



COUNCIL FOR
SCIENCE AND
TECHNOLOGY

A Vision for UK Research

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Executive Summary and Recommendations

The UK's leading position in research – currently second only to the United States – has demonstrable economic and social benefits which amply justify public and private investment. However, the world is changing rapidly and our position is under threat from major investments being made by existing and emerging economic powers.

There is a real sense of urgency – and one that is brought into sharper relief by the global economic crisis and the present age of austerity – which reinforces the need for expenditure on research to compete successfully with other financial demands facing Government.

The US, which is the strongest research player in the world, is voicing its own concerns about the deep seismic shifts in the global competitive landscape brought about – in particular, but not exclusively – by the growing research strength of China and India. The UK must equally understand the magnitude of this threat and take action to address it.

We recognise that over the coming decade public spending will be far tighter than in the last decade. While we would argue that public spending on research provides great returns to the taxpayer, it would not be surprising if research spending in the UK came under considerable pressure. Where additional spending is required to deliver the recommendations in this Report, the Council recognises that there will need to be tough decisions on how to release resources.

We believe that discussions of science and research should not be trapped in terminology such as “pure” or “blue skies” or “applied” research. We advocate a looser language which reflects the complex, reflexive relationship between research (of all types) and impacts, whether social or economic. We urge that the debate is re-cast to emphasise two linked processes: first *focusing on excellence across the research base*, and second *harvesting the products of the research base*.

In order to maintain the UK's position in the face of increasingly severe global competition in research, Government should adopt a clear long term vision for support for the research base, and for deriving economic and social benefits from that investment.

Recommendation 1: Adopting and articulating a Vision for UK Research.

CST urges the government to adopt and to articulate a Vision for UK research, which should embrace the following features. The Vision must:

- **value the research base**
 - the UK must be a confident global player in research, knowing our strengths and unique capabilities, and punching above our weight. We will lead the world in particular areas – having prioritised to achieve that position – by excellence upstream and by stimulating knowledge-based sectors downstream
- **focus on people**
 - the UK must be the prime destination, where the best researchers from around the globe dream to come and stay. We will nurture and retain home-grown and overseas talent
 - we must have an education system which prepares everyone for living in a world where science and research are deeply embedded in our culture

Recommendation 1: Adopting and articulating a Vision for UK Research. (cont'd...)

- **prioritise, create, exploit and solve**
 - the UK must be a world-leader in solving particular global challenges by deploying excellent research, working across sectors, in strategic and cross-disciplinary ways
 - we must continue to generate great ideas and knowledge, but get better at exploiting them, and exploiting ideas from elsewhere, to harvest greater benefits to the economy and society
- **ensure the UK is well-organised for research**
 - the UK must act as a magnet for global investment by maintaining and improving our pre-eminent position in research and selling the image of the UK as the quality location for research
 - we must have thriving universities and research communities, enriched by working with and across different sectors, delivering highly-skilled, entrepreneurial people to the labour market

The following recommendations are designed to implement the core strands of this Vision.

People

In order to nurture the very best researchers, and to ensure that the UK benefits from their work, a significant focus should be investment in people and stimulating and supporting their creativity. This is more important than trying to predict the most promising topics or areas into the future. Investment in the best people – those able to work at the leading edge of research and its exploitation – is a crucial investment for the future. The best people will adapt and seize new opportunities as the world around them changes.

The quality of research students in UK universities needs to be as high as possible and mechanisms to identify the best need to be as robust as possible, including exit points at Masters level for those who will not make the very top. More use should also be made of the research Masters degree to equip people who are not necessarily going into research careers to acquire the skill which will enable them to utilise research in a sophisticated way in business, innovation and public service.

There is an under-supply of both graduate and technician engineers. The capacity to deliver on and benefit economically from national strategic priorities such as the modernisation of the national infrastructure and low-carbon energy solutions will depend fundamentally on the supply of qualified engineers. Many of the challenges that we now face demand a new, heroic age of engineering, which the UK is poorly placed to exploit unless it is able to inspire and recruit a larger, reinvigorated cohort of engineers.

Recommendation 2: Identifying, attracting and developing the best researchers.

Government needs to put in place a range of measures which will attract the most talented international researchers to the UK, nurture the UK's own leading researchers, and provide them with the facilities and stability of funding to enable the UK to be a magnet for those undertaking the best research in the world. The current financial position makes this difficult in the short-term, but we believe over the longer-term, Government can achieve this by:

- rethinking the Master degree/PhD landscape so that PhD degrees generally last for 4 years, with the first one or two years potentially leading to a Masters degree which could develop specific and widely-deployable skills, such as communication, problem-solving, team-working, entrepreneurship and management; this would be valuable both for those continuing to PhDs, and for those who are aiming at the Masters level as an end qualification
- putting in place a highly competitive national scholarship scheme across all UK universities aimed at recruiting and supporting the very best research students from the UK and around the world to do PhDs in UK universities
- putting in place mechanisms for recruiting and retaining the best researchers at post-doctoral level through competitive personal support schemes that give them both the freedom and the time to develop powerful individual creativity
- stimulating greater flexibility and mobility of researchers, in particular between academia and the business and public sectors, and rewarding them through the new Research Excellence Framework (REF)
- introducing a national personal support scheme of prestigious research professorships for the very best 100 or so researchers in the country
- embracing the internationalisation of the research workforce, and making it both easy and attractive for the very best researchers from around the world to develop their work in the UK
- encouraging top-quality researchers over 65 to continue past retirement

Government should strengthen the pipeline into science in schools through good teaching, communicating the excitement and importance of science, and by exposure to hands-on research.

Prioritisation

We recommend prioritisation of two crucial processes: stimulating creativity in upstream research focusing on discovery, where excellence is the overriding criterion in creating a world class research base; and stimulating downstream research to exploit the outcomes for economic and social benefit.

(i) Nurturing a world-class research base

The first step is for Government to continue to prioritise research funding against other competing financial pressures, against the background of public expenditure constraints.

Prioritisation must not compromise the need for the UK to maintain a broad research base – the need to ensure capacity. At the project level, funding should be determined solely by the excellence of the research proposal itself.

However at the broadest level of sustaining a strong research base, it is important to ensure that an overview of the strength of core disciplines is maintained. For example, Research Councils must ensure that sufficient attention and investment is made in engineering, mathematics and the physical sciences in the face of very significant investment and competition from China and India in particular. They must also continue to build better strategically-driven cross-disciplinary programmes and ensure that the essential role of social sciences in understanding and exploiting new ideas emerging from STEM and the creative and arts disciplines is fully developed.

(ii) Making strategic choices downstream

Strategic choices need to be made at the *downstream*, demand-led end of the research spectrum. The focus should be on those business sectors where:

- the UK has global research strength or the capability to develop that strength
- there is the greatest chance of effectively exploiting the research through knowledge exchange so the UK gains competitive advantage and retains the value-added that it generates for the economic and social benefit of the UK
- the potential markets for exploitation of research are of sufficient scale and future importance to justify significant public support

Recommendation 3: a powerful, flourishing, world class research base in the UK

Government needs ensure that its actions continue to create the optimum environment for research to flourish, in the face of changing global competition, by funding highly creative discovery research, with the purpose of maintaining the excellence, diversity and creativity of the research base and ensuring that the UK remains a major attractor for international researchers – funders of upstream research should be ruthless about excellence as the over-riding criterion

Translational Priorities

The UK's international position in research is not matched by its position in terms of productivity growth or innovative performance. Changing this requires identifying, developing and exploiting the best ideas from around the world as well as in the UK. It is widely recognised that the weakness of UK research policy has been in translating research outputs into economic and social benefit, and that this needs to be addressed urgently. The Research Councils and the Technology Strategy Board (TSB) have a range of initiatives directed at research translation. We recognise the good relationships that Research Councils and TSB have developed over the last year or so, but we would encourage them to continue their efforts to bring greater focus to their translational activities.

UK business as a whole spends slightly over 1% of GDP on research and development – around half that spent by business in the US, Japan and Germany. UK business needs to become bolder in its approach and more receptive to the opportunities that research has to offer – making a stronger pull on the outputs of the research base.

In order to improve the position in the UK we believe that there is a role for Government in creating a long term, stable climate through the articulation of a clear vision and priorities for the development of the economy over the next decade or more. This will then give greater confidence to the private sector to invest in research to support these objectives. For example, we believe that the renewal of the national infrastructure and other challenges will provide a real opportunity to build new industries and stimulate the translation of upstream research to downstream application.

Where strategic choices are being made, these should reflect a range of factors, including analysis of particular sectors and technologies and their likely value chain and market development pathways.

Recommendation 4: Translating research into economic and social benefits.

Government needs to articulate a long term vision and priorities for development over the next decade or more, which will provide a framework for research investment by the private sector, the Research Councils and the TSB. This should focus on a number of key strategic areas, for example:

- technologies underpinning 21st century national infrastructure
- solving major global problems, for example climate change and shifting resources to those areas where the UK has capability to build new industries, for example green technologies, the creative industries or plastic electronics
- addressing major social challenges including food security, healthcare and an ageing population

The Research Councils and the TSB should consider how to build on recent initiatives to coordinate major translational activities under a joint banner and, as resources become available, achieve greater critical mass in selected areas by a smaller number of longer-term funded developmental centres combining the best of the TSB Innovation Platforms and the Research Councils' Innovation and Knowledge Centres.

Recommendation 4: Translating research into economic and social benefits. *(cont'd...)*

As an initial step we recommend that the Government review the benefits of developing a system of Platform Technology Centres. We also recommend that the Government, in consultation with TSB, the Research Councils, Charitable Foundations and the private sector reviews the way in which current support funding and future support could be used to develop such a system. We therefore welcome the Government's recent announcement of a review in this area.

Government needs to build on current developments in the Research Excellence Framework (REF) to put in place clear incentivisation and reward mechanisms for academics engaged in high-impact translational activity of excellent research. We do not see the evaluation of departments' ability to maximise the impact of its work as being at odds with the focus on excellence in funding research. It is right that a good research department should recognise a responsibility to play its part in ensuring that its research is translated into economic value to the UK.

Organisation

(i) Universities

The university research base needs diversity in order to deliver:

- world-class and world-leading research centres which can compete with the best in the world and which act as magnets for international business by, for example, collaborating on particular themes
- world-class capability across the spectrum of translational activities
- broader based collaborations within and between institutions, individuals and disciplinary boundaries
- the capacity to support higher level skills development for new industries and other developments stimulated by research

In the recent past there has been a high level of competition for research funding for individuals and small groups of researchers, based on excellence, which has delivered substantial benefits for the UK. For the future we see the need to balance this competition with the more extensive, and larger scale, strategic collaborations which will be necessary if the UK is to compete successfully in the changing global environment of science and research.

Given the size of the UK relative to the other economies competing globally in research, there is a case for directing funding to support large-scale collaborations, both within the UK and internationally. One particular challenge is that the UK needs to improve its capability in putting together bids for large strategic awards, including for international facilities. It is also important for leading research groups in the UK to be collaborating with their peers in other countries.

We recognise the dilemma that the strong competition for funding individuals and groups of researchers which helps to build world-class universities and research institutes may militate against the more collaborative approach needed, for example, to put together a strong bid for an international facility. We believe that there is a role for Government in developing funding mechanisms that encourage and reward collaborations between the leading research groups in particular areas, without blunting their competitive edge.

Recommendation 5: Funding excellence and encouraging collaboration.

Government should support excellent research wherever it exists (but clearly not commercial research), and research funding should be directed towards those research centres and groups, wherever they are, who are excellent in research and in the translation of research outcomes into economic and social benefit. Universities should be developing strategies to:

- maintain a diversity of excellence in research, defined by international standards
- structure themselves better to carry out multi-disciplinary research with business and improve their abilities to be more strategic and practical in devising, winning and delivering large-scale cross-sector and cross-disciplinary projects

Universities need to give greater priority to working together to develop more strategic, pan-university collaborations of their leading research groups, both within the UK and with overseas universities in the US, EU, China, India and other emerging economies. Government needs to help facilitate these collaborations through its policy commitments and through the use of available funding mechanisms.

(ii) Government Departments

We are concerned that policy objectives for the acknowledged 'big ticket' items that should cut across Government Departments (for example in areas such as national infrastructure) are often not reflected in individual departmental research activities.

Recommendation 6:

Government must ensure that it has the necessary research capability within departments, and that this capability is strategically joined-up across departments.

Public Engagement and Dialogue

To secure maximum benefit from the research base we need a better, publicly-shared understanding of the nature of the knowledge that research confers; and greater public engagement about the way in which the outcomes of research should be explored and exploited.

Recommendation 7:

Government must continue to prioritise and focus public engagement and dialogue as an integral part of developing its policies, particularly where novel technologies are being researched. Government, universities and all the major stakeholders for public engagement must show leadership right across the spectrum of public engagement and dialogue.

1. Introduction

1 The UK research base¹ provides two key outputs:

Economic and social benefit in particular knowledge exchange through both individuals and innovation chains, including indirect impacts, for example researchers moving into employment in business or public service, or becoming entrepreneurs. The over-riding question is how best to improve competitive business performance, productivity and impact linked to the best emerging commercialisation opportunities from our research base.

People themselves – the key to the UK’s continued success – which in turn requires the UK to attract, train and retain the best researchers, both home-grown and globally.

The three main drivers to achieving these outputs are:

Organisational in particular to ensure our universities and leading research groups continue to be world-class – and that some are world-leading² – and to promote diversity and new types of collaboration between organisations, individuals and external public and private sector organisations concerned with knowledge exchange.

Global competition in particular from established and emerging economies – the UK needs to understand the nature of the competition and how best to respond. We must recognise that international status *is* important, and ensure we maintain or improve it. We must also ensure that the UK is well placed to exploit new ideas from wherever they come from.

2 The richness and variety of the wider set of connecting roles played by the research base, in terms of increasing the stock of useable codified knowledge³, problem-solving and providing public space in which parties may explore and discover opportunities to develop new collaborative paths and organisational forms to enhance people exchange productivity performance and social and economic well being.

3 This report is therefore investigating:

- how to ensure that the UK research base maintains its high level of performance and productivity and that the outputs of the research are maximised in terms of economic and social impacts.
- how the UK should respond to international competition, e.g. from the research base in China, India and other emerging economies.
- how we continue to maintain our global position against other countries that are investing heavily in their research capability.
- how to optimise business ‘pull’ and research ‘push’ – are the processes and structures we have optimised for effective knowledge exchange and the translation of research outputs into economic and social benefit?
- how to recruit, train, reward and retain the best talent in science and research – bearing in mind that the research base and its translation into economic and social outcomes is crucially dependent on the quality of its researchers and the capacity of the public and private sectors to effectively access and interact with them.

1 The UK research base covers research in science (including social science), technology, engineering and mathematics; and, where appropriate, research in arts and humanities.

2 The UK has four of the world’s top six universities; Cambridge, Imperial College London, Oxford and University College London; and 18 of the top 100 (THE world university rankings 2009).

3 For example through publications, patents and prototypes.

Terminology

- 4 Research should be about asking important questions. Existing terminology – in particular the attempts to distinguish between *pure* (or *basic* or *blue skies*) and *applied* (or *directed*) research – causes problems and division amongst the research community. At the same time, some descriptors such as *curiosity-driven research* are both misleading and damaging⁴. Most current terminologies get in the way of understanding the relationship between research and social and economic benefits. We should think in terms of *excellence which carries the potential for impact* and *harvesting the products of the research base to maximise impacts*.
- 5 It is important therefore to develop a new terminology which gives clarity and which the research community can unite behind. It is vital that the terminology should **not** be interpreted to mean that the relationship between research and innovation is linear – all the evidence shows it is a highly complex reflexive system with interplay between upstream and downstream activities.
- 6 The motivation to undertake upstream research is often driven by the identification of such problems in the course of downstream research. This means that in assessing economic and social impact, the whole of the research base expenditure is relevant and not just that deemed to be downstream or for which there appear to be immediate applications.
- 7 Research takes place along a broad, interconnected and multi-faceted spectrum which we propose to divide into two broad domains:
 - discovery research that is concerned to establish the essence of phenomena – we shall call that ***upstream research***⁵;
 - developmental research that draws down existing understanding in response to the needs of a particular application – we shall call that ***downstream research***⁶.
- 8 Processes which connect these two domains are complex and multi-faceted. It has long been recognised that the connection is not linear, and therefore initiatives which presume linearity are likely to fail. Our report recognises that the diversity of the connections which explore applications of discovery research – we shall call these ***translational activities***⁷;
- 9 There are some important implications:
 - translation into economic or social outcome can arise from any part of the spectrum, from long established or newly discovered basic understanding, from the strategic exploration of potential applications, or in response to market-driven imperatives.
 - many research groups are involved at all points of the spectrum, with activities in one part inspiring activities in another.

4 Over 90% of Research Council expenditure continues to be directed towards activities that are **not** aimed at specific detailed products, processes etc, with around 70% being classified as some form of 'basic' research.

5 This broadly includes the categories of pure basic research and user inspired basic research within Stokes' Quadrant Analysis.

6 This is broadly the category of applied research within Stokes' Quadrant Analysis.

7 This falls into a number of categories within Stokes' Quadrant Analysis – including pure applied research. The classification does not mean either that an individual researcher will necessarily be confined into one of the quadrants but may span boundaries in the conduct of their work.

2. A vision for the UK research base

10 Our vision for the future is that the UK research base will be successful and globally competitive 20 years out.

11 We need to avoid the UK research base undergoing either managed or neglected decline.

12 In order to maintain the UK's position in the face of increasingly severe global competition in research, Government should adopt a clear long term vision for support for the research base, and for deriving economic and social benefits from that investment. We suggest a vision which must:

- **value the research base**
 - the UK must be a confident global player in research, knowing our strengths and unique capabilities, and punching above our weight. We will lead the world in particular areas – having prioritised to achieve that position – by excellence upstream and by stimulating knowledge-based sectors downstream
- **focus on people**
 - the UK must be the prime destination, where the best researchers from around the globe dream to come and stay. We will nurture and retain home-grown and overseas talent
 - we must have an education system which prepares everyone for living in a world where science and research are deeply embedded in our culture
- **prioritise, create, exploit and solve**
 - the UK must be a world-leader in solving particular global challenges by deploying excellent research, working across sectors, in strategic and cross-disciplinary ways
 - we must continue to generate great ideas and knowledge, but get better at exploiting them, and exploiting ideas from elsewhere, to harvest greater benefits to the economy and society
- **ensure the UK is well-organised for research**
 - the UK must act as a magnet for global investment by maintaining and improving our pre-eminent position in research and selling the image of the UK as **the** quality location for research
 - we must have thriving universities and research communities, enriched by working with and across different sectors, delivering highly-skilled, entrepreneurial people to the labour market

3. The importance of the research base

13 The vision requires the UK to be a confident global player in research, knowing our strengths and punching above our weight and acting as a magnet for global investment by maintaining and improving our pre-eminent position in research and selling the image of the UK as the quality location for research.

14 The UK's research budget has doubled in real terms and tripled in cash terms, from £1.3 billions in 1997 to £3.9 billions in 2010/11. Government invested around £4.5 billions into the university research base in 2007. This delivers economic and social impact, by:

- improving the performance of existing businesses, attracting investment from global businesses and creating new businesses
- delivering highly-skilled people to the labour market
- delivering social and societal benefits by improving public policy and public services

15 There are three core requirements if the research base is to deliver benefit to the economy and society:

First, **Government must create the right environment for business investment** by setting out sustained, long term objectives for particular sectors (such as renewable energy, pharmaceuticals and aerospace) and public investment (for example to renew the national infrastructure) that gives business the confidence to invest in the expectation of long term financial returns and the incentive to pull strongly on the research base.

Second, **Government must fund highly creative discovery research**, with the purpose of maintaining, the excellence, diversity and creativity of the research base and ensuring that the UK remains a major attractor for international researchers.

Third, **Government and business must put in place mechanisms for promoting and funding pre-commercial translational research** and setting thematic research priorities on issues of current importance such as energy technologies.

16 World-class research and high quality teaching are crucial to enable the UK to compete successfully. The UK is second only to the US in terms of the strength of its research base. Globally mobile companies will increasingly invest in world-class people and facilities. If the UK's position slips, it will be less of a magnet for overseas investment⁸; the UK therefore needs to ensure it maintains its world ranking, has a number of universities that are world-leaders, and a cadre which can compete with the leading universities around the world. At the same time there is a need to increase the research volume by different methods of collaboration between researchers, universities and other research institutes.

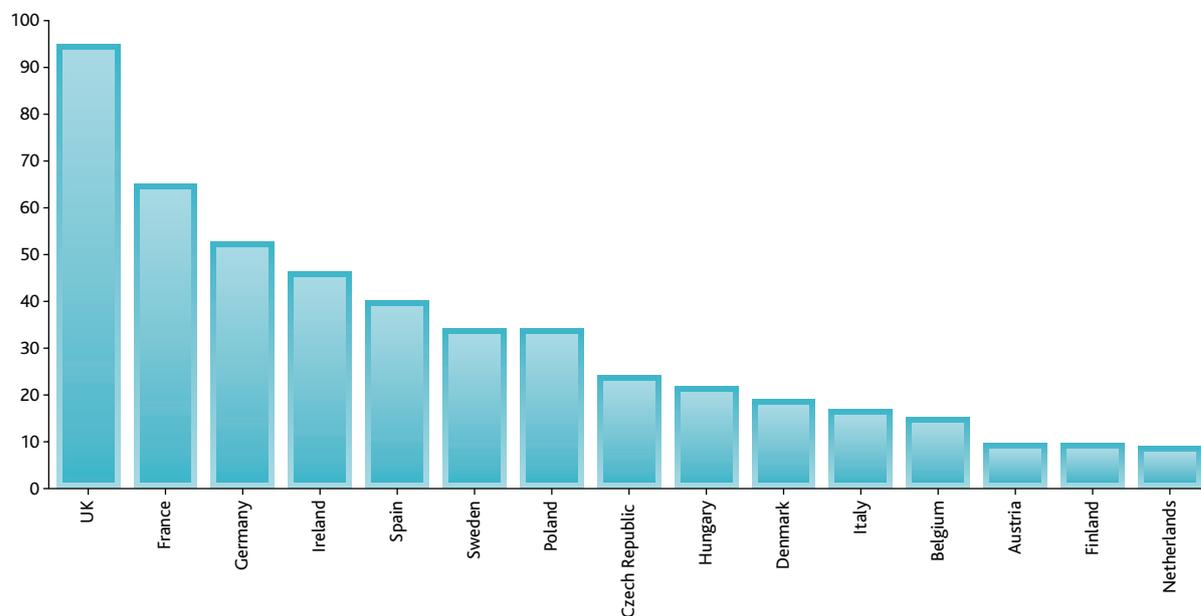
17 The UK has a strong record on attracting investment from global business: during 2008-09 over 200 R&D projects were attracted to the UK⁹. The latest figures show that over the last 30 months, UKTI has helped to attract an estimated £500 millions in R&D investment to the UK.

⁸ This is a concern shared by the US National Academies. The Augustine Report (see reference 2) cites concerns that the US leadership in knowledge-intensive industries is fast eroding. For example Intel: "We go where the smart people are. Now our business operations are two-thirds in the US and one-third overseas. But the ratio will flip over the next ten years".

⁹ Data from UK Trade and Investment.

- 18 The quality and availability of researchers in the UK is the prime driver for attracting foreign direct investment (FDI); much more so than other incentives such as the offer of grants. We believe that research-based businesses survive difficult times better than other types of business, even when capital is withdrawn.

Attracting R&D Investment from Global Business



Graph: Number of R&D FDI projects by destination country (2002-2006)

- 19 Research leads to the generation of know-how capability. This remains a significant force in terms of the UK's competitive advantage and is primarily in larger research-intensive companies such as Rolls-Royce and major pharmaceutical businesses. A strong research base plays a major role in the creation of good jobs – but attribution of success to the UK's research base alone is difficult¹⁰.
- 20 A wide variety of studies over many countries and different time periods support the view that the social returns to public sector support are high, varying between 20 and 57%¹¹.
- 21 The social returns (gains beyond those captured by market prices alone) exceed the purely private returns (which are captured by market prices). This is generally explained by spillover or externality effects¹².
- 22 Further evidence is available to show that the routes by which university knowledge exchange with the private sector occurs goes beyond patenting and licensing of ideas. Extensive survey-based evidence shows that the pathways followed are extensive. They relate in important ways to informal networking, contract research, and codified outputs such as publications. Moreover, the transfer of people and the exchange of people are often more important than patent and licensing-based transactions (see Annex 2).

¹⁰ In 2007 the UK was third behind India and China and ahead of the US in the table of top-ranking destination countries by estimated R&D jobs.

¹¹ see for example Salter and Martin (2001), Martin and Tang (2006).

¹² These are effects whereby the benefits of new ideas cannot be wholly captured by the inventor or innovator. They lie behind most common justifications for public support for research. They also lie behind the justification for patent protection.

Some impacts from the UK research base¹³

Every £1 invested in cardiovascular or mental health research between 1975 and 1992 earns approximately 39p per annum for the UK over the long term

A PricewaterhouseCoopers study suggested that for every £1 invested in research grants in the arts and humanities, the immediate return could be £10.29

Government has estimated that space science generated £5.8 billion for the UK economy in 2006/07 and directly supports 16,000 jobs in the UK

RCUK works with over 2,500 businesses in sectors ranging from engineering to insurance, broadcasting to biotechnology

In October 2009, RCUK had partnerships with 18 of the top 20 FTSE companies

Since 2006, over £2 billion of funding has been secured directly by RCUK through collaboration with UK business and industry

21 per cent of PhD projects have a formal collaboration with business and industry partners

In the last three years, almost £1 billion of inward investment can be directly linked to RCUK efforts to attract international funding into UK research

International competitiveness of UK research

- 23 The world is changing rapidly, emerging economies are investing significantly in their own research and many are intentionally looking to create world-class institutions¹⁴. The UK cannot afford to stand still.
- 24 There is a real sense of urgency, and one that is brought into sharper relief by the global economic crisis and the present age of austerity, which reinforces the need for expenditure on research to compete successfully with other financial demands facing Government. The stimulus packages below show the important role attributed to research base investment across a wide range of countries. The US, which is the strongest research player in the world, is voicing its own concerns about the deep seismic shifts in the global competitive landscape brought about – in particular, but not exclusively – by the growing scientific and technological strength of China and India¹⁵. The UK must equally understand the magnitude of this threat and take action to address it.

¹³ Extracts from the RCUK website.

¹⁴ For example Tsinghua University in Beijing and the Indian Institute of Science in Bangalore.

¹⁵ See for example: 'Rising above the gathering storm' by Norman Augustine; and: 'Is America falling off the flat earth?'.

Table: economic stimuli through R&D announced by other countries in recent months

USA	Doubling basic science spend 2006–16, plus \$21bn increase in R&D
China	\$860m R&D investment to help Chinese companies
Canada	\$6 billion dollars for R&D, including funding to temporarily expand graduate student programmes.
Germany	€500m for transport research, €900m for collaborative R&D in SMEs
France	€730m boost for HE and research, more generous R&D tax credits, estimated to create 25,000 research jobs in the mid-term
Spain	2009 budget for R&D increasing 6.7% plus €500m for specific initiatives
Australia	\$580 million (£260million) fast-tracked into universities
Austria	€100m for R&D, €120m for university infrastructure

25 The US is addressing its own position, and perceived weaknesses, in a significant way. *Rising above the gathering storm* is a wake-up call to the US on the threats to its dominance. It has had a significant impact on President Obama’s administration. In the corporate world, not only in relation to education, there is apprehension in the US that American leadership in knowledge intensive industries is fast eroding:

“... only 41 per cent of the global corporations responding to a recent survey ranked the US as an ‘attractive’ location for new R&D facilities, compared with 62 per cent for China. This, of course, represents a remarkable shift.” [Augustine, p. 63]

26 The major recommendations are for tax incentives and support for ‘basic science’. Whilst the amount of money in the Obama stimulus package is potentially very large¹⁶, it is being directed at plugging short-term gaps – for example extending current contracts for two years. Initial reactions are that it is not likely to be a very attractive package for encouraging UK and other researchers to move to the US, and that there may be benefits to the UK two years down the line in attracting researchers from the US as the stimulus package ends.

27 India and China are experiencing very high growth in research capability but this has not yet achieved the scale of the G8 competitors. The competition from India and China is more in engineering than science – the science research base in China is not **yet** a great threat, but will become so – China aims to be at least in the top five globally in terms of science and industrial innovation, with every sign that the target for science at least will be exceeded. India has been described as ‘*consolidating its place at the high table of international science*’. It has the human capital, the necessary funding and the policy agenda necessary to establish this position.

¹⁶ the final version of the 2009 economic stimulus appropriations bill is estimated as \$21.5 billion in federal research and development (R&D) funding, \$18.0 billion for the conduct of R&D and \$3.5 billion for R&D facilities and capital equipment.

Research in India

India invests approximately 1% of GDP on R&D – the Government aims to increase this to 2%¹⁷.

The majority of public research spending is allocated to Government Departments for intramural research projects undertaken in Government-owned research institutes. The top research spending departments are Defence, Space, Agriculture and Atomic Energy.

The Ministry of Science and Technology does support extramural research projects through the Department of Science and Technology (DST) and, in particular, through its Science and Engineering Research Council (SERC). The Ministry of Science and Technology also invests directly in a large number of research institutes through the Department for Scientific and Industrial Research (DSIR). A third Department of Biotechnology (DBT) sits in between these extramural and intramural extremes. However, the proportion R&D spend allocated through this route is less than in the UK and direct funding of research in universities is limited (but this is being questioned at senior levels and may change).

Investment in research by the private sector is less than that of most developed countries with chemical and pharmaceutical sectors dominating spending, followed by automobile, food and drink, and instrumentation.

On 1 April 2005, 391,000 personnel were employed in R&D establishments in India, of which 40% were directly engaged in research. In 2006-2007, the Higher Education Sector consisted of 11 "institutes of national importance", 358 universities and 20,677 colleges. These taught in excess of 11 million students. Policies for Higher Education in India are more separated from Science than is currently the case in the UK. In India, policy is coordinated by the Ministry of Human Resource Development and implemented by the University Grants Commission.

Priority setting revolves around five year planning periods with the latest running between 2007 and 2012, which highlights:

- an education system which nurtures creativity
- an R&D culture and value system which supports both basic and applied research and technology development
- an industry culture which is keen to interact with academia
- a bureaucracy which is supportive
- a policy framework which encourages young people to enter into scientific careers
- an ability to scan scientific developments in the world and use technology foresight to select critical technologies in a national perspective

¹⁷ Nearly 75% of total R&D expenditure was met from Government sources (including 60% from central Government), with just over a quarter from private sources, in 2005-06.

Research in China

China has increased annual R&D investment by an average of 18% for nearly a decade and now spends about the same as the UK, having already passed the UK in terms of publications¹⁸. R&D spend is 1.44% of GDP, with the aim of reaching 2.5% by 2020. Most of this spend (just over 80%) is on development in industry (for example demonstration projects), though in relatively recent years there has also been an emphasis on basic science. At the same time, total provincial R&D spending now exceeds the national figure. Business funded research accounts for around 70% of total R&D expenditure, followed by Government at 25%. Research institutes conduct about twice as much research as universities.

Research quality is improving, with China achieving 4% of the world's highest impact (i.e. top 1%) research papers in 2008. Across major science themes it now appears in the top three countries by citation more often than Japan or France. But its citation per paper are only half that of the UK.

China's domestic higher education system has expanded rapidly and large numbers of Chinese students study abroad (including 85,000 in UK during 2009). In 1997, China's technologically skilled human resources reached 42 million, of which 18 million were educated to university level or above. This was an increase of 12.5% on 2006 and overtook the US's 17 million in 2006. China prioritises engineering graduate production in particular, and this has been the case for at least a decade.

China's research is planned top-down, managed under the State Council by a central steering group under successive five-year plans. In recent years increased funding has also been routed through Provincial Governments, who target investment to grow local industry. The leading national laboratories (State Key Laboratories) also have some freedom to drive their own research agendas and the National Science Foundation of China supports largely bottom-up peer reviewed research.

China's biggest challenge is strengthening its domestic technology and research base and substantially growing the share of domestically-owned intellectual property used in China¹⁹.

The current national priority sectors for research and development appear to include food and energy security, and prevention of infectious diseases. The Government has ambitious plans for carbon efficiency and sustainable development; for increasing agricultural productivity (by about 50%) to address the challenges of climate change, water shortage and increasing wealth; and national defence features strongly within its science and technology goals.

¹⁸ The actual spend on R&D was more than \$54 billion in 2007, the 4th highest R&D investment world wide, next to US (1st), Japan (2nd), and Germany (3rd).

¹⁹ The government is concerned that, despite China being a leading exporter of high technology goods and services, 80% of the intellectual property involved is owned by non-Chinese companies.

Targeted research areas include energy, water and mineral resources, environment, agriculture, manufacturing, transport, information technology, public health, urbanisation, public security, and national defence²⁰.

China has welcomed international investors and required them to transfer technology to domestic partners. China continues to seek international research partnerships with a wide range of countries, but particularly targeting countries it regards as leading in a particular sector. Its researchers can participate in the EU Framework Programmes, supplemented recently by an agreement for jointly funded and selected research in areas such as low carbon and aerospace. The UK pursues collaboration under several science and technology agreements, ranging from space to co-operation with the UK Research Councils and institutional-level agreements.

- 28 The UK's own position needs to be strengthened if it is to remain competitive in research. We must ensure that we are able to stay abreast or ahead of other countries that are investing heavily in their research capability to ensure competitive success in delivering high value goods and services to the global economy. We must ensure that sufficient attention and investment is made in engineering, mathematics and the physical sciences in the face of very significant investment and competition from China and India in particular. We must build on the significant contributions to innovation and business performance made by the social sciences and arts and humanities in the UK. We must also ensure that the UK has high quality physical research infrastructure which is an important element in attracting the best researchers to the UK – it is not simply a question of salary.
- 29 The research base will further diversify over the next 15-20 years and the UK must be in the vanguard, not least in terms of different models and ways of operating.

²⁰ China is also focusing efforts on 'mega-projects' relating to electronic devices, very large-scale integrated circuits, broadband wireless communication technology, advanced large-scale pressured-water reactor, new trans-genic biological varieties, new pharmaceutical products, giant planes and manned space flight. Research is also focused on eight cutting-edge technology areas: biotechnology, IT, new materials technology, advanced manufacturing technology, advanced energy, marine technologies, laser and aerospace technology. There are also plans for major new scientific research in proteins, quantum modulation, nano-science, growth and reproduction. Other research includes cognitive science, deep structure of matter, core mathematics themes, condensed matter and new effects, scientific experiments and observation methods, techniques and equipment innovation. Research on earth system processes and resources, environmental and disaster effects, chemistry of creation and transformation of matter, quantitative study of the process of life and systems integration is also taking place.

The current strength of the research base

- 30 The UK currently remains strong across the disciplines. Overall, we are second to the US. Citations have risen (we have 13% of the most cited papers) and are responsible for 8% of world publications. The UK is first in biological sciences and social science; however, there are some disciplines where the UK is lower, for example in mathematics, physical sciences and engineering²¹. We know the UK is not competitive in certain areas – for example clinical trials which are very expensive²² – so clearly costs do matter. We should not forget that nine-tenths of the world's research output is produced outside the UK.
- 31 The strength of the UK science and research base lies in the high productivity of UK researchers (publications etc per £1 of research spend) and not through the level of absolute expenditure itself. The UK strength is in converting money into citations through the high level of productivity of the research base.
- 32 Factors behind the UK's strength include:
- culture – the 'free-thinking' nature of UK researchers – and the dual-support system which promotes high levels of competition for money
 - co-investment by different partners – but there is multiple jeopardy in bringing together different funders for a particular project especially if each contributor/funding agency has their own particular terms and conditions
 - recognition, transparency and reward – which is tied to excellence so the system has strong incentives to drive up productivity
- 33 Innovative discoveries often occur between traditional research areas so maintaining a strong, broad base is essential – for example developments in life sciences can often depend on research in other disciplines such as physics and mathematics²³ and the innovation process in the commercial sector itself involves multiple inputs from social sciences and other disciplines.
- 34 There is a perception among researchers that a greater emphasis upon economic impact will lead to a reduction of funding for more fundamental research and an emphasis on conservative nearer-to-market applications rather than excellence in choosing between projects. Better communication of present and planned research support is urgently needed to rectify this misconception. This is especially so given the long periods of time which occur between technical and scientific breakthroughs and the recognition and exploitation of commercial opportunities. The emphasis must be on improving the opportunity recognition and exploitation structures whilst maintaining the excellence and creativity of the underlying research base.

21 The UK's relative research output is strong in the biomedical and environmental sciences, ranking 2nd to the US with broadly maintained share (around 10%). In mathematics, physical sciences and engineering, the UK has a similar or slightly lower output than main EU partners and its share is around 7% of world. Impact has been maintained and is competitive with the US in many areas. The UK's average citation impact has risen steadily and is now close to the US; but it has been overtaken by Germany and also lies behind Switzerland, Denmark and the Netherlands. The UK's share of world citations is rising and it has 12% of world citations moving ahead of G8 competitors. The UK's relative citation share is 2nd only to the US in all subject areas except mathematics, physical sciences and engineering (Germany, Japan and China). (Evidence Ltd 2008).

22 For example, analysis of the US pharmaceuticals industry found that a 1% increase in public clinical research lifted industry R&D by 0.4% after 3 years.

23 Lord Krebs in his evidence to the House of Commons Innovation, Universities, Science and Skills Committee (2008-09; HC 168-1) pointed to a study in which ten key advances in cardiovascular medicine were traced back to about 600 papers from different disciplines which provided the basis for the advances. Over 40% of them had nothing to do with cardiovascular medicine at all and many of them were not carried out in medical departments but in departments of chemistry, engineering, physics, botany, agriculture, zoology etc.

Gaps and weaknesses in the research base

- 35 We are concerned that some research areas are stronger than others and that there are gaps and weaknesses – for example in engineering and neuro-degeneration²⁴.
- 36 It is properly the role of Government to maintain an overview of the relative strengths of disciplines in the upstream research base. When areas are identified where the UK is vulnerable, then a decision needs to be taken about whether the gaps should be filled, and if so, how. For example, at the present time, whilst high levels of investment from both Government and the charitable sector means we are very strong in the biomedical sciences we are facing real competition in the physical sciences.
- 37 Government and the Research Councils need to resolve the dilemma whereby on the one hand the strong competition for strategic research funding in the UK helps to build world-class universities and research institutes but on the other hand mitigates against a more collaborative approach needed to put together a strong bid, for example for an international facility (see later). The UK needs to improve its ability to devise, win and deliver cross-sector and cross-disciplinary projects.
- 38 Government needs to consider how policy-related research can be better stimulated and exploited. Finally Government needs to consider the design of organisational forms which can provide longer term funding for pre-commercial developmental research and which can span the boundary between research council funded activity and commercial exploitation in the private sector.

²⁴ Although there has been an announcement of funding of £16.99 millions from MRC and Wellcome Trust for three research projects.

4. People

- 39 The vision requires the UK to be the prime destination, where the best researchers from around the globe dream to come and stay; for the UK to nurture and retain home-grown and overseas talent; to have an education system which prepares everyone for living in a world where science and research are deeply embedded in our culture; and deliver highly-skilled entrepreneurial people to the labour market. In order to nurture the very best researchers, and to ensure that the UK benefits from their work, a significant focus should be investment in people and stimulating and supporting their creativity. This is more important than trying to predict the most promising topics or areas into the future. Investment in the best people – those able to work at the leading edge of research and its exploitation – is crucial investment for the future. The best people will adapt and seize new opportunities as the world around them changes.
- 40 The UK has a long history of research excellence – UK researchers and institutions have won over 70 Nobel Prizes for their achievements. Each year the UK produces over 15,000 PhD graduates, over 100,000 Masters, and over 300,000 first degree graduates.
- 41 UK Research Councils fund 42 per cent of UK domiciled PhD graduates, 35 per cent of EU domiciled PhD graduates and 25 per cent of all PhD graduates in the UK. They support 19,500 PhD students, 10,000 research staff on grants and 4,000 research staff in Research Institutes.
- 42 The UK research base, and its translation into economic and social outcomes, is crucially dependent on the quality of its researchers, across a wide range of disciplines²⁵. People must be at the centre.
- 43 This means that the very best people must be recruited from within the UK and from overseas. It is vital that the UK nurtures and supports the most promising of its home-grown researchers. However, the research workforce is an international workforce at the highest levels: the best people can and do move to seize the most promising opportunities. The UK must embrace this and attempt to attract the very best, whatever their county of origin. Once identified, whether in the UK or from elsewhere, the best researchers require excellent training and must be provided with the resources and infrastructure to work effectively. They have to be kept highly motivated to carry out the highest quality research and be supported by organisational and incentive structures that can help those who wish to do so and others to recognise and develop opportunities to derive economic and social benefit from research.
- 44 If the best researchers come from elsewhere in the world, barriers to their continuing to develop their work need to be removed. We recognise the real sensitivities, but we believe Government does need to find ways of making both entry into the UK and visa extensions easier so these highly gifted individuals can be attracted and when appropriate retained in the UK.
- 45 It is essential we consider the entire life cycle of the researcher, from education at school and university, through training as a research worker and as a young independent researcher, to the fully mature researcher and later stages of a research career. Action on all these is required to nurture the UK's own research talent, and to provide the most fruitful environment for those – from wherever they originate – who build research careers in the UK.
- 46 We need to understand what will motivate the best researchers coming to the UK and to avoid investments which subsequently migrate outside the UK.

²⁵ In this section, the word 'scientists' should be construed to mean scientists, engineers, technologists, mathematicians and social scientists (and related groups such as economists).

47 We have had discussions with Adrian Smith, Director General Science and Research, who is carrying out a review of Postgraduate Education. The proposals in this section covering postgraduate research represent the Council's input into Professor Smith's review.

Science in schools

48 The researchers' life cycle begins at school. Science²⁶ is challenging and needs to be taught well. Special attention has to be paid to the training of generalist primary school teachers so they can teach science well and these skills need to be continually refreshed during the course of their careers. Additionally at secondary school level, science should only be taught by those who have been trained in the area they teach. Those school students who express interest in science subjects should be encouraged to carry out research projects either within their schools or even through vacation placements in a research laboratory. Greater public engagement and media involvement with science should be developed to generate a stronger emotional appeal for young people so they are attracted into research. The aim should be to strengthen the pipeline into research through good teaching, communicating the excitement and importance of research, and by exposing them to hands-on research.

University teaching

49 The emphasis of undergraduate teaching should be on the excitement of research and its ability to bring about a better understanding of ourselves and of the world around us. The focus should **not** be on accumulating factual knowledge, which will increasingly be better supplied by digital resources, but rather on the great ideas and how they were developed. We would like to see those really motivated by the prospect of a research career being offered the opportunity of a placement in a research laboratory to gain practical hands-on experience. While the driver for this will be the motivation of the individual to seek such a placement, it will be important to ensure that such placements are available to those looking for them. This could involve a placement during the long vacation, or something more substantial as part of the degree course. It is important to emphasise we are not seeking a one-size-fits-all approach.

50 There is an under-supply of both graduate and technician engineers. The capacity to deliver on and benefit economically from national strategic priorities such as the redevelopment and modernisation of the national infrastructure²⁷ and low-carbon energy solutions will depend fundamentally on enhancing the supply of qualified engineers and funding the programmes that will support their training. The major investments being made not only in engineering but also in the physical and biological sciences by China and India indicate both the source and nature of the competition and demand for these skills.

University research

51 The quality of research students in UK universities needs to be as high as possible. There should be an increased emphasis on the quality of the students recruited and the training they receive, and away from a focus on the numbers of PhD students that graduate, and the tendency to treat PhD students as primarily a source of cheap labour for research. More use should be made of the research Masters degree to identify those students with the best aptitude to proceed to a Doctorate.

²⁶ In this section, the word 'science' should be construed to mean science, engineering, technology, mathematics and social science.

²⁷ A national infrastructure for the 21st century; CST report which flagged up the issue of the number of registered engineers.

- 52 Researchers need to be given wider skills sets as part of their training. There is a need to understand what stops UK companies going from \$100 million to \$1 billion – perhaps a lack of management or entrepreneurial skills? The breadth of skills delivered in research training therefore must embrace those derived from the economic and social sciences.
- 53 CST's earlier findings²⁸, and the Concordat for the career development of researchers²⁹, set out important principles for supporting and managing early research careers. Pressure on early-stage researchers to publish often militates against their collaborating with business or the public sector and this needs to be addressed urgently through the Research Excellence Framework (REF), the parameters of which are currently being developed.

Extracts from the CST report on early careers of researchers

There is a fragmentation of responsibility for ensuring that a career structure is in place which nurtures research staff. There needs to be a wholesale improvement in the management of early research careers. We propose two key areas for reform:

Development of a national framework for research careers...agreed by a partnership of funders, higher education and research institutions and research staff at all levels. Research staff must be allowed greater independence, at an earlier stage than at present, so they may take on greater responsibility for projects and staff. We believe that the use of research fellowships can play an important role and should be used more widely: personal *ad hominem* fellowships allowing researchers greater freedom to move between institutions and fields; and institutional fellowships, whereby a researcher is attached to a department of a university and deployed within that unit rather than attached to a specific funded project.

As universities move to a new paradigm with contract research staff there must be a change of mindset from HEIs: early career research staff should be properly treated as employees and given appropriate back-up for their staff development requirements.

- 54 We do have some concerns about whether the current three-year PhD in the UK always produces researchers of the very first rank. Arguably this would be an expectation hard to meet in any research system, and not just for the UK. Whilst the UK system is cost-efficient it does not always compare well with its US and EU equivalents in terms of the training it offers.
- 55 The number of PhD graduates who then carry on into a research career varies: in some leading research universities in the US it is between three-quarters and nine-tenths. In the UK, 43 per cent of Research Council-funded PhD students go into research roles across all sectors, while 26 per cent move into industry and commerce³⁰.
- 56 We would therefore like to see some rethinking of the Master degree/PhD landscape, though we recognise that there is already a variety of practice in different disciplines. We would like to see PhD degrees generally lasting for four years, with the first one or two years potentially leading to a Masters degree and an assessment at the one-year or two-year stage on whether the researchers should continue for a further two or three years to a PhD, or be awarded a Masters at that point. This would ensure that the best and most committed people proceeded

28 Pathways to the future – the early careers of researchers in the UK: CST report.

29 The Concordat to support the career development of researchers (2008).

30 Data from RCUK.

to a Doctorate. The design of the first one or two years should ensure that the award of the degree has distinctive value in itself and offers an exit route both in terms of choice by the candidate and assessment of suitability to continue to a Doctorate in terms of the merit of the project and the candidate.

57 We have some caveats:

- first, we do not necessarily advocate this across the board and in all areas – there are particular subjects, for example medicine or civil engineering where a considerable bedrock of existing training already exists and where a four-year PhD might not be appropriate. There may be other areas where earlier training and experience can be accredited;
- second, it will be essential to maintain flexibility depending on the research area as to whether a two-year Masters, two-year PhD is the most appropriate split; or whether a one-year Masters and three-year PhD would be better; and
- third, the examination burden on young people of a one or two-year Masters should be minimised as far as possible.

58 In addition to nurturing the best home-grown talent, we must recruit the best students from around the world into graduate training in the UK, especially from the emerging research nations such as India and China. Too often such students are seen mainly as financial support for universities given the high overseas fees they are charged. Whereas 30-40 years ago the most brilliant (say) Indian students would have naturally gravitated to the UK, following increases in UK university fees and the lack of UK scholarship funds many such students have shifted their attention to the US.

59 We therefore propose for the longer-term a highly competitive national scholarship scheme across all UK universities aimed at recruiting and supporting the very best research students from the UK and around the world. Such a scheme would not only generate excellent students who are engaged in UK research but would also in the longer term forge strong links with their countries of origin. Selection for the scheme would be highly prestigious and would identify those who were, or who had the potential to be, the future stars of research. Some will remain in the UK strengthening the research base; our later proposals would seek to encourage excellent doctoral students from overseas to build their long-term futures in the UK. Others will return to their home countries or be recruited by a third country where this can also be beneficial if future collaborations and links can be developed. It should be emphasised that this scholarship scheme should be aimed only at the very best students in the world.

Chinese researchers

The number of Chinese researchers has exceeded those in the US since 2006³¹ and is growing rapidly, including through the policy of securing the return of top Chinese researchers from round the world. The UK is seen as a source of that resource because of the numbers of Chinese researchers employed in our universities (double figure percentages of staff in many UK universities). Hence the UK is likely to be hit in two ways – the loss of Chinese researchers from UK universities; and the increase in capacity of Chinese research.

³¹ There were 1.423 million R&D scientists and engineers in 2007, accounting for 82% of the total R&D workforce. Just over two-thirds were employed in the business sector. But the ratio of the R&D workforce to the working population is low – a fifth of that in the UK.

60 These developments in the Masters/PhD landscape would have the additional advantage that for the first one or two years Masters students could develop specific skills that would be deployable in a wide range of careers (for example to teaching, business and enterprise, climate change mitigation/adaptation, or policy work) and include a focus on entrepreneurship, management training and experience, and collaborative working to tackle issues. The one or two-year Masters programme could include greater exposure to a range of research disciplines to encourage interdisciplinary thinking and opportunities to become familiar with innovation and entrepreneurship – to improve the supply of researchers into the commercial and public service sectors. There are existing variations around this theme – for example the Engineering Doctorate supported by the EPSRC whereby students conduct research and undertake taught business and technical courses whilst working with an industrial sponsor.

61 We believe that there is great benefit to be derived from more people undergoing a rigorous, research-based Masters programme as a preparation for careers in business, industry or public service, or for those who will become entrepreneurs. The skills acquired through research training should be more widespread as the UK builds a new economy for the 21st Century.

Post-doctoral researchers

62 Beyond the Doctorate, research fellowships provide a further opportunity for recruitment of the best from overseas and ensuring greater retention where we risk losing the best because of concerns about longer-term career opportunities in research.

63 A powerful mechanism for recruiting and retaining the best post-doctoral researchers is through competitive personal support schemes which provide support for the individual together with some operational costs and better remuneration, who then can choose the research advisor with whom they wish to work. Such mechanisms could be supported in the longer-term by shifting some resources from response mode funding of project or programme grants from the advisor to the fellow. The increased status of personal support schemes and their improved conditions of employment will be attractive for recruitment and retention of high quality individuals who are often more independently-minded and gravitate towards top-level researcher positions. Such a mechanism would better enable the UK to compete globally for the very best research talent and retain them in the UK during arguably some of their most creative years.

64 Retaining the best talent to the UK's benefit should be the prime aim, given that the pool of the best research talent is global and that other countries will seek to attract the best of the UK's home-grown researchers. However, post-doctoral researchers from overseas who decided at some point to return to their home country, or who are recruited by a third country, would be highly likely to maintain strong research contacts with the UK, as the formative links between them as individuals and the UK would already be in place.

Independence and mobility of researchers

65 A critical stage in the career of a researcher is the first independent research position. The UK gives independence at a young age, which is a good feature given this is often the most creative period for a research worker. Important at this time is a very supportive environment, both intellectually and fiscally, which may not be provided at all universities and institutes³².

32 This is addressed in the CST report: Pathways to the future – the early careers of researchers in the UK.

66 Mechanisms are needed in the longer-term to stimulate greater flexibility and mobility in general³³. Encouraging interactions and networking across the UK and the EU can help improve the local environment. There are opportunities to develop centres of excellence with specific interests in training young independent researchers at this career stage, but it is important such arrangements are coupled with the explicit understanding that the scientists look elsewhere in other universities and institutions for later career positions, for example following the UKCMRI philosophy which is to train people to the highest standard and then diffuse them through the system via appointments elsewhere³⁴. This will assist increasing the mobility of researchers within the UK which is too limited at the present time.

67 There also needs to be much greater mobility between academic and the commercial and public sectors, for example mechanisms to stimulate movement between academia and business in particular, and academia and the public sector³⁵ which must address urgently the reluctance of young academics to put in jeopardy their publications' record. It should become commonplace that individuals can regularly shift between these different sectors, and career structures should be such that such mobility is welcomed rather than discouraged. Given the strength of UK research there are great opportunities to encourage inward migration from other countries since these individuals, if attracted at this stage in their career, are likely to settle for an extended period in the UK. We therefore welcome the Government's recent national action plan on research careers and mobility in the European research area.

68 Not only is early independence an attractive feature for recruitment but also the UK's fair reviewing system based on the quality and transparency of the process as well as a generally longer term view of research activity compared with many other countries. These aspects combined with good resources and a freedom to pursue a line of enquiry wherever it may lead are important for keeping researchers highly motivated. There will be good opportunities for inward recruitment from the US in two to four years from now as the stimulus packages in the US for research are mostly rather short-term, and around two years from now the predicted drop in fiscal support for research may encourage excellent researchers to look elsewhere.

Mature researchers

69 Many of the proposals made concerning early careers also apply to the mature researcher, but two specific points need to be made.

70 The first is that there should be a wider range of personal remuneration to reflect the fact that researchers who are amongst the very best in the world can attract very competitive salaries elsewhere in the world, particularly in the US. It is important that increased remuneration is not used just to attract researchers to the UK but is used to reward excellence including those who are UK-grown.

71 In the longer-term there should be a national personal support scheme of prestigious research professorships for the very best 100 or so researchers in the country. This could be based on the Royal Society Research Professor scheme but like the Wellcome Senior and Principal Fellowships or the Howard Hughes Medical Institute in the US should include direct research support. Such a scheme would be almost unique, demonstrating to the world that the UK is one of the best places in the world to pursue a research career.

33 Proximity effects show the importance of interpersonal interactions. Spill-overs from research often form local clusters of high-technology businesses around research-intensive universities. SMEs are generally more innovative if they are near universities (Cabinet Office 2008). Being close to a highly-ranked chemistry department doubled the number of private pharmaceutical laboratories, tripled the number that were foreign-owned and increased the number of chemical industries (Abramovsky et al University research and the location of business R&D Economic Journal, 117, pp114-141).

34 The UK Centre for Medical Research and Innovation will bring together researchers from Cancer Research UK, Wellcome Trust, MRC and University College London.

35 See the recommendations in the CST report: How academia and government can work together, October 2008 as well as the GO-Science implementation plan.

- 72 The scheme should cover all disciplines and particularly include translational research and the physical sciences, which are less well served at the present time in the UK compared with the biomedical sciences. Relatively few individuals really 'move the needle' and this scheme is aimed at attracting and supporting this exceptional talent and will have a significant multiplier effect on the rest of the research sector.
- 73 Finally, mature researchers should be constantly encouraged using workshops and other proactive inducements to reconsider their research programme, to think outside the box and to consider interdisciplinary approaches.

Retirement

- 74 There are a significant number of researchers who are still innovative and productive at the age of 65 years but who have to give up full time employment. Some of the UK's best researchers have been recruited overseas at this stage of their careers. If monies can be made available without detriment to younger researchers, encouragement is needed for such researchers to remain in post with renewable appointments whilst they continue to contribute significantly to UK research. They should be eligible for all the funding schemes which are mentioned above, and which are targeted at retaining the best researchers, for as long as they are carrying out world class research.

5. Prioritisation

- 75 The vision requires the UK leading the world in particular areas, having prioritised to achieve that position – by excellence upstream and by knowledge-based sectors downstream – continuing to generate great ideas and knowledge, but be better at exploiting them and ideas from elsewhere, to harvest greater benefits to the economy and society.
- 76 The first step is for Government to continue to prioritise research funding against other competing financial pressures, against the background of public expenditure constraints.
- 77 In times of austerity, difficult choices will need to be made and there is a need to develop mechanisms to help determine where priority investments should be made, so that the research base is best-placed to drive the UK's future competitive advantage as we emerge from the global recession. An approach along the lines of business-as-usual is no longer an option.
- 78 There are two crucial processes where prioritisation is needed: first, stimulating creativity in upstream research focusing on discovery, where excellence is the over-riding criterion in creating a world class research base; and second, stimulating downstream research and translational activities to exploit the outcomes of the research base for economic and social benefit.

Maintaining a broad research base

- 79 Our message is that the UK must maintain *capability* across the research base.
- 80 The returns to public funding of the research base are substantial but the prior identification of which research advances which will lead to the most gains are not. The outcomes from upstream research are highly uncertain and often unknowable. Attempts at upstream prioritisation on the basis of projected impacts are not feasible (see Annex 1). The aim should be to ensure a broad range of excellent upstream research combined with translational research funding and organisational structures to enhance the recognition and pre-commercial development of economic and social opportunities.
- 81 At the micro-level, whether or not a particular Research Council should fund a particular project should be determined solely by the excellence of the research proposal itself and the potential to harvest the products of that research to maximise impact. Therefore the focus should be on *excellence wherever it is found*. Funders of upstream research should be ruthless about excellence as the overriding criterion for funding prioritisation. The quality of the researcher will be an integral part of that ensuring excellence.
- 82 In times of financial austerity, difficult choices will have to be made, and where these are made they need to be done by looking right across the landscape, not simply on a Research Council-by-Research Council basis. For example, medical research has grown significantly over the last ten years, and for obvious reasons. But successful outcomes in medical research depend on high quality research from the engineering, physical and social sciences base. We know the UK's international position in physical sciences is facing real competition.

- 83 This leads to a series of questions. Is the balance we have between medical and other areas of research still the appropriate one? We know that expenditure per researcher inevitably varies enormously between different research areas, and that investment in a large facility will inevitably attract extra funding for projects using the facility to ensure maximum utilisation of what is inevitably an expensive capital facility. But are these factors themselves skewing the balance between different priorities at the macro-level?
- 84 Research Councils must ensure that sufficient attention and investment is made in engineering, mathematics and the physical sciences in the face of very significant investment and competition from China and India in particular.
- 85 We recognise that discussions on resource allocations are never straightforward, and that forward commitments inevitably constrain adjustments that can be made in the short-term. But in difficult economic circumstances these discussions will need to take place and we are pleased that the Director General of Research Councils will be consulting a wide range of organisations, including CST, ahead of spending reviews.
- 86 Investments in large research facilities will present particular challenges in times of economic austerity, and it will be important to ensure that funding of the research projects, necessary to ensure the UK gets maximum return from such facilities, are not compromised either by the costs to maintain such facilities or, in the case of international facilities, the subscription costs.
- 87 In addressing strategic challenges Research Councils need to ensure clear, joined-up strategies and mechanisms for interdisciplinary and downstream research. These should be consistent with and work in parallel with the collaborative and downstream innovation and commercialisation focussed programmes of for example TSB and the Energy Technology Institute (ETI)³⁶.

Downstream Prioritisation

- 88 Strategic choices need to be made at the downstream, demand-led end of the research spectrum. It is right that Government should assess particular business sectors in terms of their potential for UK business to develop and succeed. At the same time, there is a need to look hard at the UK's research strengths and ensure they align with current and future areas of economic and business strength.
- 89 The focus for downstream and translational research support should be on those business sectors where:
- the UK has global strength or the capability to develop that strength
 - there is the greatest chance of effectively exploiting knowledge transfer so the UK gains competitive advantage
 - exploitation of research is likely to produce widespread effects across a range of industries and form the basis for the industries of the future³⁷

³⁶ Contrary to some reports, the balance between responsive and directed mode funding has remained constant for the majority of Research Councils over the past years. Responsive funding continues to dominate Research Council allocations. Between 2004/05 and 2007/08 responsive mode funding rose in MRC and NERC (up from 85 to 93%, and 68 to 76%, respectively); and fell from 76% to 70% for BBSRC and 57 to 54% for EPSRC.

³⁷ Government has identified the following strategic business sectors as priorities: low carbon; digital Britain; life sciences and pharmaceuticals; advanced manufacturing; professional and financial services; engineering construction; industrial opportunities in an ageing society. CST has identified six key technology areas: Carbon capture and storage; Disaster mitigation technologies; Low carbon distribution networks for electricity generation; medical devices; E-health; and Plastic electronics. The Technology Strategy Board has also identified six key technology areas: High value manufacturing; Advanced materials; Nanotechnology; Bioscience; Electronics, photonics and electrical systems; and Information and communication technology.

90 There is a need to ensure that Government policies continue to address the cross-cutting issues, for example skills and training needs, and that a sector-specific focus is not at the expense of these cross-cutting requirements.

Downstream knowledge exchange and translational activities

91 The weakness of UK research policy has historically been in translating research outputs into economic and social benefit. Changing this requires effective knowledge exchange between the research base and user communities and enhanced developmental capability in both. These need to be addressed urgently.

92 Government has a significant role in helping to ensure upstream research and the accompanying outputs are translated into economic and social benefit. There is very seldom a linear relationship in the processes through which upstream research is translated into downstream application, and to economic and social benefit. Often it can appear serendipitous; it is always complex and the connections can be difficult to trace. People and interpersonal interactions are central and one of the best ways to exchange knowledge is to encourage interaction between individuals and organisations including exchanges of the personnel.

93 There is a need for greater emphasis and focus on:

- excellence in knowledge exchange – stimulating exploratory activity that connects excellent upstream research with downstream application
- investment in the skills needed to support downstream application
- supporting pre-commercial downstream research in emerging opportunities on a long enough time frame and on an appropriate scale; and in particular
- ensuring a powerful flow of ideas and skills towards the long-term national priorities
- focussing support on emerging platform technologies offering the most pervasive impacts or generating new industries for the UK

94 With notable exceptions, such as pharmaceuticals and aerospace, there has been a significant lack of 'pull' from industry on the science and research base. Demand pull is more important than supply push in determining the extent to which a society benefits from the underlying investments in public sector supported research activity. Attempts to replace this by research 'push', though laudable, will ultimately fail: supply-push based on increasing the amount of research activity will not, by itself, engender social and economic returns.

95 Government has introduced a range of initiatives, notably R&D tax credits, reduced capital gains tax, and a start-up friendly legal and financial environment, to stimulate research but needs to do more to develop consistent, focused, long-term industrial strategies backing novel key technologies with global market potential.

96 The three main issues are:

- how bodies such as the Research Councils and the TSB stimulate the optimum knowledge exchange and translational processes, and whether additional mechanisms and structures are needed
- how to improve the absorptive capacity of business to research outputs – which in turn will strengthen the case to the public and Government on why it is vital to continue to invest in research in times of austerity

- how to use research to develop 'new' know-how in technology businesses. This will take time and there is a question of whether the UK has the critical mass of technology-based companies able to rise to this challenge – for example a company such as ICI had tremendous know-how but that is now dissipated.

Research Initiatives

The Research Councils have a number of cross-Council programmes – *Energy; Living with Environmental Change; Global Threats to Security; the Digital Economy; and Ageing* and one multi-disciplinary project: *Nanoscience*.

The Technology Strategy Board has seven Innovation Platforms: *Intelligent transport systems and services; Low impact buildings; Assisted living; Network security; Low carbon vehicles; Detection and identification of infectious agents; and Sustainable agriculture and food*.

The TSB also has a number of application areas where technology is an important driver: *Environmental sustainability; Energy generation and supply; Healthcare; Transport; Creative industries; High-value services; Built environment*.

The EPSRC has set up four Innovation and Knowledge Centres³⁸: *Advanced manufacturing technologies for photonics and electronics – exploiting molecular and macromolecular materials (at Cambridge); Ultra-precision and structured surfaces (at Cranfield); Centre of secure information technologies (at Queens, Belfast); and Regenerative therapies and devices (at Leeds)*.

Weaknesses in translation

- 97 The Department for Business, Innovation and Skills is funding science and research at a level of £5.8 billion this year alone; by contrast the Technology Strategy Board will invest over £1 billion to support innovation in businesses between 2008 and 2011, in partnership with the Regional Development Agencies and the Research Councils.
- 98 The box above demonstrates the breadth of initiatives on research translation from both the TSB and Research Councils. We recognise that the Research Councils and the TSB have developed good working practices over the last year or so, but we think that in the longer-term there is scope for bringing greater focus and we set out some options later in the report.
- 99 Maximising the exploitation of research coming out of UK universities is essential but there is a need to develop 'stickiness' i.e. investment which leads to building the types of business which are then hard to shift outside the UK.
- 100 There is a need to ensure the UK exploits the best research from wherever it emerges, for example the UK needs to be a major generator and user of green technology from wherever the research ideas originate.
- 101 We must remember that the impact of research is often measured in terms of decades rather than years and that newly-emerging technologies will often form the key markets for the future. We need to start building towards these markets now. We welcome the Government's recent announcement of a strategy for Plastic Electronics which attempts to draw together the varied strands of support for this technology. In each case however an explicit analysis

³⁸ Innovation and Knowledge Centres are centres of excellence to accelerate and promote business exploitation of emerging research. They are jointly funded by EPSRC and TSB.

is required of the nature and scale of the commercial opportunity and the scale of and length of time over which support will be needed. This may mean uncomfortable choices of focussing support in a limited number of areas or institutions to achieve the critical mass required.

102

We have already emphasised that one core requirement from Government is that it creates the right environment for business investment by setting out sustained, long-term objectives or by being a lead user. This means the creation of a long-term, stable climate through the articulation of a clear vision and priorities for the development of the economy over the next decade and beyond. This then will give the private sector greater confidence to invest in research to support these objectives. For example, we believe that the renewal of the national infrastructure will provide a real opportunity to build new industries and stimulate the translation of upstream research to downstream application in the UK.

Extracts from the CST report: A national infrastructure for the 21st century

Meeting the challenges for a 21st century NI will require innovative solutions, drawn from the science base. This will include developments to existing systems, such as moves to active networks and smart metering.

Supporting innovation in key infrastructure sectors by means of direct procurement will create markets for new high-tech businesses in the UK, stimulate innovation throughout the supply chains and act as a mechanism for pulling through R&D from the science and engineering base. The TSB therefore needs to press forward with the Small Business Research Initiative and extend the pilot programmes beyond Health and Defence into other areas of the NI.

The TSB and the Research Councils need to do more to stimulate collaborative R&D between business and academia in key areas of the NI: Government, Business, Research Councils and the TSB, and regulators need to come together to address key issues around technology availability and deployment and the priority areas for R&D including new cross-Council multidisciplinary programmes.

The transition towards a more sustainable, low carbon society will require a step-change in the development and deployment of a range of existing and new technologies and infrastructures which are not currently in place. These include centralised supply side options such as carbon capture and storage, infrastructure technologies such as decentralised networks (transport, water etc), cleaner transport and micro-generation.

More scenario planning is needed. Government should work in collaboration with the research community, technology developers and investors to develop scenarios e.g. for the UK low carbon landscape for 2050. These scenarios would enable possible pathways for innovation and technology to be developed and so assist Government, energy, and other businesses and investors to develop their strategies for the long term.

CST believes the keys to success will be:

- greater focus on technologies underpinning 21st century national infrastructure – and using the capability and capacity of new technology as one criterion for deciding on where and how to invest in new national infrastructure³⁹
- solving major global problems, for example climate change and shifting resources to those areas where the UK has capability to build and grow new industries, for example green technologies, the creative industries or plastic electronics. Success will be through bodies such as the TSB, the Research Councils and the ETI
- addressing major social challenges including food security, healthcare and an ageing population
- clear incentivisation and reward mechanisms for academics engaged in high-impact translational activity of excellent research through the REF – both financial and in terms of academic promotion and progression
- augmenting *Quality Research* funding towards research groups with a proven record of high impact work, again through the REF
- more value chain analyses of key sectors, and horizon scanning of the industries of the future, to decide where and how the UK can best exploit developments

CST report on strategic decision-making for technology policy

There is a need to base translational research more firmly on the recommendations of our 2007 *Strategic decision-making for technology policy* report, updated to take account of developments since it was produced.

CST outlined⁴⁰ a process to prioritise technology investments in areas: (i) where the UK has world-leading capacity; (ii) which have large actual or potential growing global markets (in excess of £100 billion); (iii) where the UK has the businesses, structures and people able to take developments to market; (iv) where there are strong, positive societal benefits; and (v) where technology risks are low and where government is able to intervene, not merely or necessarily through funding, but also through regulation. A longer-term version of such an approach could be applied that would provide both encouragement to investment and also pull on the research base.

Such an approach is also one where it is in companies' interests to engage with the science base, as happens for instance with Rolls-Royce through their University Technology Centres. That engagement is crucially important if greater and more diversely articulated links are to be created between industry and the science base. Because it is in the self-interest of industry to create them, they are likely to be much more effective than those driven from the science base and from Research Councils.

³⁹ See the CST's report: A national infrastructure for the 21st century.

⁴⁰ See the CST report Strategic decision-making for technology policy.

The role of business

- 104 UK business as a whole spends slightly over 1% of GDP on research and development – around half that spent by business in the US, Japan and Germany. Some, but not all of the discrepancy, can be explained by the structure of the UK economy which is dominated by the services sector, where it is difficult to capture research expenditure under the traditional headings, and by sectors such as oil and gas which are traditionally low spenders.
- 105 Public and private sector research expenditure is positively related to productivity and the case for public support of the private sector is based on the view that private business cannot capture all of the gains which accrue because of knowledge spill-over⁴¹. There are therefore significant tax incentives to encourage business to spend more on research. Some business sectors, for example pharmaceuticals, recognise research investment as the *sine qua non*. Most do not, with some notable exceptions, for example Rolls-Royce with their University Technology Centres⁴².
- 106 There is moreover a trend across large business more generally towards reducing in-house R&D and increased contracting out of research and buying in of ideas. This is partly in an attempt to reduce risks and transfer them outside the parent and partly in response to disappointing evaluation of returns to in-house investments in their own corporate research laboratories. This is an opportunity for universities to undertake knowledge exchange contractual research but runs the danger of turning universities into “industrial look-alikes”⁴³. These trends might also have contributed to the reduction in STEM⁴⁴ graduates, as a career in industrial science and engineering research became less attractive as corporate research laboratories closed.
- 107 There is also a view that UK business needs to become bolder in its approach and more receptive to the opportunities that research has to offer. Business managers need to be more aware of these issues so that they will take greater advantage of the UK research base.
- 108 UK innovation performance is traditionally measured by the amount of research carried out by business, and the number of patents. The UK performance in both these is poor.
- 109 In particular UK institutions have a poor level of US patenting and a weak income derived from licences and options relative to other economies. Metrics by which the research base is measured place less emphasis on these measures than citations. What is measured, and how it is measured will determine academic behaviours and focus. The REF needs to address this issue.
- 110 Government needs to encourage business to make a stronger pull on the outputs of the research base by stressing:
- the importance of recruiting graduates as key boundary-spanners between new ideas in the research base and commercial applications
 - the economic benefits of research: for example Rolls-Royce University Technology Centres have an annual spend of >£30m each year; the vast majority of this is in the UK. Past investments, over 15 years, now contribute to revenues of £9.1bn and profits of £880m.
 - the absorptive capacity role of research; research carried out in-house enhances the ability to identify and exploit opportunities arising from research elsewhere⁴⁵

41 Analysis by the OECD (2004) estimated that a 1% increase in business R&D increases multifactor productivity by 0.13% and a 1% increase in public R&D increases multifactor productivity by 0.17%.

42 Rolls-Royce has set up 18 University Technical Centres as well as an Advanced Manufacturing Research centre in Sheffield.

43 Quote from Sir John Chisolm (Universities and industry: a perspective on the 21st century (2009) report for DIUS).

44 Science, technology, engineering and mathematics.

45 Countries with higher R&D intensity are better able to gain from foreign R&D – from Impacts of Investment (CaSE 2009).

- research career opportunities as a magnet to attract more of the best people into studying STEM subjects, and more of the best STEM people into industry
- unless business engages more with the Research Base, the arguments for increasing research spending will be harder to make, against a background of unprecedented pressure on Government finances.

Better horizon scanning

111

Given that Government needs to prioritise resources to those sectors of the economy which will be best-placed to succeed as the economic upturn occurs, it needs to know what those sectors are. Equally, it is hard to know what the opportunities will be, and which jobs which will exist in 10 years time. Government Departments and Research Councils therefore need to strengthen their horizon scanning and foresight activities to better predict the future so that conditions can be anticipated which will help enable the economy to respond to hitherto unknown opportunities.

6. Organisation

- 112 The vision requires the UK to be a world-leader in solving particular global challenges by deploying excellent research, working across sectors in strategic and cross-disciplinary ways; thriving universities and research communities, enriched by working with and across different sectors, generating great ideas and knowledge and being better at exploiting them.
- 113 The UK's university base has undergone major changes over the last 50 years, particularly the expansion in the 1960s and 1990s, and again early this century when new universities were created out of the former polytechnics.
- 114 The university research base needs diversity in order to deliver:
- world-class and world-leading research which can compete with the best in the world and which act as magnets for international business by, for example, collaborating on particular themes
 - world-class capability across the spectrum of knowledge exchange and translational activities
 - broader based collaborations within and between institutions, individuals and disciplinary boundaries
 - the capacity to support higher level skills development for the new industries and other developments stimulated by research
- 115 There is no requirement for every University to attempt all of these objectives, but the University sector as a whole needs to be able to deliver them.
- 116 CST takes the view that Government policy should be to fund excellence wherever it is found, at an individual or group level, and not, for example, to concentrate research funding at the institutional level – although we recognise that to some extent this will happen naturally as a result of applying the excellence principle. Research funding is already quite highly concentrated in institutional terms but what matters is not the level of concentration per se but that the level reflects the distribution of excellence and whatever critical mass or scale effects are necessary to maintain excellence in particular locations.
- 117 The principle of focussing funding on the highest levels of excellence implies continued, rigorous competition for research funding. We endorse this competitive environment, which has benefited the UK significantly in the past. However a highly competitive environment also brings challenges which concern us. For example:
- this environment appears to have militated against the more collaborative approach needed to put together a strong bid for an international facility, such as the BP Biofuels Institute which went to California. There is a need to balance the competition/ collaboration equation and this will be best achieved through the REF
 - solving the big global challenges will require a multi-disciplinary approach; universities need to improve their abilities to be more strategic in devising, winning and delivering large-scale cross-sector and cross-disciplinary projects, which often means collaboration with other institutions.

118 We believe the answers to many of these issues lie primarily within the universities themselves, in terms of their ensuring they have the right strategies for their institution, and high quality people, initiating new models of collaboration between their institutions and individuals, and new models for promoting the translation of research outputs to economic and social benefit.

119 Government also has a role in facilitating and encouraging Universities to find new ways of collaborating at the highest levels of international excellence. Government should set a new agenda for encouraging inter-institutional collaborations, in a way which does not blunt the UK's competitive edge.

(i) Within universities

120 CST has made recommendations on how universities themselves could provide a clearer focus internally to deliver policy advice to Government.

Extracts from the CST report: How academia and Government can work together

Core recommendation to Academia: Universities should seek to improve and professionalise their capabilities and structures for engaging with Government so that they operate more like consultancy organisations, in particular by:

Building on their experience of working with business, including concepts such as relationship managers

Considering whether new structures within the university itself might be needed
Utilising appropriate funding sources

Many universities already have existing structures for co-ordinating and promoting engagement with business⁴⁶. These bodies have helped revolutionise the relationship academia has with business, and in many cases also promote academic work to government. Such knowledge transfer bodies have often been supported at least in part by Government funding, for example through HEIF⁴⁷, which specifically promotes such translational activities.

121 We think further realignment is needed to maximise interface with business, in particular:

- through mission-focused investments. Universities should be looking to structure themselves better to carry out multi-disciplinary research with business
- maximising the outcomes from their different roles, not just in terms of education but in terms of increasing the stock of codified useful knowledge, problem-solving and providing public space (see Annex 2)

⁴⁶ For example Technology Transfer Offices (TTOs) have been established at most research-intensive universities to provide advice and services to the university community to facilitate the protection and commercialization of IP generated. TTOs exist to both encourage and protect staff and students developing IP and to encourage and manage commercial collaborations, bridging the gap between academic research and commercialization. Over the last ten years a number of Government initiatives – in particular HEIF – have been developed to incentivise universities to transfer knowledge into business and society.

⁴⁷ The Higher Education Innovation Fund.

122 We would like to emphasise the importance of universities as centres of learning and skills excellence, as well as pursuing international research excellence. Indeed universities will play a critical role in the development of higher level skills to support the new economy as it emerges. Whilst it will be for universities themselves to decide the balance of their objectives in these very different areas, reward systems need to be in place as part of the nexus of REF and HEIF funding. We welcome the fact that the REF will explicitly assess the impact of research from an economic and social perspective.

123 Research excellence at the project and researcher level is central to success. Government should support excellent research wherever it exists, and research funding should be directed towards those research centres and groups, wherever they are, who are excellent in research and in the translation of research outcomes into economic and social benefit.

(ii) Intermediary bodies

124 The UK's upstream research is world-leading in life sciences (for example regenerative medicine including stem cells), and in particular areas of ICT, such as plastic electronics. There is a real danger that the UK lead in some of these areas is being lost to major initiatives at the downstream end in other countries. We have highlighted the breadth of initiatives on research translation from both the TSB and Research Councils. We recognise that the Research Councils and the TSB have developed good working practices over the last year or so, but we think that there is scope in the longer-term for bringing even greater focus.

125 In other countries intermediary development organisations have often played an important role in focusing and stimulating developmental research spanning the boundaries between the university research base and commercial application. Examples include the long established Fraunhofer Gesellschaft in Germany; the Holst centre in Holland; and IMEC in Belgium⁴⁸. These organisational forms have acted as key focal points in electronics research and most recently have led both Germany and Holland now to have larger plastic electronics development groups than the UK, for example the Fraunhofer Centre for Organic Materials and Electronic Devices in Dresden and the Holst Centre (joint venture between IMEC in Belgium and TNO in the Netherlands).

126 In the UK it is rather different. For example, support for plastic electronics is spread across several 'centres of excellence' and delivered by a variety of funding and support sources including the TSB and the research councils. The funding horizons for some of the key investments are relatively short (for example five years). A central question which goes beyond this particular example is whether structures similar to those developed elsewhere provide a more effective mechanism for pre-commercial developmental research and the leverage of private sector funding alongside public investments.

127 We believe that critical mass investments in pre-commercial development of new technology platforms will be an essential part of a focused strategy to exploit the potential of the UK research base. The way that these should develop in the UK will need to take into account the present structure of UK universities and the pattern of funding through the higher education funding councils, the Research Councils and TSB.

⁴⁸ The Fraunhofer Gesellschaft is 60 years old and has 57 institutes. It spends €1.4bn on applied research and has 15,000 employees, mainly scientists and engineers. 60% of the revenue comes from industry and government contracts and 40%, are government grants. It registers over 600 inventions and over 200 patents a year and is open to international cooperation. It supports start-ups and spin-offs but is primarily part of the formidable German manufacturing fabric, which consists of many large and even more medium size companies. Many of these have development contracts with Fraunhofer.

- 128 We recommend that the Government review the benefits of developing a system of Platform Technology Centres. We also recommend that the government, in consultation with TSB the Research Councils, Charitable Foundations and the private sector, review the way in which current support funding and future support could be used to develop such a system. We therefore welcome the Government's recent announcement of a review in this area.
- 129 There are a number of possible options to explore. Over the longer-term, we can see at least two options for achieving the same end, within the organisational structures which already exist in the UK. One option would be to expand the role of the Technology Strategy Board. The question would then arise how this would interface with the activities of the Research Councils in this domain, or even whether the Research Councils should be either as active in it as they currently are, or indeed be active at all, and thereby re-directing more of their efforts to their fundamental role of stimulating creative research⁴⁹. A second longer-term option would be to bring together all major translational activities under a joint TSB/Research Council banner, together with other stakeholders such as business, the RDAs and Government departments, and focus on a smaller number of Large Technology Platforms bringing together the best of the Innovation Platforms and the Innovation and Knowledge Centres.
- 130 There are other options which could be considered but under any option the criteria for support must be clear and rigorous. We set out the criteria we believe to be most salient in the box below which we expect to be met in only a few exceptional cases.

Suggested criteria for Large Technology Platforms

New technologies often need to be further developed by substantial teams for a number of years before they are commercial. These teams need to be larger than the research teams which first made the discovery. They often need expensive production equipment to make the research industrially useful. This requires a dedicated environment with a clear focus for a period of 5 to 10 years.

This can only be achieved through a major partnership between universities, government and industry for those very few exceptional opportunities that meet the following criteria:

- Large (£multi-billion) market
- Verified global UK technical leadership
- Defensible technology position (patents, know-how)
- UK absorptive capacity for the developed platform (skill base, sector companies)
- The opportunity to create a platform technology with wide applicability

Funding

Funding should come from various public sources (TSB, EPSRC, European Framework Programme, RDAs, Universities etc) but should have a substantial industrial component, possibly starting at 25% in the beginning and expanding to 70% over time.

⁴⁹ A potential advantage of this latter possibility would be to move away from the "zero-sum game" which assumes that the balance between upstream and downstream research must be struck or changed within Research Council funding to adapt to new political realities. Incentivisation by Government of private investment could provide a crucial additional element of funding.

To make a difference in a global context we suspect that each of these platform technologies will need between £50 to £100m over a 5 to 10 year period to become the basis of numerous start-ups and licensed projects to large companies. This will lead to clusters of expertise in these sectors that feed off each other in a virtuous circle enabling the UK to retain global leadership in large markets. The particular amount required will need to be specifically justified in each case.

Intellectual Property

IP arrangements have to be clearly defined and flexible to reflect the contributions made by the different funders i.e:

- IP transfers from the university to the platform
- Shared new IP created by the centre and commercial funders
- Licensing arrangements for companies who want to exploit the results of the platform

(iii) New models for university collaboration

131 Geographically and in terms of population the UK is a small country, but we significantly punch above our weight in research, in particular in productivity terms. Researchers traditionally collaborate with other researchers⁵⁰. We welcome the fact that the REF will encourage the greater mobility of researchers between academia and industry.

132 Nevertheless, the developing research environment globally demands that the UK develops the capacity to compete with the new science-based economies emerging in India in China, as well as with the United States. The sheer scale of these competitors will, over the next decade, require that the UK's leading research groups to collaborate with each other, and with international partners, if there is to be any chance of matching them. These new collaborative models need to be developed, and need to be reconciled with continuing fierce competition between those seeking Research Council and other funding.

133 There is a need to unpack the different types of collaboration that are possible; different types of collaboration are needed for different kinds of research:

- *large facilities collaboration*: where factors such as cost preclude one organisation or country from creating and operating large scientific facilities, for example the Large Hadron Collider
- *large-scale international collaboration*: where the sheer scale of effort needed can best be delivered through collaboration, or where collaboration at an international level can deliver both breadth and economies of scale not possible for each participant alone, for example the collection and sharing of data in astrophysics, or trans-national research on climate change, or under the EU Framework programmes
- *to ensure pan-UK coverage*: where there is a need to create a UK-wide co-ordinated network, for example on clinical trials
- *collaboration at the university/department level*: for example pooling resources and expertise

⁵⁰ Collaboration is expanding. Both France and Germany now add greater impact to UK co-authored papers than does the US. Over ten years, the number of the UK's internationally co-authored papers has risen from 22,500 (32% of total) to 37,000 (45%). And in 2005-06 37% of doctoral STEM students came from overseas.

134 Government and its agencies need to stimulate active and productive research connections. We believe that, in a new environment which encourages collaboration amongst leading research groups, there is a place for each of these models, depending on the objectives of a particular collaboration.

International collaborations

135 Our embassies abroad need to continue to prioritise science and research. We support the UK Science and Innovation Network which is now co-ordinated within BIS. We welcome the RCUK's presence in emerging economies such as India, China; as well as their offices in the US and the UK Research Office in Brussels. We also welcome the EU Presidency's decision to appoint a Chief Scientific Advisor to the European Commission.

136 It is vital that the UK continues to maximise the value it obtains from both the EU Framework Programme and the EU Research Council, and that needs the UK to continue to play a leadership role in Europe.

The UK Science and Innovation Network

This was established by the FCO in 2000 in response to the growing importance of science, technology and innovation for our future.

The Network undertakes a wide variety of work and is one of the ways that Government demonstrates its commitment to a global platform for UK science.

The Network's purpose is to:

- promote scientific expertise
- strengthen UK innovation
- inform effective policymaking and leadership
- use science and innovation as an influencing tool

137 Government needs to decide carefully where best to place its resources in terms of international science and research. CST would like to see some form of market analysis on collaboration in research, to understand better the range of activities; what works best and least well in particular circumstances; where the focus should be over the next (say) ten years; and the benefits that accrue.

Pan university/departmental collaborations

138 We should like to see universities and research institutions themselves taking a more strategic approach by collaborating with other universities and institutions (and their leading researchers) in the UK, US, EU, China, India and other emerging economies. Collaboration at the level of the research group, or on broad themes, with different configurations of institutions on different topics, may be where the most promise lies.

139 Such collaborations will need to be at a much more strategic level than they already are, not least in terms of their being fewer, but at a deeper level, and at the departmental or institutional level rather than simply between researchers themselves. We do not underestimate the challenges – where competition rather than collaboration has historically been the watchword – and mechanisms will be needed to facilitate the processes. There is a need to avoid 'empty' international collaboration – both sides must be committed and university vice-chancellors must be supportive.

University Collaborations: Science Bridges

RCUK has announced £12 million of funding for collaborations between British universities and institutions in China, India and the US. Awards include a project by Manchester University and Boston looking into new healthcare technologies, a UK-China consortium looking at new developments in high-speed, secure internet communications and a UK-Indian research project involving Aston University which aims to deliver sustainable decentralised bio-energy for both the developed and developing world.

Cambridge-MIT Institute

The Cambridge-MIT Institute (CMI) was established in 2000 to explore how academics, industrialists and educators might work together to stimulate competitiveness, productivity and entrepreneurship. CMI has worked with over 100 universities and more than 1000 companies and public enterprises on projects involving education, research and knowledge exchange.

SET Squared

This is an enterprise and entrepreneurship collaboration between the Universities of Bath, Bristol, Southampton and Surrey. Amongst other services it offers technology entrepreneurs in Southern England a wide range of support to move them forward from initial ideas to becoming start-ups and then ultimately commercial viability.

140

Embassies and High Commissions, Science and Innovation attachés and the Science and Innovation Network, RCUK, UKTI, the British Council and individual universities will each have important roles to play in developing this new form of collaborative approach.

India's collaborative output by country

Collaborating country	1996-2000			2001-2005			Ratio 01-05 to 96-00	
	Coll. output with India	Total coll. output	India's % share of total coll. output	Coll. output with India	Total coll. output	India's % share of total coll. output	Growth in coll. output with India	Growth in India's % share of total coll. output
USA	4555	244911	1.9	7021	334662	2.1	1.54	1.13
GERMANY	1713	106821	1.6	3101	146615	2.1	1.81	1.32
JAPAN	1076	54346	2.0	2262	77197	2.9	2.10	1.48
UK	1369	97592	1.4	2253	144457	1.6	1.65	1.11
FRANCE	1036	82076	1.3	1530	107729	1.4	1.48	1.13
CHINA	404	25836	1.6	1127	54529	2.1	2.79	1.32
CANADA	627	55429	1.1	981	75659	1.3	1.56	1.15
AUSTRALIA	391	30743	1.3	776	46502	1.7	1.98	1.31

Source: Thomson Scientific[®] Inc National Citation Reports 2005

Evidence Ltd. India's national research performance and international collaboration. 2007

China's international collaboration

China is looking to transform itself into an innovation-orientated nation. China has recognised that this will not be achieved in isolation and consequently seeks international collaboration in most areas of R&D that will help policy makers, industry and communities meet the challenges of China's rapidly expanding economic and social development.

China's international research co-operation covers many countries. According to Thomson-Reuters, UK authors lead all countries apart from the USA in the number of papers published that include Chinese counterparts. A recent UK benchmarking study reported that joint papers with China accounted for 5.7% of UK papers, compared with a 1.9% share from joint papers with India. Research impact in 2008 for joint papers with China was greater than the UK average and slightly higher than those with India, but significantly less than for joint research with the USA or Germany⁵¹.

Several countries have set up joint research institutes – such as the Pasteur Institute and Max Plank Gesellschaft – and the Chinese Government regards these favourably as a strong signal of commitment to long-term research partnership. The UK's bottom-up approach is less amenable to this type of development, though some UK universities have struck major bilateral agreements directly with Chinese partners.

The new model for collaboration should encourage greater focus by universities on EU-supported research eg via the European Research Centre and through the Framework Programmes, where UK participation is under-represented given the strength and quality of our STEM base.

The UK signed its first science and technology agreement with China in 1978 and now pursues collaboration under several of these, ranging from space to co-operation with the UK Research Councils and agreements between individual research institutions. Every two years a Joint Commission chaired by Ministers brings together a wide range of stakeholders to review progress and agree priorities. Targets agreed at the Prime Ministerial/Premier level include doubling the number of joint research papers in the period 2008-2012 and increasing the number of R&D investments by 100. A joint Ministerial statement in 2008 emphasised co-operation on innovation and low-carbon technologies, and the principle of joint funding.

There are several major UK inward R&D investments in China, and small but rapidly growing Chinese R&D investment in the UK.

Collaboration between Government Departments

- 141 Planned expenditure by Government departments (including the NHS and Defence) on research and development for their own purposes is estimated to be £4.2 billions in 2008/09⁵².
- 142 CST is concerned that Government departments should have the necessary research capability to deliver their policies and address societal and economic opportunities and threats, and that departments adopt a joined-up approach on cross-cutting issues and minimise duplication. It is important that departmental expenditure on research is scrutinised to address areas where there are vulnerabilities, for example if health laboratories were to be cut back, and also to ensure value for money.

⁵¹ Evidence Ltd for Department of Business Innovation and Skills October 2009, International benchmarking study of UK research performance 2009.
⁵² Source: ONS Government R&D survey, SET statistics (April 2008).

- 143 CST therefore welcomes the *Science Review* programme⁵³ and the new Science and Engineering Assurance (SEA) Review programme.
- 144 We are concerned that policy objectives in the acknowledged 'big ticket' items that should cut across Government Departments are often not reflected in individual departmental research activities. Nor are they always joined-up or synergistic across Government departments; furthermore there are considerable gaps in funding in areas known to be of critical importance for the future. The area of intermediary processes needs review and reform.
- 145 Government has an important role in supporting potentially strategic areas where, for example, there is little or no Research Council funding and the UK has little or no research excellence. Examples might include environmental and health impacts of nanotechnology (where steps are being taken); or occupational health; or other examples of research which are important to the UK but where there is little academic activity. We believe that some of these areas are so critical to future developments, for example in nanotechnology, that Government should be stepping in either to fund the work itself or incentivising and persuading academia to do so.

⁵³ Science Reviews have been completed and reports published on eight departments: Department for Culture, Media and Sport (DCMS), Department for Environment, Food and Rural Affairs (Defra), Health & Safety Executive (HSE), Communities and Local Government (CLG), Home Office/Ministry of Justice (HO/MoJ), Department of Health (DH), Food Standards Agency (FSA).

7. Public engagement and public dialogue

Public engagement

- 146 A strong research base is increasingly important to the intellectual, social and economic vitality of a modern society. We are pleased that, through the media and a wide range of initiatives across the UK, awareness and pride in the achievements of research is widespread. We must continue to stimulate this awareness, pride and also involvement.
- 147 Over the past twenty years there has been enormous growth in 'public understanding of science', and the movement has shifted emphasis to encourage more two-way interactions, 'public engagement in science'. There are now many more science centres, festivals, cafés, popular science books, science and research on television and in the media and a growth in number and quality of science journalists.
- 148 We particularly applaud developments which try to join up the existing activity, and increase the impact. For example, the Science Media Centre plays a crucial role in helping science and the media have a more mature relationship, briefing journalists on topical issues, helping scientists respond. The Beacons for Public Engagement are experimenting with ways of shifting the culture in Universities to value researchers engaging with the public in impactful ways. Every year RCUK invests over £1 million to fund researchers to engage young people and schools with their research, reaching over 20,000 young people and 1,000 secondary teachers nationwide through a variety of projects.
- 149 However, there is a remaining need for further work in joining up the excellent work, to further increase impact and quality, without stifling the creativity of the many excellent people activities involved. There is a need to:
- focus better on audiences that are not the 'usual suspects'
 - make sure science and research is seen in its appropriate place, as part of our wider culture
 - ensure that engaging with the public is seen as a valued part of the role of Universities
- 150 The recent work that BIS is overseeing in five workstreams (Media, Science for All, Learning, Careers and Trust) is a potentially valuable process to give focus for some of the many different organisations and groups to pull together better. We look forward to seeing the results, as there is a need for better leadership and focus.
- 151 But both the strategic activity in the workstreams and the drive and focus on 'impact' from funders of science and research must be managed carefully, iteratively and in dialogue with researchers and the public and business.
- 152 Measurement of impact and quality is crucial, but is difficult and needs time to learn with the sector how to do it thoughtfully, and without making measurement too onerous an administrative burden. In order to retain the UK's strengths in creativity – in both research and in public engagement – these important and necessary drives for greater focus and measurement need not to become too top-down.
- 153 There is a need for supporting good leadership, not just at senior levels in HEIs⁵⁴, but at all levels, and within the public engagement sphere. Leaders of funding bodies, universities and departments and groups within them need the courage to use their values to define behaviour, not just be driven by what they are being measured by.

54 Higher Education Institutes.

Conveying the nature of science and research and 'experiences' of science

- 154 We should strive for a better, publicly-shared understanding of the nature of the knowledge that research confers, in addition to trying to show better how science and research is a part of our culture.
- 155 In engagement with the public, as with children in schools and students in universities, people need some experience and flavour of what real science and research is like: hands-on activity, practicals and projects with some open-endedness. We need to show better what researchers actually do; that research is a way of exploring what we do not know; of asking and testing questions; trying to solve problems; and that it is dealing with uncertainty.
- 156 There is a widespread misapprehension that research always gives unambiguous and definite answers. The misapprehension is serious, because although much science deals with things that are extremely well understood, although inevitably with residual uncertainty, many of the innovations in technology or scientific forecasts of risk that engage public attention lie at, or just beyond, the frontiers of what is currently known well.
- 157 We also need to show better that studying science can be a passport for a wide range of careers (something that '*Science – so what? So everything*' aims to achieve); and the many roles that researchers can play whether exploring and understanding the unknown, helping tackle societal problems, contributing to the economy.

Public dialogue about research

- 158 Many of the recommendations of our report *Policy through Dialogue* in 2005 are still valid.

Policy through dialogue – a report by CST

CST has advocated⁵⁵ that Government should adopt processes of deliberative public dialogue in the development of many of its policies and priorities, so that they are informed by public aspirations and concerns from the outset. It would involve a change in culture where dialogue is seen as a normal part of government's policy development processes on science and technology related issues, and would require:

- identifying issues where an investment in public dialogue is likely to bring benefit
- «clear definition of the purpose of dialogue and how it might be used in policy formation
- ministerial buy-in to the purpose of any dialogue process and commitment to explain how the dialogue has informed government policy or thinking
- collaboration with others, including Research Councils, universities, professional bodies and industry, to build a broad capacity to engage with the public through dialogue
- development of a corporate memory within government of dialogue processes based on formal and informal evaluations of dialogue processes that have been used to inform science and technology policy
- sharing of this information across government and its non-departmental public bodies
- appropriate means of governance and resourcing

⁵⁵ Policy through dialogue: informing policies based on science and technology; report by the CST March 2005.

- urgent need for greater collaboration by the research community to build a broad capacity to engage in public dialogue, and the need for this information to be shared widely across Government and its agencies.

RCUK has also provided a set of definitions⁵⁶.

159 There has been much progress since our report. Indeed, other countries are increasingly coming here to learn good practice. Some government departments, agencies and non-departmental public bodies (NDPBs – for example the Department of Health, FSA⁵⁷, EPSRC⁵⁸) have made impressive advances in shifting their culture to involve the public at many levels in their decision-making processes. The *Sciencewise Expert Resource Centre* has supported many departments and agencies running dialogue processes that have been evaluated well. They are doing some extremely valuable work on establishing a ‘*corporate memory*’, capturing and sharing good practice.

160 However, there is still much work for the ‘*change in culture where dialogue is seen as a normal part of government’s policy development processes*’; the need for *much greater collaboration by the research community as a whole to build a broad capacity to engage in public dialogue*, and the need for this information to be *shared widely across Government and its NDPBs*.

161 In addition, there have been some excellent public dialogues exercises carried out by government departments and others specifically on nanotechnologies (often as exemplar cases of tackling an emerging technology), and some real progress made and actions taken. However, some key themes still need some further attention, which have also been repeated by expert groups over the last six years⁵⁹. For example, research into health and environmental impacts of nano-particles still needs greater prioritising and funding (although some steps are being made). Even though such research is hard to get funded strategically, as responsibility is spread across many departments and agencies, it is important to tackle, if dialogue, expert group input and governance of science and research is to retain credibility.

162 The purpose of dialogue is not to determine but to inform policy. It does this by challenging the thinking of policymakers and scientists who contribute to policy making, as well as that of the public, stakeholders and special interest groups. Government must retain responsibility for decision-making⁶⁰.

163 CST conducted a review of progress last year, and looked at some case studies. Some observations we made are:

- Dialogue processes should be transparent, and records kept and made available on web-sites, to help the development of a ‘*corporate memory*’ wherever possible.

High turn-over of Government officials means that actual experience of running dialogue well is quickly lost from departments. The Food Standards Agency’s keeping of records, evaluations, recorded Board Meetings has helped them, and others, retain their learning about dialogue processes.

- Government should not do dialogue when decisions have already been made.

‘False dialogue is worse than no dialogue’.

56 Public engagement – an umbrella term for any Science in Society activities, from science communication in science centres or festivals to public dialogue. Any good engagement activity should involve aspects of listening and interaction; Public dialogue – deliberative participatory engagement where the outcomes are used to inform decision-making; Consultation – a formal process in response to policies/proposals.

57 the Food Standards Agency.

58 The Engineering and Physical Sciences Research Council.

59 Royal Society and Royal Academy of Engineering Report, 2005, RCEP report, 2009.

60 Recommendation 2 of our ‘Policy through dialogue’ report.

- Involve policy-makers in the process

Involving policy-makers in the events lends credibility to the process. It helps the policy-makers understand the process better, and allows them opportunities to explain the limitations they face.

- Involve scientists and researchers in the process

There are usually very positive descriptions of interactions between scientists/researchers and the public. If anything, evaluations from dialogues show that the public would value more access to more scientists, especially in small groups where questions can be answered in non-threatening ways. Scientists often emerge impressed, commenting on how thoughtful the public's discussions have been, and how well people have understood complex issues⁶¹.

⁶¹ in CST case studies and Sciencewise dialogues.

Annex 1

The risks of up-stream prioritisation

164 We are sceptical about prioritizing at the up-stream end of the R&D spectrum for the following reasons:

Unpredictability

165 The emergence of new understanding that is powerful in creating new market or social opportunities or identifying risk is highly unpredictable, and foresight exercises or assessments of technological potential have had a lamentable record of anticipating future developments only a few years away.⁶² Investing in a particular research area in the hope that it will be one of those to produce major medium – or short-term returns is thus highly risky.

Multi-disciplinarity

166 Many new and powerful applications are based on wide variety of disciplinary inputs⁶³. This adds another element of risk and uncertainty in making choices that explicitly favour one research area over another. It is crucial that science and research base retains vitality over the widest range of disciplines – the issue of capability. Critical diversity and capability can be as important as critical mass.

'Not invented here'

167 Ninety per cent of research is done outside the UK. The advances in research from which the UK has benefited and would hope to benefit in future will come from elsewhere. Engagement at the frontiers of research admits UK researchers to the international networks from which early warning of new discoveries come and confers the capacity to understand the significance of new knowledge, no matter what its source, and how that understanding might be exploited in the UK. If there are major gaps in the UK research tapestry that occur because of a policy of excessive concentration, we will be unable to benefit in the above fashion, whilst a policy that depends on buying in expertise from elsewhere is unlikely to plug the gaps. The decay of nuclear expertise for example has ensured that implementation of a new phase of nuclear power generation in the UK will be in the hands of overseas companies.

The time lag

168 Notwithstanding the high rates of return for public investment in science, such returns are not immediate⁶⁴. The seeds of current benefit were generally sown many years before, and the precise route to benefit was not clear when they were sown. If Government prioritises research where the lead time to benefit is predictable and short, by implication ones where market applications are obvious and returns relatively low, it risks jeopardising the harvest of greater returns from research that unexpectedly open up new and powerful possibilities. This does not mean to say that we should sit idly by waiting for the economic fruits of basic research to reveal themselves. Mechanisms that scan the output of basic research for application are crucial, but we should not measure its utility on too short a time frame. The benefits from research can still be large if a series of long-term investments come to fruition on a frequent basis.

62 For example, US President Roosevelt, in 1937, set up a Commission to advise on the most likely innovations of the succeeding 30 years. They not only identified many unrealised technologies, but missed nuclear energy, lasers, computers, xerox, jet engines, radar, sonar, antibiotics, pharmaceuticals, the genetic code and many more.

63 Lord Krebs in his evidence to the House of Commons Innovation, Universities, Science and Skills Committee (2008-09; HC 168-1) pointed to a study in which ten key advances in cardiovascular medicine were traced back to about 600 papers from different disciplines which provided the basis for the advances. Over 40% of them had nothing to do with cardiovascular medicine at all and many of them were not carried out in medical departments but in departments of chemistry, engineering, physics, botany, agriculture, zoology, etc.

64 Fundamental work on the biochemistry and cell biology of protein kinases was of no commercial interest for 25 years. Now, one in three targets being pursued by the pharmaceutical industry is a protein kinase and drugs like Gleevec have revolutionised the treatment of chronic myeloid leukaemia.

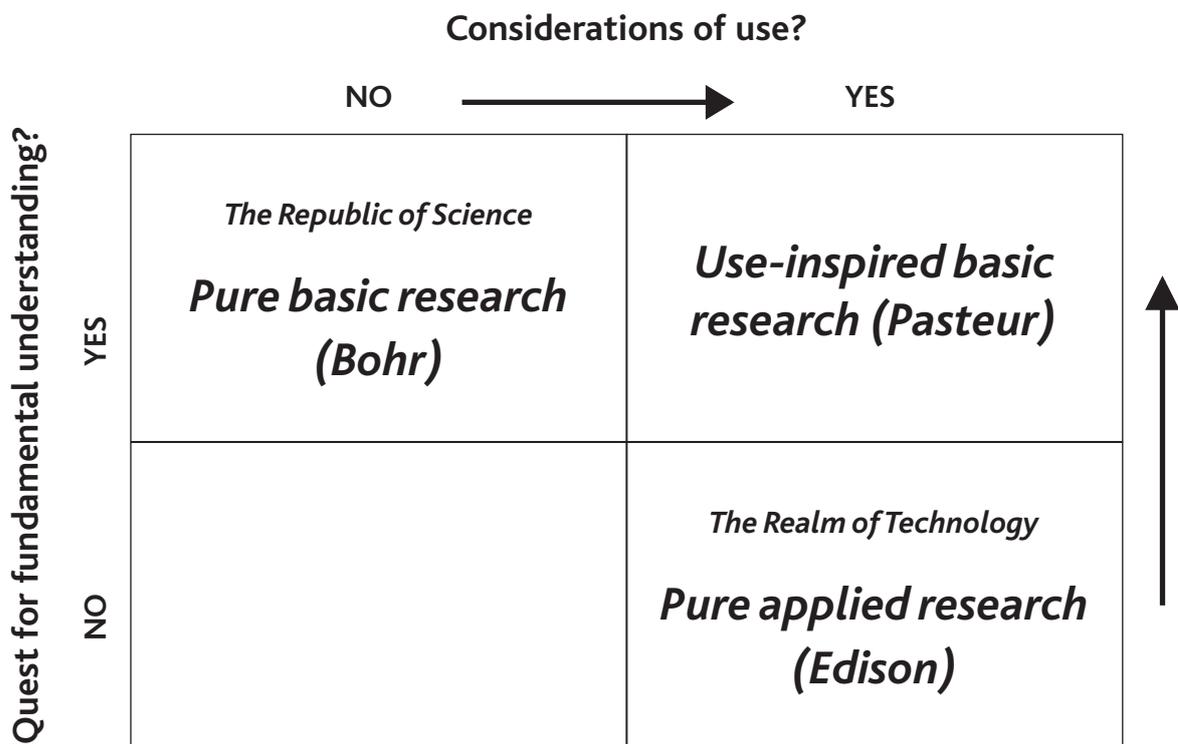
Annex 2

Measuring the Impact of Public Sector Support for the Research Base

169

Identifying the impact of research expenditure has on society is a complex task. The impacts include not only direct and indirect economic impacts, for example in terms of new ideas transformed into commercial innovations, but a variety of other impacts which affect much broader aspects of social and economic welfare. Nor is it only downstream research which is relevant. The nature of research activity is such that there is not a simple linear path by which upstream research is transformed into downstream research and then economic and social impact. Instead there is a reflexive system in operation in which there is an inter-play between advances both in downstream and upstream research activities. This has been captured in Stokes' Quadrant.

Chart 1: Stokes' Quadrant Analysis



Source: Adapted from D. Stokes (1997) *Pasteur's Quadrant* Washington Brookings Institution and Dasgupta and David (1994)

170

Research activities essentially driven by the pursuit of fundamental understanding are represented by the Bohr Quadrant. Research represented by a single minded pursuit of application is represented by the Edison Quadrant. A great deal of research, however, is carried out where both fundamental understanding and considerations of use are relevant. This is Pasteur's Quadrant. When academics are asked to self-classify their research activities, the vast majority allocate themselves into the user-inspired Pasteur Quadrant and the Edison quadrant rather than the Bohr quadrant. Transitions between the boundaries defining the quadrants are a feature of the research activity of many academics in the research community. The motivation to study "basic" problems is often driven by the identification of such problems in the course of developmental or "applied" research. This means that in assessing economic and social impact, the whole of the research base expenditure is relevant and not just that deemed to be applied or for which there appear to be immediate applications.

171

Assessing the returns to public sector support is difficult for a number of fundamental reasons. The first is that in relation, for example, to strictly economic returns, it is difficult to track

the role of a single piece of research. The process of innovation involves a distributed activity across many sources of knowledge within and beyond the research base itself. Singling out the contribution of a particular piece of research is therefore difficult. Secondly, the rate at which scientific and research advances may be converted into social and economic benefits varies enormously. It often involves very long time lags from initial research discoveries to translation into commercial reality. Finally, an assessment of whether public expenditure on research in a particular sector or country is yielding greater social and economic impacts than other competing uses must recognise that actors beyond the university system itself play the most crucial role in transforming ideas from the university system into economic and social outcomes. Supply push based on increasing the amount of research activity will not, by itself, engender social and economic returns. Complementary assets, motivation and capacities in the private or public sector must be there to capitalise and exploit the opportunities available. Demand-pull is equally, if not more, important than Supply-push in determining the extent to which a society benefits from the underlying investments in public sector supported research activity. A low return from research does not mean that the problem lies in the research base itself.

172 Notwithstanding these difficulties there is a great deal of evidence to show that there are substantial social and economic benefits from public sector support of the research base. There is also an increasing body of evidence to suggest that these gains go beyond the STEM subjects, and encompass activity in a wide range of disciplines. These benefits are also mediated through a very wide range of patterns of interaction between the research base and external organisations. These go beyond a narrow commercial focus on licensing, spin-outs and related commercial activities. Attempts to use large scale econometric analyses to estimate the impact of public sector research on international patenting, or the productivity, or overall output performance of economies all suggest positive returns from public sector expenditures. The most widespread results are reported in either relation to innovation capacity measured in terms of international patenting, or in terms of social rates of return to public sector support for R&D.

173 A wide variety of studies over many countries and different time periods support the view that the social returns to public sector support are high, varying between 20-57%⁶⁵. The social returns (measuring gains beyond those captured by market prices alone) exceed the purely private returns (which are captured by market prices). Similarly positive impacts are found in studies of patenting. The idea that social returns exceed private returns is generally explained by references to spillover or externality effects. These are effects whereby the benefits of new ideas cannot be wholly captured by the inventor or innovator. They lie behind most common justifications for public support for research. They also lie behind the justification for patent protection.

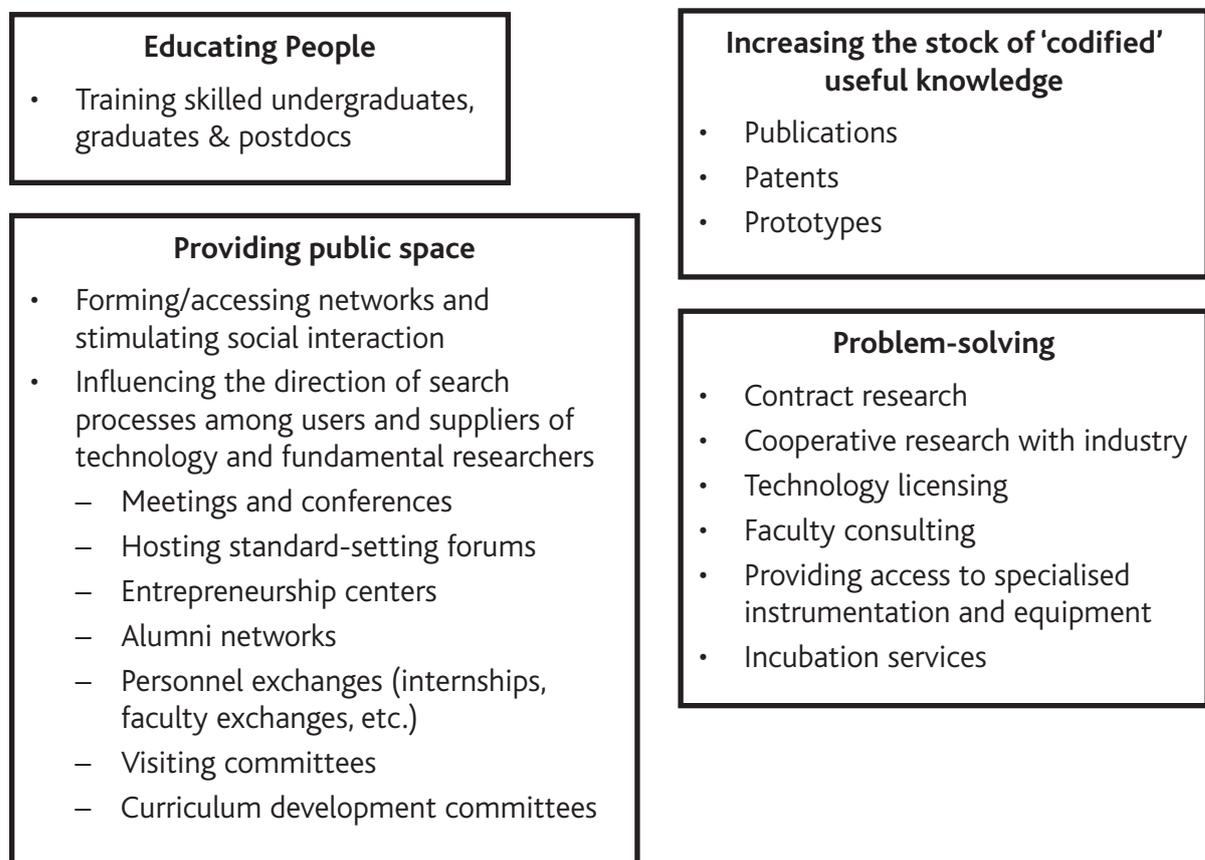
174 There are wide margins of error around these estimates and strong assumptions have to be made in estimating them. That positive benefits do arise is, however, reinforced by more detailed and qualitative assessments of returns achieved in particular industrial and scientific research contexts. For example, surveys of innovation managers confirm that significant numbers of innovations would have either not been introduced or would have been significantly delayed in the absence of prior academic research⁶⁶. The latter study suggests that 20% of private sector innovations involve some degree of public sector prior research activity. In a related manner a number of studies have revealed the steadily growing rate of reference to scientific papers in patent applications by private sector companies in the OECD economies. Whilst these patent related studies are more relevant for some industries than others, they represent an important indication of the relationship between commercialising activity and the underlying research base.

65 See for example Salter and Martin (2001); Martin and Tang (2006).

66 See Mansfield (1991, 1995, 1998; Beiser and Stahl (1999); Tysson (2002)).

This evidence on economic impacts says little about the mechanisms by which the identification and resolution and conversion to commercial practice of scientific and research base ideas is brought about. Further evidence is available to show that the routes by which university knowledge exchange with the private sector occurs goes beyond patenting under licensing of ideas. There is extensive survey based evidence to show that the pathways followed are extensive. They relate in important ways to informal networking, contract research, and codified outputs such as publications. Moreover, the transfer of people and the exchange of people rather than patent and licensing based transactions. It is helpful in tracking these pathways to bear in mind the multi-faceted role which universities play in the production of knowledge and knowledge exchange. Chart 2 provides a breakdown into broad categories of the potential dimensions of interaction between the research base and external organisations. It focuses on links with commercial applications, but the same principles would apply to wider social interrelationships with not-for-profit third sector and public sector organisations.

Chart 2: The multi-faceted Role of Universities



Source: Cosh, Hughes and Lester (2006)

- 176 There are four broad categories. The first of these relate to the conventional role of universities in the provision of skilled and educated individuals. Since virtually all academics in the UK combine both teaching and research in their activities, the link between research and the quality and nature of the teaching provided must be recognised as a benefit of research. The second box contains what are normally considered as the conventional codified outputs of the research process in terms of publications, patenting and increasingly prototyping. The third box represents a long-established and well developed route by which knowledge exchange takes place and is represented here by problem-solving activities. This includes a wide range of contracting, consulting and support service activities, including the provision of specialised equipment which the university sector is capable of carrying out. The final box identified as the provision of “public space” represents the fundamental role which universities can play in linking together potentially disparate elements in the knowledge exchange process. The provision of public space is an arena in which individual businesses, academics, representatives of the public and third sectors can interact. This interaction helps to identify and to find routes to solving common problems and exchange knowledge. It is an important aspect of the many routes by which benefits can be gained from the public support of the research base.
- 177 There is now extensive evidence based on the reported activities of academics and the views of businesses as to the importance they place on these different pathways⁶⁷. It suggests that there are substantial benefits to the private sector and the public and third sector from the funding of the research base. For example, businesses seek and value support for their activities which go far beyond technological knowledge exchange. Universities are valued for the contribution they make to the whole of the business value chain, from the provision of support for human resource development, financial and strategic planning and the quality of service provision, in addition to technology specific advice and support⁶⁸.

67 See for example Abreu, M., Grinevich, V., Hughes, A. and Kitson, M. (2009) Knowledge Exchange Between Academics and the Business, Public and Third sectors Centre for Business Research University of Cambridge.

68 See for example Abreu, M., Grinevich, V., Hughes, A., Kitson, M. and Ternouth, P. (2008) Universities, Business and Knowledge Exchange. Council for Industry and Higher Education and Centre for Business Research London and Cambridge. HEFCE (2009) Evaluating the Effectiveness and role of HEFCE/OSI Third Stream Funding: Culture Change and Embedding Capacity in the Higher Education Sector Toward Greater Economic Impact. A Report to HEFCE by PACEC and Centre for Business Research. D'Este, P.D. and Patel, P. (2007), 'University Industry linkages in the UK: What are the factors underlying the variety of interactions with industry?' Research Policy, 36, 1295-1313.

