other UK universities. CMI is now starting to deliver tangible benefits to UK research and business. Although funded separately from the entrepreneurship activities developed in Science Enterprise Centres, the CMI is increasingly integrated into this UK network to deliver wider benefits beyond the Cambridge-MIT axis. The Government as major investor (with business co-finance) will continue to require substantial dividends in the form of enterprise education and research for the UK in return for continued backing over the remaining three years of the funding period.

Links between basic and applied research

5.32 Universities differ markedly in the balance of their research, teaching and business interface activities. With research becoming more interdisciplinary, linking departments and institutions across the spectrum of basic and applied research, there are increasingly varied combinations of activities which together contribute to knowledge transfer. This means research results are less likely to be developed into commercial innovations in a formulaic, predictable way.

5.33 Many universities build on their basic research presence in order to provide knowledge transfer services and research relevant to industry. Those universities which specialise in links with industry and applied research often have an underpinning core of basic research on which their industry links rely. Other less research intensive departments in universities have the potential to add a further dimension to the knowledge transfer process. By using their organisational focus on interacting with regional businesses, and by working in partnership with other universities, they can help translate research outputs to engage SMEs and less technologically sophisticated businesses. The extra money for HEIF will be used by OST to fund such initiatives, where there are demonstrable skills and motivation in the universities to lead these ventures and they are clearly supported by business and integrated with the needs of the regional economy.

The regional dimension of knowledge transfer

5.34 Government spending on science and research is largely organised on a national basis, giving priority to funding excellent research and development, wherever it is found. This secures value for money, and is the most effective way of ensuring the UK's research capability remains internationally competitive. But wherever research and development activity takes place, in universities, research establishments or business, it has the potential to contribute directly to regional economic development as well as innovation at the national level. Just as national productivity growth in the long run depends on harnessing innovations to add value, so regional growth is likely increasingly to be founded on the innovation performance of business and the research base in the region.

5.35 Research and innovation rely crucially on human interactions, to share ideas and experiences in a richer dialogue and working more closely together than the exchange of the written word. Firms and universities benefit from proximity to other research intensive organisations in geographical clusters, both to enhance the dialogue between their personnel and to tap into thicker and more liquid labour markets. Clusters (defined by the OECD as 'networks of interdependent firms, knowledge-producing institutions, bridging institutions and customers, linked in a production chain which creates added value') are important building blocks of regional innovation systems. Efficient knowledge transfer between a range of inter-dependent bodies within a region is therefore crucial to successful clusters.

5.36 The Regional Development Agencies have been given increased funding and flexibilities, building on the earlier £50m per annum Regional Innovation Fund, which will enable them to assist in the development of clusters of strategic economic importance and in understanding other regionally focused innovation activities. RDAs are developing and refining an understanding of the strengths and weaknesses of their regions, including how their regional science and engineering base can integrate with the needs of business as part of regional economic strategies. RDAs are therefore best placed to identify mismatches between regional industrial strength and relative research weakness, or vice versa. Some of these mismatches can be addressed by co-ordination from the RDAs, bringing together business and universities to secure agreement to common regional innovation objectives. The Government will therefore also be encouraging RDAs to establish regional Science and Industry Councils or equivalent bodies, along the lines of those in the North West and North East, to provide local leadership in strengthening regionally based innovation. RDAs will also be able to invest their own funds, or lever in external funding, to develop capacity where necessary.

5.37 The Government will also be considering how best to make use of the RDAs' regional knowledge in the allocation of knowledge transfer funding, such as HEIF and DTI's portfolio of innovation programmes. The RDAs will be in a good position to advise Government on regional priorities reflecting relative performance on innovation across the country, and to work with universities on the development of proposals which avoid duplication, and encourage complementarity and connections with regional economic development priorities.

Conclusions

5.38 The Government's aim is to improve the UK's innovation performance as a central part of its strategy to raise productivity and economic growth. Previous chapters have set out how the Government will act to ensure that universities can continue to produce world class scientific research over the long term and to provide an adequate supply of highly skilled scientist to carry out research and development.

5.39 As UK companies face ever increasing global competition, it is critical to their long term survival that they move up the value added chain through investment in innovation, leading to new and better products and processes. The positive benefits of this lead to both increased productivity and further economic growth as new or improved products and services are also taken into new markets. This requires two way interaction between the science base and the private sector, and the private sector having the ambition, opportunities and capacity to innovate. This chapter has shown how the Government will continue to support and encourage knowledge transfer and to overcome initial obstacles and persistent barriers to achieve this.

5.40 The next chapter looks more closely at how the Government can build on the reforms to the science base and the labour market that have been outlined so far to set the right environment for firms to increase their investment in innovation and technological progress.

6 INNOVATING BUSINESSES

Introduction

6.1 Both the public and the private sectors have vital roles to play in increasing the amount of R&D undertaken in the UK, and thereby raising the technological innovative potential of the economy. Previous chapters have set out the Government's strategy for working in partnership with other stakeholders to ensure that university science research is world class and that there is a sufficient supply of highly skilled scientists and engineers. These measures will ensure that high quality R&D can be undertaken in the UK over the long term.

6.2 Ultimately, however, it is businesses that develop new ideas and inventions into new products and services that can deliver economic gains. Their motivation is to deliver value to customers and shareholders. Increasingly, firms in industrialised nations are competing internationally primarily on quality, design and service, to move into higher value added activities: being competitive on price is no longer sufficient to maintain a commercial advantage. Investment in innovation is integral to creating higher value.

6.3 To move onto a virtuous circle of increased investment in innovation leading to value creation and re-investment, it is important that the Government takes a holistic approach to innovation as a system across the whole economy. It was for this reason that the Government published its Manufacturing Strategy in May 2002, setting a strategic framework for working in partnership with industry, industry bodies, trades unions, Regional Development Agencies, other Government departments and all key stakeholders, to ensure that Government addresses the commercial needs of business in driving forward the manufacturing agenda. As well as ensuring that university research is world-class, connected to business needs, and that the UK has a sufficient supply of highly skilled scientists, Government has responsibility for setting the framework conditions for competition and investment, knowledge creation and R&D.

6.4 This chapter sets out the Government's approach to fostering innovation by UK businesses.

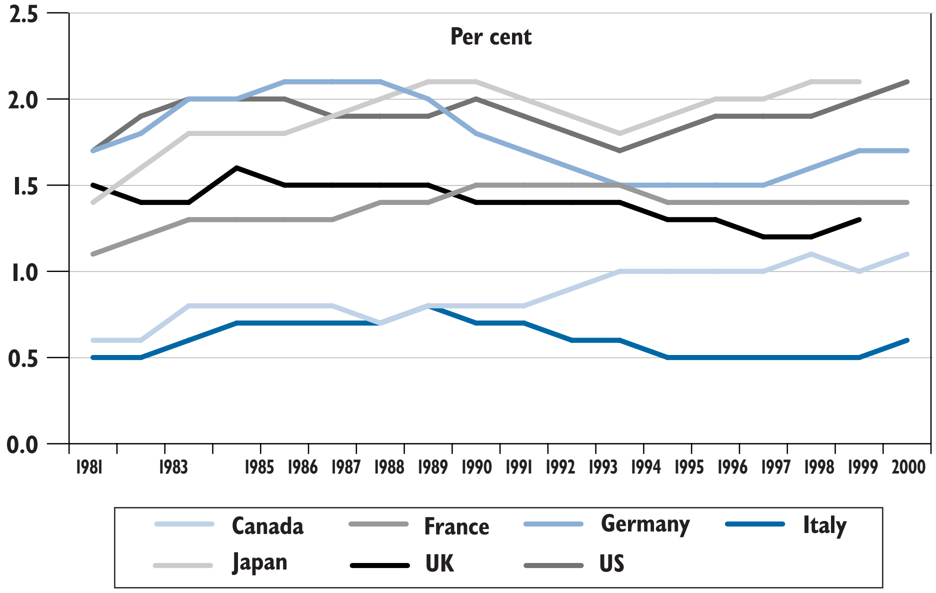
Private sector research performance

6.5 As Chapter 2 has shown, the private sector carries out most of the R&D undertaken in all G7 countries. In quantitative terms these businesses therefore have a critical role in driving national innovation performance. But beyond this, business R&D is the prime route for ensuring that value is derived from research undertaken by public sector and higher education institutions, through creating marketable outputs from the skills and ideas developed in these institutions. If this channel for converting knowledge into added value is functioning effectively, it will draw out the benefits of public research; evidence[34] suggests that government-funded R&D has a greater impact on productivity growth in countries with a high intensity of business-funded R&D.

[34] Guellec and van Pottelsberghe de la Potterie, (2001) R&D and productivity growth: Panel data analysis of 16 OECD countries.

6.6 R&D carried out by businesses in the UK fell as a proportion of UK GDP, from 1.5 per cent in 1981 to 1.2 per cent in 1997. As a result, the UK performs significantly worse than the US, Germany, and France in terms of the amount of R&D performed and funded by the private sector measured as a percentage of GDP (see chart 6.1). However, Chapter 2 also showed that there has been a recent upturn in business-financed R&D, which suggests that more businesses are recognising the importance of R&D and innovation for future performance.

Chart 6.1: Business R&D Spending as a per cent of GDP across G7 countries



Source: OECD.

6.7 The R&D Scoreboard[35] shows that R&D undertaken by large firms is dominated by pharmaceuticals and aerospace which together account for 48 per cent of total UK R&D (compared to 19 per cent internationally) in 2001. UK companies in both sectors and the health care industry have an average R&D intensity[36] above that of their foreign counterparts. However, the UK scores poorly in all other sectors (for example, IT and automotive – the top two sectors for R&D outside the UK) where its R&D intensity lags behind competitor countries. For example, average UK R&D intensity for all sectors in 2001 was 2.1 per cent, representing half the level of the US (4.3 per cent), Japan (4.2 per cent) and the international average (4.2 per cent).

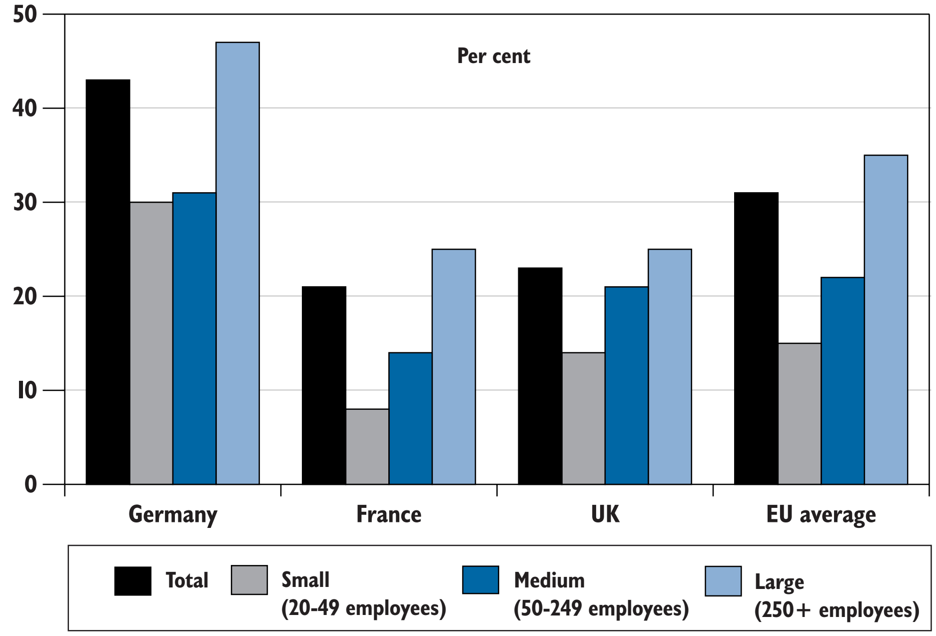
[35] DTI (2001), R&D Scoreboard.

[36] R&D intensity refers to the ratio of R&D expenditure as a proportion of total sales.

6.8 Recent research by the OECD on business R&D intensity has investigated whether industry composition effects partly explain business R&D intensity[37]: for example, whether the UK has a poor R&D record because it is weak in sectors that are traditionally very R&D-intensive. However, the OECD found that these composition effects were not the most significant factor in explaining the UK's poor record; instead differences in R&D intensity across most sectors were seen to explain the differences in the overall R&D intensity.

6.9 The UK business sector's low spend on R&D relative to countries such as the USA, France, and Germany would be expected to translate into a relatively weaker innovation performance. Although innovation as an output is inherently difficult to measure, the available evidence does indeed suggest that UK firms are in practice less innovative than those in countries in which business expenditure on R&D is greater. The UK's larger manufacturing companies, in particular, fall behind the European average in the extent to which their sales are based on innovative or improved products (see chart 6.2 below).

Chart 6.2: Proportion of turnover due to new improved products in the manufacturing sector, 1996



Source: European Community Innovation Survey.

Setting the right environment for private sector investment

6.10 The Government recognises that businesses will only invest in R&D and innovation when there are good commercial reasons for doing so, the incentives are right, and when they are likely to see returns from that investment. In the UK in recent decades, these framework conditions have

[37] OECD (2002), Productivity and Innovation: The Impact of Product and Labour Market Policies, Economic Outlook 71.

not been as supportive of business investment as they could have been. As argued in Chapter 2, it is partly for this reason that even when the UK's total spend on R&D was the second highest in the G7 as a share of GDP (in around 1980), this investment did not translate into outstanding economic performance.

6.11 The Government's science and innovation strategy is designed to ensure that the overall environment is supportive of business investment in R&D and innovation. This requires the Government to ensure that:

- the supply conditions are right. This involves ensuring there is a steady flow of ideas from the science and engineering base and a sufficient supply of appropriately skilled scientists and technologists to carry out R&D;
- the demand conditions match this with high levels of university and business interaction and incentives for businesses to invest in R&D via a sound intellectual property regime and a favourable tax treatment of R&D investment; and
- wider economic conditions also encourage investment. Macroeconomic stability, a favourable general tax regime and a strong competition policy will all encourage businesses to invest in R&D.

6.12 On the supply of research ideas and skills, Chapters 3 and 4 have set out the Government's strategy for ensuring that universities can fund their research departments on a sustainable basis and that they can continue to develop new areas of research. They also highlight proposals to improve the supply of skilled scientists and engineers.

6.13 On the demand side, Chapter 5 outlines the Government's strategy for encouraging more interaction between universities and businesses. It is also important to create direct incentives for firms to invest in R&D. The substantial reforms to the UK tax system for businesses, investors and entrepreneurs in recent years (highlighted below) have helped improve both general and targeted fiscal support for corporate innovation investment in the UK.

6.14 Finally, the Government is committed to ensuring that intellectual property regime in the UK and Europe continues to provide incentives to research and innovation, through protection of original ideas. Scientific gains in new areas of human genome research, and the continued growth in the importance of information technology raise challenges for intellectual property rights policy. These scientific and technological advances place a premium on ensuring that the creation and protection of intellectual property rights support and sustain a vibrant innovation system.

Creating a favourable economic environment

6.15 Specific demand and supply measures are important to ensuring that businesses have the capacity and motivation to invest further in innovation. However, for the economic gains to flow from this it is crucial that the wider economic framework is conducive to capitalising on R&D and innovation. The Government's approach to achieving this involves:

- creating a stable macroeconomic environment in which firms can invest for the future;
- establishing a strong competition regime that provides powerful incentives for firms to innovate and reduces the costs of, and barriers to, entry to markets;
- reducing barriers to entrepreneurship to encourage new innovative businesses to emerge. New entrants to markets increase competitive pressures on market incumbents, thereby further encouraging firms to innovate;
- developing a general tax regime that is favourable to growth businesses; and
- assisting the development of efficient and sophisticated capital markets that are attuned to the needs of R&D intensive undertakings.

6.16 Creating macroeconomic stability was the primary economic aim of this Government in 1997. Through making the Bank of England independent and the introduction of the fiscal rules, the Government has created greater certainty that interest rates will remain both low and stable. This encourages firms to invest for the long term because returns are more predictable and risks reduced. This situation is radically different from that in preceding years, when instability was partly responsible for low business investment in the UK.

Encouraging innovation through competition

6.17 The UK has historically had a weak competition regime. This may have acted to subdue incentives for investment in R&D and the commercialisation of innovations. In an uncompetitive market, barriers to entry are high, making it difficult for new entrants, often small and medium sized enterprises, to bring innovations to market and thus challenge the power of incumbents. In this environment the pressure to reduce costs is reduced. The result is that incumbent firms themselves may become complacent in exploring new innovations or hold back marketing new generations of products to exploit market power in the current generation.

6.18 By contrast, in a vigorously competitive environment firms are forced to adopt best practice techniques, continuously seek to innovate and improve efficiency in order to survive and prosper. And as each firm seeks to innovate to gain advantage over rivals, so those ideas are built on by other competitors, or by potential entrants to the market, thus raising the overall rate of innovation. This benefit can be even greater when firms, toughened by domestic competition, go on to compete effectively on the world stage. A strong domestic competition framework can therefore create benefits for industry as a whole that are greater than the sum of the benefits for each individual firm. This phenomenon is clearly observed in industry clusters, geographic concentrations of a particular industry that can achieve fast productivity growth.

6.19 There is substantial evidence on links between strong competition and high productivity growth. Studies[38] examining the impact of competition on R&D in the UK conclude that concentration, and other measures of market power, tend to reduce the rate of innovation and hence productivity growth. Wider international studies[39] conclude that British industry has long been undermined by monopoly companies and protective regulations with the result that innovation in these industries has been stunted.

6.20 The Competition Act 1998 greatly strengthened the domestic competition regime through the introduction of a prohibition against anti-competitive agreements and abuses of dominant market position. This has been augmented by greater resources for the Office of Fair Trading to increase its ability to deter, detect and punish anti-competitive behaviour. The Enterprise Bill, currently before Parliament, will take reforms further by introducing full independence for the UK competition authorities, and criminal sanctions against individuals who engage in cartels.

6.21 Whilst a competitive environment will provide the best general incentive for firms to innovate, firms need to be confident that they can reap the rewards of their innovation. This is why the intellectual property regime allows firms to prevent, for a limited period, their competitors from copying their innovations. This is a necessary reward for the costs of research and development, and helps to encourage innovation. Given the natural tension between these objectives, it is critical that Government policies strike the right balance between encouraging competition and rewarding innovation.

6.22 Beyond the macroeconomic and competition frameworks, the Government has taken forward a range of policy reforms to enhance the financial incentives to invest at the business level, and the efficiency of capital markets in supplying business finance.

[38] Geroski (1990), Innovation, Technological Opportunity and Market Structure, Oxford Economics Papers 42.
[39] Porter (1990), The Competitive Advantage of Nations.

Reducing financial barriers to innovation

6.23 The bulk of business innovation is conducted by major companies. It is therefore important that the tax regime for such companies supports investment decision-making. However, new entrants also have an important role to play in commercialising new ideas and challenging incumbents. In some sectors, such as biotechnology, whole market niches are populated by new ventures, which have the advantages of focus over larger companies. Weaknesses in the external financing of smaller and start-up enterprises provide the starting point for the Government's reforms to improve the returns to investment by, and in, SMEs. These have been supported by improvements in venture capital and access to public equity markets in recent years.

6.24 For established larger corporations, the Government has reformed the business tax regime to encourage investment and remove distortions that would otherwise have impacted on financial planning. This encourages investment by increasing the returns available to the investor. The Government has also used the tax framework to create positive incentives to invest in innovative high growth companies:

- Corporate tax rates have been reduced across the board – from 33 per cent to 30 per cent for large companies, and from 23 per cent to 19 per cent for companies with lower levels of profits.
- The tax system has been reformed to reduce tax impediments to businesses' innovation activities. In the past, the tax system has not allowed all of the costs of innovation to be written off against taxable profits. To remove this distortion and further align tax with commercial accounting, reforms introduced in this year's Budget allow companies tax deductions for the cost of acquiring intellectual property, including patents, trademarks, brands, copyrights and a range of intangible rights, commercial information and goodwill.

6.25 For smaller companies facing greater financing hurdles, the Government has implemented a comprehensive set of measures to encourage enterprise start-up and growth:

- A new starting rate for companies with low profits has been introduced, and this year reduced from 10 per cent to zero.
- Investors in high growth companies look for returns in capital growth, rather than dividends, and so mitigation of capital gains on corporate shares represents a targeted tax incentive for investment in growth-oriented companies. Government has reduced the effective tax rate on unquoted shares held for two or more years from 40 per cent to 10 per cent.

- Further incentives for venture capital investment by individuals in smaller higher risk companies are provided by improved tax incentives via Venture Capital Trusts, the Enterprise Investment Scheme and the Community Investment Tax Credit.

- Small high growth companies can find it difficult to offer the competitive salaries needed to attract the right employees, but may use share options to reward employees for the growth the company achieves. The Government has introduced a tax favoured share option scheme for smaller companies (Enterprise Management Incentives), which allows them to give up to £3 million of share options tax free, across the company, to help recruit and retain personnel.

- The Small Firms Loan Guarantee Scheme assists firms to access debt finance where they do not have sufficient collateral or track record to do so unaided.

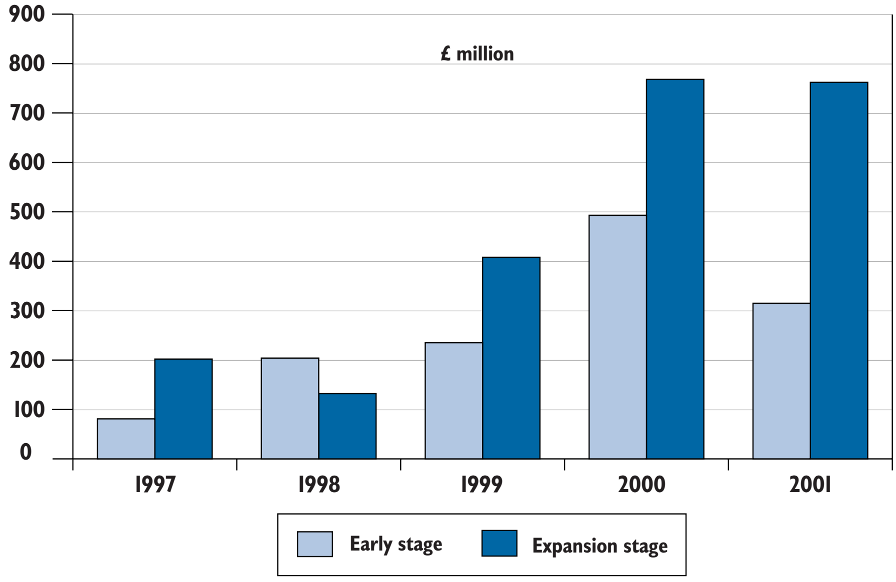
6.26 In addition to these tax measures, the Government has further increased access to risk capital through the Regional Venture Capital Funds programme. Funds are being set up in every English region which will provide up to £270 million of investment in businesses with growth potential, backed by up to £80 million of Government funding and £53.5 million from the European Investment Fund. The funds are targeted at the 'equity gap', for injections of risk capital below £500,000, where private sector venture capital funds are reluctant to offer finance. The Government is also making available up to £50 million of Early Growth Funding, to help innovative businesses in their early stages through provision of small amounts of finance. Furthermore, as a result of a £20 million Government cornerstone investment, over £100 million of investment will be targeted at early stage high technology businesses through the UK High Technology Fund.

6.27 Government measures have contributed to an improvement in the supply of risk capital in the UK in recent years. While larger management buy-outs of established businesses continue to dominate market volumes, risk capital is increasingly available for smaller technology-based firms. As the chart below shows, private equity investment in high technology firms[40] in the early and expansion stage has increased threefold between 1997 and 2001. This marked trend increase in investment indicates the healthy underlying attitude toward investing in the technology sector, despite the recent downturn in capital markets. The UK now accounts for around one quarter of all European investments in early stage venture capital for technology companies[41].

[40] The high technology category includes communications e.g. computer hardware and software other electronics related technology and biotechnology.

[41] PricewaterhouseCoopers (2002), Money for growth – The European Technology Investment Report 2001.

Chart 6.3: Venture capital investment in the high technology sector – early and expansion stage



Source: British Venture Capital Association.

6.28 To complement and reinforce venture capital investment in innovative firms, there are now easier entry routes onto the public equity markets for technology-based firms which are yet to reach profit. This is supported by the increasing number of companies entering the unlisted AIM and OFEX markets. Despite the downturn in the technology sector, the number of companies registered on AIM more than doubled from 308 in 1997 to 629 in 2001 and the number of companies registered on OFEX increased from 138 in 1997 to 195 in 2001.

6.29 As well as helping to stimulate an increase in the effective supply of finance for SMEs, the Government is also acting to increase the effective demand. The Small Business Service has announced successful bidders to run six pilot projects operating in different parts of the country. These will help inform small businesses about their financing options and offer a programme of support to help them become investment ready.

6.30 These relatively new programmes complement existing measures such as the SMART awards (see Chapter 5) that offer grants to small businesses developing new products or processes.

6.31 To complement generic tax measures, the Government has also introduced direct incentives for companies to increase investment in R&D through the R&D tax credits, which recognise and respond to the additional financing hurdles which both large and small firms face in committing long term capital towards research.

6.32 In 2000, the Government introduced an R&D tax credit for small and medium sized companies, increasing the tax deduction for current R&D expenditure to 150 per cent, in place of the usual 100 per cent. And because technology-based early stage companies undertaking R&D often face cash flow constraints, loss-making companies can obtain immediate benefit from the credit by converting it into a cash payment worth up to one quarter of their R&D spend.

6.33 In Budget 2002, R&D tax credits were extended to all companies with the introduction of a 125 per cent tax credit for larger companies, which undertake around 90 per cent of all business R&D in the UK. The large companies credit reduces the cost of R&D by 7.5 per cent for most large companies, and the two tax credits together represent £500 million support from Government for business R&D investment.

6.34 The tax credits have been designed to be transparent and predictable, delivering a flat rate of subsidy that companies can incorporate into their investment decisions. Evidence[42] suggests that firms show a strong response to a reduction in the cost of R&D – increasing their expenditure pound for pound in line with the tax support.

6.35 A large proportion of R&D is undertaken by very large multinational groups of companies, who have considerable choice about where they locate their R&D activity. The large companies credit also targets R&D undertaken in the UK, which will encourage both inward investment of R&D by foreign multinationals and UK based multinationals to locate their R&D here.

6.36 While not a substitute for well targeted grant funding, the advantages of a tax credit are that it allows investment decisions to remain with companies, and is cheaper to administer, for both companies and Government. However, to deliver these advantages it is essential that companies are confident about the scope of the credit and their ability to realise the tax advantage it offers. The Inland Revenue is therefore working with industry to promote the tax credits to companies of all sizes and to clarify the R&D definition.

Creating a conducive regulatory environment

6.37 Regulation of science reflects society's demands for an ethical approach to research. By designing and implementing regulations sensitively, the Government can encourage rather than deter innovation in the UK by creating confidence for firms and research organisations to undertake science. For example, biotechnological innovation has been stimulated whilst protecting human health and the environment through a pragmatic and transparent regulatory framework that ensures cutting edge research aimed at developing new treatments can proceed. The Human Fertilisation and Embryology Act 1990 and the Human Fertilisation and Embryology (Research Purposes) Regulations 2001 have enabled the UK to encourage innovative research on stem cells while balancing ethical concerns. Such research is now attracting world class scientists to work in the UK, and demonstrating that the UK remains a favourable location for science and investment. Similarly, the UK's approach to regulation of gene therapy has helped the UK to become the European leader and close the gap on the USA in terms of new clinical trials over the last two years.

[42] Bloom, Griffith & Van Reenen (2000), Do R&D tax credits work? Evidence from an international panel of countries, 1979-94.

The challenge to the private sector

6.38 Reaping the rising productivity gains and subsequent economic benefits of innovation is a long term process, requiring sustained investment throughout the innovation system and effective mechanisms for diffusion and exploitation of scientific knowledge. The Government recognises its responsibility for implementing a range of interlinked structural policies to provide credible long term incentives for all partners in the UK's innovation system to play their part. Building on the macroeconomic benefits already delivered through reforms to monetary and fiscal policy, and the structural benefits which should flow from competition policy and business tax reforms, the Government is now tackling the challenge of putting science research funding on a more sustainable long term footing. This should deliver greater confidence for all those engaged in the UK's innovation endeavour that the underpinning investment in production of research knowledge and skills will continue to grow. This in turn should reinforce wider reforms to encourage long term investment in R&D and innovation across the economy.

6.39 Ultimately, however, it is up to individual businesses to make the most of the opportunities that are provided as a result of the reforms set out in this strategy. Only business can generate tangible economic value for the knowledge economy from science and technology inputs. Only business faces the growing competitive challenge to be more innovative in boosting their value added.

6.40 Businesses are best placed to identify their needs for science and technology inputs, absorbing the skills and ideas emerging from a vibrant UK science base. To attract the skills they need in an increasingly international labour market, companies need to improve the attractiveness of careers in R&D, rewarding and motivating new generations of scientists and engineers who will enable the next generation of innovation. There is now a real opportunity for business to shift the perception of science, engineering and technology in the minds of young people, through engaging with schools, colleges and universities, to inspire the industrial researchers and innovators of the future.

6.41 Businesses are also well placed to exploit the growing effort by universities and public sector research establishments to transfer research into the market place. As they increase their interaction with the science and engineering base, business will benefit from the investment by Government in putting the research infrastructure onto a sustainable footing over this decade. In return, commercially-funded research will play its part in ensuring that research in higher education is fully funded across the range of public and private sector partners.

6.42 Innovation is at the heart of the UK's future productivity growth and is a key part of the Government's Manufacturing Strategy. Through investing now in research, skills, and knowledge transformation, businesses can provide the impetus for real and lasting economic gains for the country as a whole. There is now the opportunity for joint action: public and private capital, combined with reforms to public policy and commercial practice, to move the UK economy back onto a virtuous circle where innovation and productivity growth reinforce each other, creating the platform for future prosperity.

7 ENHANCING SCIENCE IN GOVERNMENT DEPARTMENTS

Introduction

7.1 Government needs to use high quality science, including social science, and the most appropriate new technologies in order to deliver evidence based policies and excellent public services. To this end, Government departments spend significant sums of money on research and development. Total spending, not including surveillance and testing, was nearly £4 billion in 1999-2000, with £1.35 billion being spent by civil departments. Science base funding by Research and Funding Councils, by comparison, was of the order of £2.5 billion in the same year. In addition, Government obtains scientific advice, often from independent scientists, on a wide range of functions, including policy development, regulation and service delivery.

7.2 The importance of high quality science has come into increasing focus in recent years. The Phillips Report on the BSE Inquiry, published in October 2000, and the Government's response to it emphasised the need for rigorous scientific advice and for Government to have the competence to act as an intelligent customer. More recently, during the outbreak of foot and mouth disease, scientific advice based on sophisticated epidemiological models delivered in real time helped to inform decision making and determine policy as events unfolded.

7.3 The following criteria are critical for success in using science and managing research:

- effective horizon scanning so that issues involving science, or where science could be involved, are identified in advance;
- effective arrangements for deciding what current or potential science could benefit the needs of the department and hence whether new research is needed;
- strong procurement process, run by expert research programme managers;
- commitment to excellence in research, which is fit for purpose, and carried out to high standards;
- critical use of the results of research and scientific advice in policy formulation;
- open approach to publication of results and debate about implications; and
- effective knowledge sharing and transfer.

7.4 The Government has taken a series of measures in recent years to strengthen the use of science. In particular:

- departments have published science and innovation strategies, setting out the broad framework within which research programmes and other scientific activities are carried out, and showing how these help to deliver objectives and priorities;
- the Chief Scientific Adviser's Guidelines on scientific advice in policy making, revised July 2000, set out the key principles applying to the development and presentation of scientific advice; and
- the Code of Practice for Scientific Advisory Committees, published in December 2001, promotes good practice in the operation of scientific advisory committees and their relationship with Government.

7.5 Most departments can now demonstrate that many of the features essential for success are in place. More needs to be done, with the aim of creating a dynamic for improvement in the use of science by Government, analogous to the improvements in university research delivered following the introduction of an external driver in the form of the Research Assessment Exercise.

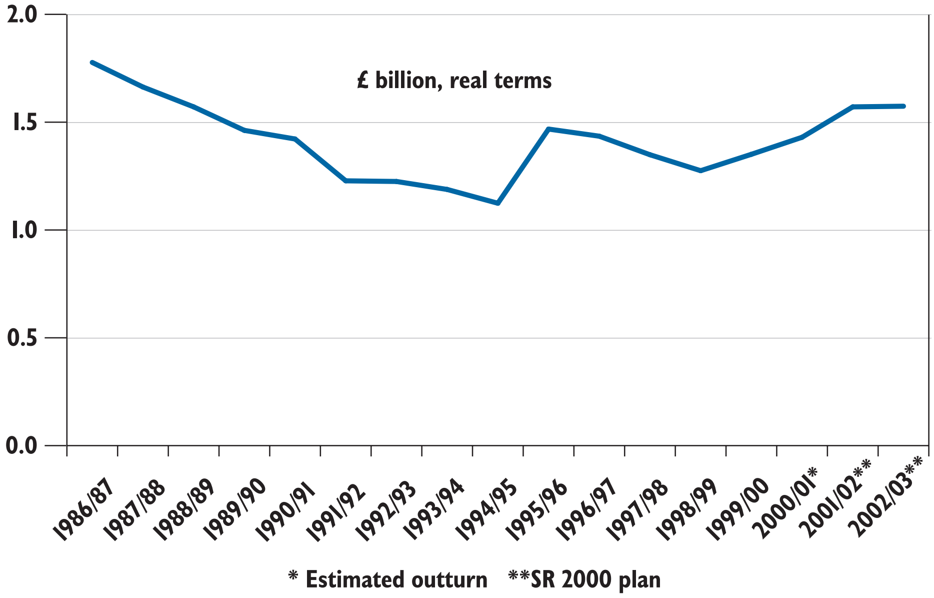
7.6 The Government is now introducing a package of measures to strengthen the use of science and management of research, covering physical, life and social sciences, and technology. These are designed to:

- ensure that science priorities are carefully considered and given proper weight alongside other priorities in spending decisions, so that there are adequate inputs for science and research;
- improve the competence of departments to act as an intelligent customer and manager;
- improve arrangements for knowledge transfer; and
- increase external scrutiny and benchmarking, led by the Government's Chief Scientific Adviser, to facilitate the exchange of good practice and to encourage a dynamic for improvement.

Budgets

7.7 High quality outputs require adequate inputs invested in research. Spending on civil research and development by Government departments tended to decline through the 1980s and 1990s (see chart 7.1 below). This trend has now been reversed. The decision in the 2000 Spending Review that the research spend of the main civil departments should at least be maintained in real terms has made a significant contribution. This improvement needs to be sustained.

Chart 7.1: Net Government expenditure on R&D by civil departments



Source: OST Forward Look 2001.

7.7 Research spend typically represents a very small proportion of departmental budgets (1 or 2 per cent). As such a small proportion of the overall budget, research spending can be vulnerable to urgent pressures because its outputs are less tangible and more uncertain than other forms of investment, although the outcome is often of major long term importance.

7.8 **To encourage a more strategic approach to setting R&D budgets, and to identify clearly the resources needed, future science and innovation strategies will be costed, taking account of the need to make an appropriate contribution to the real costs of work commissioned from universities, as set out in Chapter 3.** These costings will enable early identification of the investment needed. Changes in agreed spending plans for departments with major research programmes will be monitored by the Treasury and the Government's Chief Scientific Adviser.

Scientific expertise

7.9 Departments must have the capability to commission the right research, assess its quality, and use it effectively. To do so, they need in-house scientific expertise. A number of developments in the management of the Civil Service in the last quarter of the twentieth century have weakened traditional arrangements for supply of such expertise:

- the privatisation of scientific research establishments, and the development of an arms-length relationship between departments and the remaining public sector establishments, has eroded what was previously the main base for the supply of practising scientists to departments;

- successful implementation of reform programmes designed to facilitate interchange between scientists and the generalist Civil Service, together with the decentralisation of personnel management, means that there is no longer a separate science group in the Civil Service, and arrangements for career management and continuing professional development for scientists have become fragmented.

7.10 A strategic approach is required. Departments need to take a systematic view of the areas that need scientific input, and the critical mass of scientists needed at the interface between science and policy. While maintaining opportunities for movement between specialist and generalist posts, they must ensure that there are adequate opportunities and resources for professional development and career progression for practising scientists working in Government. This will involve exposure to the latest science in their area of work, enhancing the professional status of research management within Government, secondments, and better arrangements for scientists to move freely into related scientific areas in other departments.

7.11 Departments must have the capability to consider science issues at an appropriately senior level in the wider context of the department's work. This requires representation and strategic direction at the top end of the department. **Departments which use or commission an appreciable amount of science research will need to appoint a Chief Scientific Adviser, who can ensure that the department's scientific activities are well directed and that policy is soundly based on good science, and to be the department's scientific spokesman to the outside world.** Such a person will need active experience at the cutting edge of science, in order to ensure they have the appropriate credibility both within and outside the department. The individual concerned will also need to operate at the appropriately senior policy making and operational level in the department.

Knowledge transfer

7.12 In recent years there has been a drive, prompted by the recommendations of the Baker Report[43], for commercialisation of the research outputs of Public Sector Research Establishments (PSREs), to promote more effective exploitation of publicly funded research, including that commissioned by Government departments.

7.13 Departments and agencies involved in delivering the knowledge transfer agenda have often been hampered by a lack of appropriate incentives, skills and expertise for this area. To address these barriers, there have been a number of changes in policy, as well as new measures to assist and encourage knowledge and technology transfer.

[43] Creating knowledge, creating wealth: realising the economic potential of public sector research establishments - A report to DTI/HMT (1999)

7.14 The main initiatives have focused on delivering the agenda set out in the Government's response to the Baker Report. These include the Patent Office guidelines, Intellectual Property in Government Research Contracts; the OST's guidance on good practice for PSREs on staff incentives and the management of conflicts of interest; the establishment of a Science and Technology Commercialisation Unit within Partnerships UK; and the Small Business Research Initiative (SBRI), making research procurement accessible for smaller companies. The 2000 Spending Review also launched the £10m PSRE Fund, which provided £6m for the development of knowledge transfer capacity, and created a £4m seed corn fund to invest in early stage ideas emerging from the PSREs.

7.15 There is still some way to go for Government to embed knowledge transfer into the goals and practice of public sector research establishments. Departments will now include knowledge transfer objectives in their science and innovation strategies and in their research programmes. A senior official will be responsible for delivery, by the department and the PSREs for which it is responsible, of knowledge transfer goals and targets, and for ensuring that the department's PSREs are given the financial and other freedoms recommended by the Baker Report. **And as set out in Chapter 5, the Government will provide a further £15 million to continue the PSRE Fund in support of new knowledge transfer activities.**

Cross-cutting issues

7.16 Research needs often cut across departmental - and disciplinary - boundaries. Arrangements for co-operation and communication vary according to need. Generally, the arrangements are informal. Although there are some examples of cross-cutting research areas where stronger co-ordinating arrangements are used, procedures for allocating and accounting for budgets have not always facilitated such an approach.

7.17 Merged budgets, with departments contributing to a single pot under the leadership of a single department and with shared steering arrangements, provide a more robust basis for strategic direction and are already in use. Research co-ordination of this type generally follows policy and programme co-ordination. A good example is the interdepartmental Research and Information Working Group in the drugs research area, chaired by the Home Office, which monitors the progress of the research programmes and manages a ring fenced budget. The Government's Chief Scientific Adviser will explore the scope for increased use of merged research budgets in cross-cutting areas of research.

External review

7.18 The Government's Chief Scientific Adviser is responsible for advising the Prime Minister and the Cabinet on the overall health of science and scientific research funded by Government departments. He needs to be in a position to provide assurance on the quality and rigour of the systems which departments have in place for using science and managing research. **The Government's Chief Scientific Adviser will work closely with departments and their CSAs to introduce a new rolling programme of external scrutiny and benchmarking supported by a new team in OST, so that there is an external dynamic for improvement in the ways that departments use science and manage research.** The programme will work with the grain of existing arrangements for scrutiny and audit, reinforcing best practice and encouraging consistently high standards.

ANNEX A: THE GOVERNMENT'S RESPONSE TO THE ROBERTS REVIEW

Recommendation 2.1: The participation of women in science and engineering

The Review notes that, despite recent progress, the proportion of girls studying mathematics and the physical sciences post-16 is still considerably lower than that of boys, which contributes to the under-representation of women in science and engineering more generally. The Review is clear that the under-participation of women in SET is damaging the UK's supply of scientists and engineers, and a number of the recommendations set out in this report should have an important influence on the participation of women in science and engineering.

The Review is aware of a separate study, led by Baroness Susan Greenfield, who has been asked by the Government to recommend how to achieve a step change in the effectiveness of measures being used to increase the participation of women in science and engineering. This Review has therefore sought not to duplicate the work of that study but firmly believes that action is required.

The Government shares the desire to see more women participating in science (particularly physical science) and engineering, and agrees that implementing a number of the Review's recommendations should help in this regard. The Government will also encourage participation by women through considering the findings of the study led by Baroness Greenfield and through the work of the Promoting Science, Engineering and Technology for Women (PSETW) unit in the Office of Science and Technology. Furthermore, the Government believes that existing measures, such as the Science and Engineering Ambassadors Programme can play a role in this process (in the case of the Ambassadors Programme by providing positive role models for girls).

Recommendation 2.2: The participation of ethnic minority groups in science and engineering

The Review is disappointed by the lack of awareness and analysis of differences in achievement and participation in science and engineering between ethnic groups. It is difficult to establish the root causes of these differences, based on the evidence available. However, the Review believes that they are significant and therefore recommends that the Government investigate this issue fully in schools, further education and higher education.

The Government is alive to the concerns expressed on the participation and achievement of ethnic minority pupils in science and engineering, and in education more generally. The Government is committed to working with key partners – such as the Commission for Racial Equality and representatives from community groups – to develop a coherent national strategy for raising the achievement of ethnic minority pupils. As part of Science Year the Government is working with the organisation Black Parents in Education in creating a website celebrating the achievements of black scientists past and present. The aim is to raise the self-esteem of African Caribbean pupils and encourage them to consider careers in science and engineering.

As with recommendation 2.1, the Government believes that implementation of a number of the Review's recommendations, coupled with existing initiatives such as the Science and Engineering Ambassadors programme, will encourage participation and achievement in science and engineering by ethnic minority pupils. And in light of this specific recommendation the Government will also take steps to improve data available on the achievement and participation of ethnic minority groups in science and engineering.

Recommendation 2.3: Primary school teachers

The Review recommends that the Government ensure that primary school teachers receive greater subject specific training (in particular, in relation to the physical sciences and mathematics) both in their initial training and through Continuing Professional Development to enable primary teachers to build on the progress they have made so far. Furthermore, the Government should review, in three years' time, the progress made in improving primary school teachers' confidence in teaching all areas of the mathematics and science curricula, and take further action as necessary.

The Government is committed to ensuring that all primary school teachers are able to teach all areas of science and mathematics as well as they can teach other subjects. New standards and requirements for initial teacher training were published in January 2002. These define the skills and knowledge that new teachers are expected to have upon completing their initial teacher training, and allow flexibility to tailor training to meet individual trainees' needs. They specify that all primary trainees must be trained to teach science and mathematics so that they can effectively deliver the National Curriculum in these subjects.

Through the accompanying guidance handbook the Government will focus the attention of teacher training providers on ensuring that all primary teachers are trained and able to teach all areas of science and mathematics to a high standard. The Government will also continue to review the content and standards of initial teacher training and the effectiveness of different routes into teaching.

Through the Learning and Teaching strategy, and in particular through the National Centre for Excellence in Science Teaching (referred to in the response to recommendation 2.6), the Government will also ensure that all those existing primary school teachers who need to do so can, and are encouraged to, improve their understanding and teaching of science.

The Government is also committed to further improving primary teachers' mathematics subject knowledge. Around 40,000 teachers have already attended a National Numeracy Strategy five day intensive mathematics course and by next April the number attending will have risen to around 60,000. This year the Government is also funding training for all mathematics coordinators and leading mathematics teachers.

Recommendation 2.4: Secondary school science teachers' training

The Review recommends that in order to enhance the quality of teaching across the sciences – and in the physical sciences in particular – the Government should act to improve significantly the subject-specific training and support given to science trainee teachers on initial teacher training and other teacher entry programmes. Furthermore, the Government should review, in three years' time, the progress in improving secondary school teachers' confidence in teaching all areas of the science curriculum, and take further action as necessary.

The Review also recommends that in recruiting science graduates the Government should pay more attention to their areas of specialism (*e.g.* physics, chemistry or biology) in order to ensure an adequate supply of teachers able to teach the individual sciences (particularly physics and chemistry) at higher levels.

Currently, where a student's degree does not cover the spectrum of knowledge required to teach a particular subject, a scheme called Pre and In Course Study (PICS) is available to help bridge the gap.

In order to ensure that the aims of Review's recommendation are met, the Government will make it a clear expectation that all science trainee teachers should undertake science-specific training to provide them with a good knowledge base to teach all areas of science up to the end of Key Stage 4. (Although trainees would not be required to undertake this training if they can demonstrate that their recent education has provided them with a sufficient spectrum of knowledge.) In developing this, the Government will draw upon an evaluation of the PICS scheme by the Teacher Training Agency.

The Government will also develop explicit targets for the numbers of teachers needed to teach different areas of science post-16, and will use these targets to influence its strategy for recruiting to initial teacher training.

Recommendation 2.5: Teachers' remuneration

The Review recommends that, to solve the serious shortages in mathematics, science, ICT and D&T teachers, more must be done to address the pay and other incentives offered to teachers in these subjects. The Government, schools and colleges must compete for graduates in these disciplines in the labour market by, amongst other measures, providing more attractive remuneration for teachers in these subjects to better enable schools to attract graduates who can earn higher salaries in other sectors of the economy. This will require head teachers and governing bodies to pay teachers in shortage subjects more than other teachers, which is the economically efficient response to specific shortage in supply.

The Review therefore recommends that the Government tackle such recruitment and retention problems through increasing the remuneration offered to teachers of these shortage subjects – and also that head teachers and governing bodies use all the pay flexibility at their disposal. Furthermore, the Review recommends that this additional pay be linked – wherever possible – to teachers' take-up of CPD activities and opportunities, thereby rewarding those teachers who make particular efforts to further improve their subject knowledge and teaching style.

Teachers' pay in England and Wales is based on recommendations made by the independent School Teachers' Review Body (STRB). The settlement for 2002–03 gives all teachers a 3.5% increase and a radically shortened main pay scale, which will help to improve the attractiveness of teaching as a profession.

Nevertheless, the Government accepts that an employment market operates, and that teachers of shortage subjects have higher value in that market than other teachers. The Government acknowledges the difficulty that this brings in recruiting the required numbers of science and mathematics graduates to teaching. That is why the Government has introduced a range of measures, including golden hellos, differentiated training grants and paying-off teachers' student loans over a period of time. The Government has also put in place scope for local pay flexibility to address particular recruitment and retention issues, including recruitment and retention allowances of up to £5,262 pa, and management allowances, which recognise particular responsibilities, of up to £10,275 pa. Schools may also help with housing, travel and relocation costs.

These and other measures (such as tackling workload) to improve teaching as a profession have had an effect. For example, vacancy rates are falling and recruitment to ITT courses in 2001/02 was up by 20% in mathematics; 8% in science; and 15% in technology.

Although these measures have begun to have a positive effect, difficulties remain. Over the Spending Review period, the Government is determined to enhance pupils' science, mathematics and technology education by improving prospects for the recruitment and retention of science and mathematics teachers, including through paying more to good science and mathematics teachers. Therefore, the Government will consider further targeted incentives, building on student loan write-offs and the flexibilities already available to schools, and will be asking the School Teachers' Review Body to consider how the teachers' pay and conditions system might be adapted over the Spending Review period to enable schools to offer more targeted incentive packages to tackle problems with the recruitment and retention of science and mathematics teachers. Further details will be announced later this year.

The Government will also work with the Teacher Training Agency to publicise the profession in a positive way and to highlight the various measures that are in place to stimulate recruitment. Recruitment marketing is already integrated under the "*Those who can, teach*" campaign, which has attracted great interest and which seeks to raise awareness of improvements to the profession, in areas of pay, training bursaries, golden hellos and the proposed scheme to pay off student loans. This scheme, to repay the student loans of new teachers in shortage subjects will be at the core of a major publicity initiative this autumn.

Recommendation 2.6: Secondary school teachers' Continuing Professional Development (CPD)

The Review recommends that the Government improve science teachers' access to, and take up of, subject related CPD, which will benefit their teaching and also act to improve retention. In particular, the Review recommends that all science teachers be incentivised to undertake CPD, and that the range of recognised CPD activities be as broad as possible. For example, it should include the possibility of participating in scientific research carried out in industry and universities. The Review welcomes the Government's commitment to a National Centre for Excellence in Science Teaching. It also notes the interest of the Wellcome Trust and hopes that the Government and the Trust can form the sort of partnership that has been so fruitful in other areas of science policy.

The Government welcomes the Review's support for the idea of a National Centre for Excellence in Science Teaching. The Government consulted widely with all interested parties earlier this year and following a positive response to the consultation is now in a position to set out the design of the National Centre.

The Wellcome Trust is a strong advocate of a National Centre for Excellence in Science Teaching and the Government is delighted that the Trust has agreed to enter a partnership to deliver the concept of a National Centre. The Centre will consist of one National Centre and up to 10 regional centres, connected to each other, and to teachers in schools, by a virtual network. It will be funded jointly between the Government and the Wellcome Trust, with the Trust providing up to £25m. The Government and the Wellcome Trust are currently developing detailed specifications for the centre, and further information will be made available later in the year. The Government is keen to involve the Association for Science Education and the Astra Zeneca Teaching Trust Science Forum (which brings together leading employers, academics and school education professionals) in the running of the centre.

When it is up and running in 2004 the Centre will drive the quality, accessibility and relevance of Continuing Professional Development for teachers. It will offer a range of experiences to teachers, including short residential, day or half-day CPD opportunities, together with support, advice and web-based resources. The Government will ensure that teachers and schools are encouraged to make use of the Centre through subsidising participants' travel costs, as well as the costs of supply teacher cover.

The National Centre for Excellence in Science Teaching will complement the national strategy for continuing professional development launched in March 2001. The national strategy is designed to give all teachers greatly increased opportunities for relevant, focused, effective professional development, and to place professional development at the heart of school improvement. It complements specific policy initiatives, such as early professional development pilots, best practice scholarships and science specialist schools.

Recommendation 2.7: School laboratories

School science and D&T laboratories are a vital part of students' learning experiences in these subjects, and should play an important role in encouraging students to study these subjects at higher levels. However, it is clear that for many pupils this is not the case. To address this, the Review recommends that the Government and Local Education Authorities prioritise school science and D&T laboratories, and ensure that investment is made available to bring all such laboratories up to a satisfactory standard (as measured by OFSTED) by 2005. Furthermore, the Review recommends that these laboratories should be brought up to a good or excellent standard (again, as measured by OFSTED) by 2010; a standard which is representative of the world of science and technology today and will help to inspire and motivate students to study these subjects further. The Government should take all appropriate steps to ensure that these targets are met.

The Government agrees that well-equipped, modern laboratories are critical to pupils' learning experiences. For this reason the Government has already set aside £60 million specifically for school laboratories over the last two years, in addition to the significant increase in capital expenditure in schools since 1997. And in this year's capital funding guidance, school science and design and technology accommodation is highlighted as a priority for Local Education Authorities.

In this Spending Review, therefore, the Government will provide funds within the overall increase of over £1 billion for capital investment in education to improve significantly the quality of school science and technology laboratories and equipment. The Government will also prioritise investment in school laboratories from all sources of capital funding, and will include progress on improving the quality of science laboratories in its appraisal of local education authorities' Asset Management Plans. The Government's aim is to meet the initial modernisation target set in the Roberts report by the end of the Spending Review period, and to be on track to meet the 2010 modernisation target set in the report.

Recommendation 2.8: Teaching assistants

The Review is convinced that the high pupil-to-staff ratios in schools in England – particularly in practical classes – is having an adverse effect on the quality of pupils' science and D&T education, and in turn on the supply of science and engineering skills. The Review believes these high pupil-to-staff ratios in practical classes are best addressed through the employment of skilled teaching assistants acting to support the teacher, and that science and engineering undergraduates and postgraduates are well placed to support teachers in this way, since they have a good recent understanding not only of the subject but also of the school environment. They can also provide important role models for pupils.

The Review therefore recommends that the Government establish a major new programme, paying undergraduate and postgraduate students to support science and D&T teachers. The scheme should be implemented alongside the Researchers in Residence scheme, and should be open to postgraduates as well as undergraduates. The Government should pay students on a competitive footing with other sources of employment open to them. The Government should set an ambitious target for the number of science and engineering students participating in such a scheme by 2005.

The precise role of the teaching assistants should be for schools, universities and the students to decide locally, on the basis of guidance from the Government. Examples of possible roles could be direct support to teachers in supervising practical work, giving demonstrations or supporting science and D&T technicians. Naturally, it will be important to ensure that those participating have the skills and training to work in these capacities.

The Government agrees that teaching assistants and support staff, including undergraduates and postgraduate students, can play an important role in supporting the teaching of design and technology and science, as well as other subjects in schools – particularly in practical classes where pupil-to-staff ratios are an important factor in pupils' learning experiences.

To further improve schools' ability to provide high-quality teaching in science, the Government is providing resources in the Spending Review to introduce a major programme that will pay science, mathematics, IT and engineering undergraduates and postgraduates to return to schools during their studies and support teachers in the classroom and laboratory, with appropriate support and training to equip them to be effective. This will operate as part of an initiative covering other subjects as well and will act to improve the support to teachers and pupils – particularly in practical classes – and provide pupils with excellent role models. The Government will build on the teacher associate scheme – which pays participants up to £40 a day – to deliver this programme. The Government's aim is to ensure that, as quickly as possible, all secondary schools within easy reach of a university are covered by the programme. The Government will seek to work with the organisers of the Researchers in Residence Scheme, SETNET, the pilot Undergraduate Ambassadors Programme and the new initiative developed in collaboration with Imperial College and GlaxoSmithKline in taking forward this programme.

Recommendation 2.9: The science curriculum

The science curriculum – particularly in the physical sciences – is not, at present, sufficiently approachable nor appealing to all pupils between the ages of 11 and 16. This is a significant factor in the declining numbers of pupils taking these subjects at higher levels, and is widely thought to be a particularly important factor in discouraging girls.

The Review therefore welcomes both the QCA's ongoing work to modernise the science curriculum and the Government's Key Stage 3 strategy. These are important elements in making the study of science more attractive to pupils, and, in turn, helping to enthuse pupils to study science and related subjects at a higher level. The Review recommends that the Government ensure that these changes deliver significant improvements to the way that the sciences (particularly the physical sciences) are taught. In particular:

- improving the ability of all pupils to relate the science they study to the world around them and to potential career opportunities;
- encouraging appropriate links to be made with other subjects (particularly D&T);
- ensuring that, whilst pupils continue to study the fundamental principles of science, the curricula and assessments are not dominated unhealthily by reliance on the overall volume of scientific knowledge.

The Review notes that modernising the curriculum must go hand-in-hand with providing teachers with the necessary support and training to teach the new curriculum in a way that appeals to all pupils (especially girls).

The Review further recommends that the Government should review, in three years' time, the progress in improving the attractiveness and relevance of the mathematics and science curriculum, and take further action as necessary.

Finally, the Review welcomes the QCA's proposals for reforming GCSE science, which are a necessary and positive step in increasing the appeal of science to pupils. However, it will be important to support schools and colleges to deal with what is likely to be a more varied intake to A- and AS-level courses, and enable students to successfully make the transition to A- and AS-level science.

The Government welcomes the Review's support for its attempts to make the science curriculum relevant to the 21st century. The Government agrees with the Roberts Review that this will be crucial in increasing interest in the physical sciences, especially among girls and ethnic minorities, who are often under-represented in such subjects. The Government is piloting a new GCSE science programme and will review it in this context as soon as possible.

The QCA and the Government will also be considering the findings of the Young People's review of the Science Curriculum (a Science Year initiative conducted by the Science Museum). Some of the young people involved in the review presented their initial findings to the Government in April and also gave evidence to the House of Commons Science and Technology Committee.

The Government also recognises the need to support teachers in delivering these new developments in course design, and will draw on successful elements of the Key Stage 2 and 3 strategies in providing this support. The National Centre of Excellence will also have an important role to play in supporting teachers in introducing new teaching approaches.

Recommendation 2.10: Transition from GCSE to A-level

> The Review welcomes the proactive approach of the QCA in considering the transition from GCSE science and mathematics to AS- and A-levels in these subjects. However, the consultation process revealed that the issue may not yet have been fully addressed and the Review therefore recommends that the Government give it further consideration, and take suitable action to allow pupils to make the transition from GCSE to AS- and A-level study – particular in the physical sciences and mathematics – smoothly.

The Government recognises that the transition from GCSE to AS- and A-level needs to be as smooth as possible. Improving this transition was one of the goals of the Curriculum 2000 reforms. As part of the summer 2003 review of the Curriculum 2000 reforms, the Government will ask the QCA to advise on how effective the recent changes to A-level science have been, and on whether further changes are needed to ease the transition.

In the case of the AS mathematics course, because there have been immediate problems, students will also be able to sit examinations in the autumn of their second year (in addition to the summer of their first year). This 're-phasing' will assist pupils in making the transition to AS mathematics. Additional funding is being made available for the extra teaching involved. In the meantime, re-sit opportunities are available for those who wish to improve their AS and subsequent A level results.

More generally, the Government believes there is a need to hold an inquiry into mathematics, focusing on the requirements of employers, professional bodies and education institutions at each key point of entry through education from age 14 to employment at all levels. The aim of the Review will be to ensure that the UK has a strong supply of young people with good mathematical skills and knowledge that meets the needs of employers and further and higher education. The Review will make recommendations to Government on changes to the curriculum, qualifications and pedagogy in schools, colleges and HEIs. It will include major employers with a particular demand for higher mathematical skills; members of a range of relevant professional institutions, educationalists in mathematics, engineering, physics and other related subjects, mathematics teachers in HE and schools and general educationalists.

Recommendation 2.11: Difficulty of subjects

The Review welcomes the attention that the QCA has given to the issue of inter-subject standards, and urges the Government to undertake definitive research into the greater apparent difficulty of science and mathematics A-levels and to take appropriate subsequent action. It is essential that pupils have a broadly equal chance to achieve high grades in science and mathematics as they would in other subjects. Without this, fewer pupils will choose to study science and mathematics at higher levels. The Review is firm that arguments about the merits of 'levelling up' or 'dumbing down' are a distraction – if pupils generally find it more difficult to achieve high marks in science and mathematics, this needs to be corrected. The Review believes that this can and should be done without compromising the core knowledge and skills needed for studying science and engineering courses in higher education.

Comparing inter-subject standards is extremely difficult as true comparisons can only be made between subjects that assess similar skills (for example, any two science subjects). Studies, such as the ALIS work referred to by the Review, are available, although none is without problems. (For example, the ALIS system has been criticised for adopting an over simplistic approach.) Nevertheless, the Government and the QCA accept the conclusion of the review and will investigate the issue as part of the review of Curriculum 2000 next year. As before, necessary changes could then be made in 2004.

More immediately, the QCA will report to Ministers the outcomes of their review of post-16 mathematics later this year, which may also have a bearing on this issue.

Recommendation 2.12: Enhancing the curriculum

The profusion of independent schemes aimed at enthusing and educating pupils in science and engineering (for example, the Industrial Trust Scheme and CREST), and the lack of support that schools and teachers have in identifying those most suited to their pupils, is inhibiting the collective effect of these schemes. The Review therefore recommends that the Government establish a single recognised channel through which schools access these independently-provided schemes. This will help schools and teachers to identify the schemes most suited to pupils at different ages in different subjects, thereby lowering the burden on teachers. Without better co-ordination (and rationalisation) of the existing schemes, important opportunities and resources will continue to be wasted.

The Review recommends that SETNET and its network of SETPoints, be given this responsibility in the areas of science technology, engineering and mathematics, while still recognising the wider role of the Education Business Links Consortia in England. However, if SETNET is to fulfil this function (and deserve the additional funding that this Review recommends the Government provide), it is important that it emphasises all areas of science and engineering equally, and also that those in the science, engineering, IT, technology and mathematics communities (particularly the scientific community) accept SETNET as the channel of communication. SETNET should work with the proposed idea of a National Centre for Excellence in Science Teaching in delivering this.

The Government agrees on the value of a single recognised channel for the delivery of independent and government schemes, awards and competitions aimed at enthusing and educating pupils in Science, Technology, Engineering and Mathematics. The Government will therefore, through significantly increasing its support for SETNET, ensure that SETNET works with the Education Business Links Consortia in England to be this channel. In particular, SETNET will need to extend its outreach into schools and act to improve and rationalise the number of schemes, awards and competitions. The Government will also take steps to ensure that SETNET works more closely with the scientific and mathematical communities, as well as the engineering and technology communities. The Science and Engineering Ambassadors Programme, coordinated by SETNET, will play an important role in all these improvements. Work will also continue on ensuring SETNET has clear measures of success and on the evaluation of the existing network to identify and disseminate best practice.

Recommendation 2.13: Improving the perception of careers in science and engineering

The Review believes that further action is needed from the Government, but also from businesses and others in scientific and technical fields, to ensure that pupils (especially girls) receive accurate and positive advice about the rewards (and the breadth of careers arising) from studying science and engineering. Specifically, the Review recommends that the Government establish a small central team of advisors (possibly within the new Connexions service, but working closely with SETNET) to support existing advisers, teachers and parents in advising pupils. Furthermore, the Government should review, in three years' time, the progress in improving pupils' knowledge of the rewards and the breadth of careers arising from studying science and engineering, and take further action as necessary.

The Government notes the Review's conclusion that more should be done to improve the quality of advice offered on the opportunities arising from the study of science and engineering related courses. As recommended by the Review the Government will establish a team that can help Connexions personal advisers and teachers in offering such careers advice. In doing so, the Government will look to draw upon the expertise of those in the scientific, engineering, technological and mathematical communities. The Government will consult with Sector Skills Councils and the Connexions Service National Unit to establish whether this team is best based within the Connexions service or whether it is best placed in the relevant Sector Skills Councils but closely linked to the Connexions service advisers.

Recommendation 3.1: Quality of SET A-level students as degree-level entrants

Students sometimes struggle to make the transition from A-level study to degree level study in science, engineering and mathematics, since undergraduate courses often do not pick up where the students' A-level courses ended. Furthermore, the increasing modularisation of A-level courses has led to students entering higher education with wider variation in subject knowledge (differences in the mathematical knowledge of students are seen to cause particular problems in mathematics, physical science and engineering degrees). The Review recommends that to help students – particularly those in the past least likely to participate in higher education – make the transition from A-level study to degree level study in science, engineering and mathematics:

- A-level awarding bodies and the HE sector should review science, engineering and (in particular) mathematics education at the boundary between school / further education and higher education, and adjust their courses accordingly to ensure that this transition can be made smoothly; and
- the Government should fund HEIs to use new 'entry support courses' and e-learning programmes to 'bridge' any gaps between students' A-level courses and their degree courses.

Furthermore, the Government should in three years' time review progress in reducing the gaps between A-level and degree-level courses – to ensure that students are not discouraged from studying these subjects, and retain interest in them – and take action as necessary.

The Government is keen to ensure that progression between stages of education and training is as seamless as possible. The move from post-16 education to higher education is a key step, and the Review has identified an important issue around A levels and degrees. This was also a consideration in the recent consultation document "14–19: extending opportunities, raising standards".

Responsibility for designing and delivering degree courses lies of course with HEIs, and it is ultimately for individual institutions to make sure that they teach students what they need to know in order to progress in science, engineering and mathematics courses.

This is sometimes a challenge for institutions. On some courses students can have quite a range of previous experience in maths and science – some with relevant A levels, some with access course experience, some with GCSE level maths. Many non-traditional students in particular need extra support in technical skills. Institutions already put a good deal of effort into supporting new students, bringing them up to speed, and providing on-going specialist support with important underpinning skills like maths.

Responsibility for designing and delivering courses lies with institutions and it is ultimately for them to make sure that they teach students what they need to know in order to progress in science, engineering and mathematics courses. The Roberts Review identified though that the variation in the prior knowledge and skills of students can be a challenge to institutions in delivering science and engineering degrees in particular. Mathematics skills can be a particular issue and, as mentioned earlier, the Government is launching an inquiry into post-14 mathematics. Furthermore, in order to improve the transition into science and engineering at HE the Government will work with the HE sector to pilot and evaluate different approaches to bridging the gap between students' prior knowledge and the requirements of higher education study.

The Government will keep under review students' progress between A-level and degree courses.

Recommendation 3.2: Undergraduate course structure

Updating the nature and content of undergraduate courses to reflect the latest developments in science and engineering (through having lecturers who can draw on recent experience of work environments other than HEIs, and through explicit changes in course content) has the benefit of improving the attractiveness and relevance of the course to both students and employers. Accordingly, the Review recommends that employers and HEIs work closer together, for example, through:

- increasing the number of industrial placements offered to academic staff;
- encouraging industrialists to spend time in universities;
- encouraging greater engagement between businesses and careers services and, in turn, between careers services and science and engineering departments; and
- encouraging universities to be more innovative in course design in science and engineering.

These actions by HEIs and employers must be supported by those bodies that accredit science and engineering courses – for example, the Engineering and Technology Board and professional bodies which are members of the Science Council – who must work with universities to drive forward innovation in course design, and not allow the accrediting processes inadvertently to inhibit it. The Government should facilitate these types of HEI / employer interactions through 'third stream' funding such as the Higher Education Innovation Fund (HEIF). Furthermore, the Government should in three years' time review progress in this area and take action as necessary to further improve HEI / employer interactions.

The Government agrees that interactions of this sort are important elements to providing innovative courses that appeal to students and educate and train them in knowledge and skills relevant to business. This type of interaction should be encouraged through teaching funding and the permanent 'third stream' of funding. To address the Review's recommendations the Government will further promote this type of activity further through the guidance notes issued to HEIs in respect of 'third stream' and other funding.

The Government will keep progress in 'third stream' activities under review, taking into account both the views of employers, through its group of R&D employers (see Recommendation 6.2), and the views of HEIs.

The Government is working in partnership with key stakeholders to develop vocational education aimed at better preparing students for work, and discusses these issues with employers, employer bodies and the higher education sector. Follow-up work to the Harris review report 'Developing Modern Higher Education Careers Services' (January 2001) will prompt institutions and careers services to consider greater engagement between businesses and careers services and careers services and academic departments.

The Government has also actively involved employers in working in partnership with HE institutions in the design of foundation degrees. The qualification also involves work-based learning, thereby involving employers in the delivery. Foundation degrees have been designed specifically to ensure that students develop the combination of technical skills, academic knowledge and transferable skills that are needed in the labour market. Science and engineering occupations are well represented amongst the first courses to come on stream. The Government is looking now to generate growth in both the number of courses and students to meet current and projected skills shortages at the associate professional and higher technical level.

Recommendation 3.3: University teaching laboratories

The Review recommends that the Government should introduce a major new stream of additional capital expenditure to tackle the backlog in the equipping and refurbishment of university teaching laboratories. The priority should be to ensure the availability of up-to-date equipment and that then, by 2010, all science and engineering laboratories should be classed as at a good standard or better, as measured by HEFCE. In delivering this recommendation, the Review believes it is important that the teaching infrastructure capital stream complements existing research infrastructure funding to facilitate the building, refurbishment or equipping of joint research and teaching facilities, where appropriate.

The Government agrees with the aim of the Roberts report that by 2010 all university science and engineering teaching laboratories should be of a good standard or better (as measured by HEFCE). Resources to start to improve laboratories and move towards this target are included within the overall increase of capital funding for higher education.

This teaching laboratory capital stream will be closely linked with parallel funding for research capital, with flexibility built in to enable institutions to manage them sensibly together. Institutions will be able to vire between the two streams without limit so long as the original balance is recovered over time.

Recommendation 3.4: Recurrent funding for teaching

In order to ensure that in future higher education institutions can and do invest properly in science and engineering teaching laboratories, the Review recommends that HEFCE should formally review, and revise appropriately, the subject teaching premia for science and engineering subjects. The revisions should ensure that the funding of undergraduate study accurately reflects the costs – including paying the market rate for staff, as well as the capital costs – involved in teaching science and engineering subjects.

As recommended by the Roberts Review, HEFCE is examining the detailed funding formulae for teaching different subjects. Through this review the Government and HEFCE can ensure that in the longer term, teaching funding for different subjects accurately reflects the costs involved in modernising their teaching environments (for example, science and engineering teaching laboratories) in line with technological progress. The Human Resources strategies and associated funding provide a mechanism for institutions to recruit and retain teaching staff in competitive markets, but HEFCE will also consider whether and, if so, how, the teaching funding for different subjects should reflect differing recruitment and retention costs.

Recommendation 3.5: Undergraduate student funding

Whilst student debt does not appear to be deterring potential students from undergraduate education, at the margin some undergraduates may be deterred from science and engineering courses, as they involve longer hours than other courses and as a result students find it more difficult to supplement their income by working part-time. In order for this not to deter the most disadvantaged students from studying science and engineering (and other courses with long 'contact hours'), and to assist with widening participation, the Review recommends that the Government (through its guidance to HEIs) should ensure that the Access Funds and Hardship Funds adequately provide for students on courses involving a high number of contact hours. The Review recommends that additional funding should be provided to accommodate this, and that HEFCE monitor the targeting of this additional funding to ensure it reaches those most in need.

The Review also recommends that the Government closely monitor the impact than an additional year of student debt has on students' choices of course, to ensure that the student funding system at undergraduate level is not discouraging students from studying (the longer) physical science and engineering courses.

Access and hardship funds can be important in helping to retain students in higher education when they encounter financial difficulties. Distribution of the funds is a matter for institutions, but Government does provide guidance on how these funds should be used. Following this recommendation, Government will ensure that this guidance recommends that institutions take account of contact hours in considering how to make these funds available.

The Government will also continue to monitor closely the effect of the student funding system on choices between courses.

Recommendation 3.6: University careers advisory services

The Review welcomes the recommendations of the Harris report on improving university careers advisory services. It is important that science and engineering students have accurate, up-to-date careers advice on the rewards and range of opportunities available to them (particularly opportunities in research and development). In particular, the Review endorses the recommendations in his report aimed at improving the links between careers advisory services and businesses, particularly small businesses, which will require action by both HEIs and by businesses.

The Government welcomes the support of the Review for improving the effectiveness of university careers advisory services. The majority of the recommendations of the Harris report were for institutions and other bodies and it is for them to take forward. A number of recommendations were addressed to the sector as a whole, and these have been taken forward by a group representing the sector convened by Universities UK, the Standing Conference of Principals, and the Quality Assurance Agency. The results of their work will be available this autumn. A snapshot survey of progress within institutions has recently been undertaken, and this shows that, generally, good progress has been made although more work could still be done in specific areas.

Recommendation 4.1: PhD Stipends

In order to recruit the best students to PhD courses, it is vital that PhD stipends keep pace with graduates' salary expectations, particularly given the increasing importance of student debt on graduates' career choices. It is also important that stipends better reflect the relative supply of, and market demand for, graduates in different disciplines. The Review therefore recommends that the Government and the Research Councils raise the average stipend paid to the students they fund over time to the tax-free equivalent of the average graduate starting salary (currently equivalent to just over £12,000), with variations in PhDs stipends to encourage recruitment in subjects where this is a problem. Furthermore, the Review recommends that a *minimum* PhD stipend of £10,000 is established, to ensure that HEIs do not use this extra flexibility to attract extra PhD students at the expense of quality.

The Government has already announced significant increases in Research Council PhD stipends for the 2002/03 and 2003/04 academic years. However, the Government accepts the Review's recommendation and appreciates the importance of PhD stipends reflecting the supply of and demand for graduates in different disciplines. In the Spending Review the Government will therefore fund the Research Councils to increase their minimum stipend to £12,000 by 2005-06. The Government will also provide additional funding to ensure that stipends in areas of recruitment difficulty can rise significantly beyond the minimum. Through this additional funding the Government expects the average PhD stipend for Research Council students to exceed £13,000 by 2005/06. The funding provided is consistent with maintaining the current numbers of Research Council PhD students.

Recommendation 4.2: PhD training elements

Despite the welcome current moves by the Funding Councils to improve the quality of PhD training, institutions are not adapting quickly enough to the needs of industry or the expectations of potential students. The Review therefore believes that the training elements of a PhD – particularly training in transferable skills – need to be strengthened considerably. In particular, the Review recommends that HEFCE and the Research Councils, as major funders of PhD students, should make all funding related to PhD students conditional on students' training meeting stringent minimum standards. These minimum standards should include the provision of at least two weeks' dedicated training a year, principally in transferable skills, for which additional funding should be provided and over which the student should be given some control. There should be no requirement on the student to choose training at their host institution. The minimum standards should also include the requirement that HEIs – and other organisations in which PhD students work – reward good supervision of PhD students, and ensure that these principles are reflected in their human resources strategies and staff appraisal processes.

Furthermore, in order to assure employers of the quality of PhD students, as part of these standards the Review recommends that institutions should introduce or tighten their procedures for the transfer of students to the PhD. In particular, the Review believes that HEIs must encourage PhD projects that test or develop the creativity prized by employers.

The Government agrees that there needs to be a new impetus to improve standards of PhD training. To encourage universities to address the skills acquired by PhD students, and to ensure they are relevant to business, the Government expects all universities to meet high quality minimum training standards on their PhD programmes, and agrees that all funding from HEFCE and the Research Councils in respect of PhD students should be made conditional on meeting these standards.The Government has also provided additional funding to the Research Councils in the Spending Review to enable enhanced training for their students, as recommended in the Roberts Report.

Recommendation 4.3: Length and nature of PhD programmes

The Review believes that measures should be put in place to help nurture a diverse range of PhD programmes to train able students in research methods and technical skills, and help them acquire the advanced knowledge and transferable skills they will need in their future careers. This should include encouraging part-time working and the gaining of experience in business R&D. Individual institutions should be given flexibility to offer a range of provision. The Review therefore recommends that:

- the Government and the Research Councils should fund their present numbers of PhD students on the basis that the average full-time student requires funding for $3^1/_2$ years;
- it should be possible for the institution to use the funding flexibly to run three and four year full-time programmes (and also study of intermediate length) to support longer and more challenging projects, advanced courses and transferable skills training;
- both three- and four-year courses should be examined to the same standards, which should be at least as high as the current standards; and
- students should be able to exit early from PhDs (subject to satisfactory performance) with an MRes or an MPhil.

The Review believes that the EPSRC's doctoral training grants system represents a good way of achieving this flexibility, and urges other Research Councils to implement similar mechanisms.

The Government accepts that it is necessary to provide the flexibility to permit a longer time for PhDs, in order to further enhance students' transferable and technical skills. Funding will therefore be provided to extend the average length of funding for Research Council students to $3^1/_2$ years. RCUK will consult later this year on detailed implementation issues, including the issue of any additional costs incurred by universities. The Government will also encourage the Research Councils, Funding Councils, HEIs and employers, to continue to work together so that, where appropriate, frameworks are in place to aid flexibility.

Recommendation 4.4: EU PhD students

The Review would welcome the extension of PhD maintenance awards to EU students by the Research Councils as a means of maintaining and improving the quality of research in the UK. The effect of this on the number and quality of UK PhD students should be closely monitored in order to ensure sufficient supply of PhD holders for the needs of the UK economy.

The Government agrees that UK universities need to attract sufficient high-quality PhD students and understands the reasons behind this recommendation. The Government is working with partners to explore how best to achieve this objective. A further announcement will be made in the autumn.

Recommendation 5.1: Academic Fellowships

> The Review believes that there should be a clearer path for those who have completed PhDs into academic lectureships. This should be achieved through creating Fellowships that allow those involved to move from principally research-based work towards the role of lecturer, with an added role of reach-out to schools (for example, becoming a Science and Engineering Ambassador) and helping to widen access to Higher Education. The Review therefore recommends that the Government provide funds to establish a significant number (the Review believes 200 a year) of prestigious academic Fellowships to be administered by the Research Councils. The Fellowships should last for five years and should be designed to prepare people explicitly for an academic career, to be distributed and awarded on the basis of academic excellence across the range of subjects considered in this Review. The Research Councils should work with the funders of similar schemes (for example, The Royal Society and the Welcome Trust) in introducing these Fellowships.

The Government agrees and will therefore provide funds to create 1,000 new academic fellowships (200 a year, each lasting five years) to provide more stable and attractive routes into academia. The Government also agrees that those in these positions should be actively involved in reaching out to schools, thereby helping to widen access and enthuse the next generation of pupils about science and engineering.

These prestigious fellowships will be developed by the Research Councils, in collaboration with organisers of similar existing fellowships, such as the Wellcome Trust and The Royal Society. Further details will be announced later this year. Particular care will be taken to ensure that these Fellowships are accessible to women and under-represented ethnic minorities.

Recommendation 5.2: Industry secondments for postdoctoral researchers

> The Review recommends that HEFCE and the Research Councils evaluate schemes such as the Research Assistants Industry Secondments run by the EPSRC as the basis for a wider mechanism for encouraging postdoctoral researchers into industrial careers, and as a mechanism for knowledge transfer.

The Government agrees and will therefore ask the Research Councils to consider how to meet the need for further mechanisms to encourage postdoctoral researchers into industrial careers. As the Review notes, this should also help to promote knowledge transfer.

Recommendation 5.3: A vision for postdoctoral researchers

> It is important for postdoctoral researchers to be able to develop individual career paths, reflecting the different career destinations – Industrial, Academic and Research Associate – open to them, and that funding arrangements reflect the development of these career paths. The Review believes that enabling the individual to establish a clear career path, and a development plan to take them along it, is critical to improving the attractiveness of postdoctoral research. The Review therefore recommends that HEIs take responsibility for ensuring that all their postdoctoral researchers have a clear career development plan and have access to appropriate training opportunities – for example, of at least two weeks per year. The Review further recommends that all relevant funding from HEFCE and the Research Councils be made conditional on HEIs implementing these recommendations.

To address these issues the Government will provide funding in this Spending Review to improve the training opportunities available to postdoctoral researchers. The Government will provide additional funding to the Research Councils to deliver additional training for contract researchers and will work with RCUK and HEFCE to ensure that this is put into practice. The Government will ask HEFCE to make clear that support for postdoctoral researchers will be expected to feature in institutions' human resources strategies. This will help ensure that researchers are prepared for future careers in academic or industry.

Recommendation 5.4: Postdoctoral researchers' salaries

> In addition to establishing clearer career progression, the Review recommends that the Research Councils should significantly increase salaries – particularly starting salaries – for the science and engineering postdoctoral researchers it funds, and sponsors of research in HEIs and PSREs should expect to follow suit. The Review considers that the starting salary for postdoctoral researchers should move in the near future to at least £20,000, and that further increases should be available to solve recruitment and retention problems in disciplines where there are shortages due to high market demand (for example, mathematics).

To meet this recommendation, the Government will fund the Research Councils in the Spending Review to increase their average postdoctoral salary by £4,000 by 2005-06. These increases will aim to ensure that post-doctoral research is an attractive option to recent PhD graduates. As with the PhD stipend, the Government believes that salaries should be varied to reflect labour market pressures.

Recommendation 5.5: Academic salaries

As with contract researchers, there is a need for universities to improve salaries – particularly starting salaries – for many scientists and engineers. The Review is clear that universities must use all the flexibility at their disposal to differentially increase salaries, especially for those engaged in research of international quality, where market conditions make it necessary for recruitment and retention purposes. The Government should assist by providing additional funding to permit universities to respond to market pressures. As a first step, the HEFCE funding currently dedicated to the human resources strategy should be made permanent. Further additional funding for recruitment and retention, which will vary between institutions, should initially be part of a separate stream linked to the existing human resources strategy fund and appropriately focussed towards research excellence. However, once more market-based systems have been embedded, the funds should be incorporated into core funding for research and also into revised subject teaching premia.

The Government recognises the importance of effective pay and human resources development in higher education. That is why £330m was made available over three years in the 2000 Spending Review for higher education pay, including recruitment and retention of high academic quality staff in strategically important disciplines. This funding was allocated by HEFCE to institutions, which were required to submit human resources strategies setting out how it would be used to achieve institutions' priorities.

The Government agrees with Sir Gareth's conclusion that more, permanent, funding is needed and will therefore allocate further funding in the 2002 Spending Review for pay increases targeted on the recruitment and retention of staff in disciplines (including, but not only, those in science and technology) where there is the greatest competition.

Recommendation 6.1: Attractiveness of careers in R&D

Responding to the challenge of improving the attractiveness of jobs in R&D to match or surpass all other opportunities open to the best science and engineering graduates and postgraduates is crucial to individual businesses' future success – since their R&D underpins their future products, services and, ultimately, their future sales and profits.

Through consultation with businesses and scientists and engineers themselves, the Review has identified a number of issues related to work in R&D that employers must address in order to be able to attract the best science and engineering graduates and postgraduates.

- **Initial pay.** Starting salaries are an increasingly important factor in students' career choices, in part due to the effect of student debt and students' increasing commercial awareness. The starting salaries and bonuses paid to scientists and engineers working in R&D are often not as high as they could receive in other sectors or occupations. While it may not be necessary to match the highest salaries paid elsewhere, the Review is clear that businesses will ultimately need to raise the salaries and other financial rewards they offer if they are to compete for the best scientists and engineers (particularly those with an entrepreneurial spark or good commercial awareness). This goes hand-in-hand with the need for businesses to look at R&D not as a cost, but as an investment in their future survival and growth.
- **Salary progression.** Similarly, retention in an increasingly mobile workforce relies upon salary progression that compares well with the other opportunities available. Evidence suggests that the salary progression for scientists and engineers in R&D does not compare favourably with that for their counterparts in other sectors.
- **Career Structure.** Science and engineering graduates and postgraduates can be put off entering R&D due to unattractive career structures – with short-term contracts, low levels of responsibility, few chances for progression within R&D and poor job design (e.g. jobs that do not use their skills to the full). It is clear from the Review's consultation that many employers can do more to improve the career structures of scientists and engineers, through addressing these and other influential factors.
- **Training and professional development.** Scientists and engineers working in research do so partly because of their interest in the subject, and it is therefore key that they can stay in touch with the latest developments in their field. Employers should do all they can to provide time and resources to allow them to do this, and partake in CPD activities, which will also bring benefits in terms of recruitment and retention. There is a role for the Government and for trades unions in helping to make sure that smaller businesses are able to provide sufficient training and CPD to research employees.
- **Recruitment mechanisms.** The Review believes that many R&D businesses must improve their recruitment mechanisms to compete better with other employers. For most R&D businesses, especially the smaller ones, increasing marketing efforts and taking opportunities to widen the number of students they make contact with should improve their ability to recruit the scientists and engineers they need. R&D businesses must also take responsibility for improving the perception of jobs in R&D.

The Review is clear that the response of R&D employers to these challenges is crucial in providing an adequate supply of scientists and engineers for R&D. Without improved and more attractive opportunities to work in R&D, the UK's best scientists and engineers will doubtless be tempted elsewhere, since the demand for their skills – and the rewards offered – will only grow over time.

The Government's responses to recommendations 6.1, 6.2 and 6.3 are grouped together at the end of these three recommendations.

Recommendation 6.2: The challenge to employers

> The Review recommends that the Government should establish a group of R&D employers to support and monitor employers' responses to the challenge of improving the pay, career structures and working experiences for scientists and engineers in R&D. The group should include representatives from businesses (large, medium and small) and others that employ scientists and engineers in an R&D capacity.
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> The Review believes the group must act as a driving force in taking the recommendations in this report forward, and should publish a report, before the next public spending review, setting out the response of employers to the challenges identified by this Review. The group might also play a key role in considering cross-regional and national R&D skills needs, referred to in Recommendation 6.4.

The Government's responses to recommendations 6.1, 6.2 and 6.3 are grouped together at the end of these three recommendations.

Recommendation 6.3: Skills planning

> It is clear that although many businesses may plan their R&D projects a number of years in advance, they often do not plan their skills needs for this research more than a year ahead. Although there are difficulties in detailed skills planning, the Review believes that R&D businesses must do more to establish what future science and engineering skills they will need for future research projects in order for them to be able to recruit the skilled scientists and engineers they need with less difficulty.

The Government agrees with the Review's conclusion that sustained action by employers is vital in securing a strong supply of highly skilled scientists and engineers who are keen to work in R&D. The specific areas identified by the Review are all important in providing attractive opportunities in R&D, particularly given the increasingly broad range of opportunities available to the best scientists and engineers. The Government can and will play a part through, for example, helping to disseminate best practice, but ultimately the challenge of improving conditions of employment is one that employers must rise to.

The Government agrees that an employers group could play an important role in improving the attractiveness of careers in R&D. Through working in partnership with the CBI and other employers organisations the Government will assist in ensuring that a group of R&D employers is established, as recommended.

Recommendation 6.4: Skills dialogue

> The Review believes that the supply of skills to R&D businesses can be improved through more coherent skills dialogue between these businesses and universities. The Regional Development Agencies (RDAs) should take a leading role in the coordination of regional dialogue between businesses and HEIs through the new FRESAs (Frameworks for Regional Employment and Skills Action) to ensure that demand for higher level skills at a regional level can be met.
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> Furthermore, the Review recommends that the sector skills councils (which the Review believes, should be represented in FRESAs) work with the Learning and Skills Council, trade associations and other business groups to identify – based on the regional skills discussions – evolving supra-regional and national R&D-related skills needs.

The Government agrees that the coherence of the skills dialogue between R&D businesses and HEIs must be improved. It will, accordingly, ensure that RDAs, through FRESAs, undertake the action recommended by the Review.

The Government will also work with the employers group referred to in recommendation 6.2 and the sectors skills councils, FRESAs, employers groups and higher education organisation to ensure that national and supra-regional skills trends can be identified and responded to.

Recommendation 6.5: Business involvement in higher education

> Although universities need to be proactive in ensuring that courses are as relevant to business as possible, the Review believes that businesses must become more actively involved in university course design. In particular, the Review recommends that employers' bodies – for example, the CBI and trade associations – and the Government work to encourage more R&D businesses to participate in providing work placements for SET graduates and postgraduates (for example, in sandwich year courses).

The Government agrees that the input of businesses and other employers into university course design is vital if the skills and knowledge of students is to be of most relevance to the employers. The Government is already working to promote this kind of partnership between HEIs and employers, and funding is available to HEIs to put in place arrangements to embed work-related skills in higher education, through HEFCE's Learning and Teaching Support Network.

The new foundation degrees promote this kind of partnership working between HE institutions and employers. The Government is however keen to ensure that all higher education delivers the skills and attributes that individuals need in the workplace and that employers require if their businesses are to grow. In November 2001, the Government announced that £1m is being made available to HEFCE over 2002-04 to put in place a Work-Related Skills Co-Ordination Team to work with established networks of subject specialists to spread and embed good practice in developing graduate employability.

The aim is to make work-related skills a feature of mainstream higher education provision. Employer involvement and establishing links between the subject networks and the relevant Sectors Skills Councils and professional bodies is an important part of that process. An Advisory Group is being established to oversee this work which will include employer representation. We are also considering arrangements for engaging with a wider range of employers to advise us on all aspects of higher education. R&D employers will feature in these arrangements.

Recommendation 6.6: Research collaboration between business and higher education

There are a number of Government sponsored schemes that act to encourage research collaboration between businesses and HEIs. However, the Review feels that the collective impact of these schemes is not as great as it should be. The Review therefore recommends that the Department of Trade and Industry, as part of its increased focus on innovation and skills, and more effective delivery of business support, should evaluate the success of existing initiatives in this area – in particular, paying attention to whether the training elements of these schemes are sufficiently supported and prioritised and the extent to which they play a strong role in employer-university communication and collaboration.

The Government is keen to improve research and development collaboration between businesses and HEIs and to improve the effectiveness of its existing policy measures in this area. Therefore, all parts of the Government that seek to encourage research collaboration between businesses and HEIs will evaluate the success of their initiatives in this area by 2003. Necessary changes will then be developed as soon as practical. The Department of Trade and Industry is considering this issue in taking forward its review of business support activities.

Recommendation 6.7: Innovation Partnerships for collaborative research

The Review recommends that the Government, while retaining successful initiatives, should develop stronger, more coherent and more substantial "Innovation Partnerships" to boost research collaboration between universities and businesses. The Review believes that these should incorporate the following principles:

- that the research be business-led and focussed on commercially-oriented R&D;
- that the partnerships be based on clusters of businesses with particular research interests, either nationally or regionally;
- that the Government invest in each partnership alongside the prime funders (business and higher education and RDAs);
- that each partnership could be virtual or could have a physical centre, depending on the nature of the research and the participants in the partnership; and
- that each partnership should have an explicit, core aim of prioritising skills training for SET students and graduates , building a critical mass of SET students and graduates with experience in commercial R&D, and encouraging the interchange of people and technology between business and academia.

The Government welcomes and agrees with the Review's principles for innovation partnerships, which are consistent with those that guide the existing Faraday Partnerships. The Government will therefore seek to develop activity in line with these principles. Further decisions on the nature and scale of these activities will depend on the outcome of the Department of Trade and Industry's ongoing review of business support activities.

Recommendation 6.8: Migration and work permits

> The Review welcomes the Government's campaign to raise HEIs' and overseas students' awareness of the recent improvements to the work permits scheme. However, given the lack of knowledge of these changes shown by businesses during the course of its consultation the Review recommends that this campaign be extended to cover the business community, including smaller and medium sized businesses engaged in R&D. Through this, more UK businesses will be able to draw upon worldwide scientific expertise in driving forward their R&D.

To address this recommendation the Government will step up the provision of information about these changes. In particular, Work Permits UK will develop concise and tailored information for smaller employers, and will work with the Small Business Service and employers groups to target the advice towards those who might benefit. Work Permits UK will also consult employers and others on the merits of adding more fields of science and engineering to the list of areas of national skills shortage. This would further ease recruitment of scientists and engineers from abroad. Furthermore, the Government will take steps to improve awareness of the options and routes into employment available to foreign students in UK universities.

Final remarks (repeated from the executive summary)

> The recommendations set out in this report, which represent challenges for the Government, for employers and for the education system, are designed to help secure a strong supply of people with science and engineering skills. The Review believes that implementing these recommendations will be a crucial element in achieving the Government's agenda for raising the R&D and innovation performance of the UK to match the world's best.
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> The Review is clear that progress towards the goals set out in the report must be reviewed regularly in order to ensure that the UK's R&D and innovation performance can grow as intended. In particular, the Review recommends that the Government should review progress on improving the supply of scientists and engineers, encompassing all the areas identified by this Review, in three years' time, and take any further necessary action to continue the process of improvement.

The Government agrees, and will review progress accordingly in three years.