Impacts of Investment

in the Science & Engineering Research Base

Campaign for Science & Engineering in the UK

CaSE Policy Report **Number 10 September 2009**

CaSE is a membership organisation that works to ensure that science and engineering are high on the political agenda and that, through the implementation of appropriate evidence-based policies and adequate funding, the UK has world-leading research and education, skilled and responsible scientists and engineers, and successful innovative business.

This report stems from a CaSE *Opinion Forum* meeting in January 2009. We thank IBM for their generosity in hosting this event. CaSE further developed ideas with a range of representatives from companies, higher education institutions, learned societies, government departments and others. The specific views expressed in this policy report are the responsibility of CaSE.

Contents

Overview

Investment in the science and engineering research base generates a wide range of benefits. Some of these are outputs that can be easily quantified such as publications, spin-out companies, private investment in R&D, and training the workforce. Many valuable impacts are less easily counted like benefits to health, security, policy development, quality of life and culture.

■ Investing in the science and engineering research base - research conducted in universities and research institutes - should play a critical part in rebalancing the UK economy following the economic downturn. Different research projects produce different profiles of benefits, but overall the return on investment is considerable and reliable. Unfortunately, the UK does not fare well in international comparisons of public or overall investment in R&D, both historically and following the recession. The UK must increase its public andprivate levels of R&D investment and genuinely try to reach its target of 2.5% GDP.

■ More can be done to maximize the benefits of ongoing research. The best way to enhance the impact of new knowledge is to ensure that it is fully communicated and developed into innovations and new products where appropriate. A range of initiatives to enhance knowledge exchange, collaboration, and translational research are now in place. But academic culture needs to value this work more - this could be achieved at the institutional level and through learned societies.

■ Strategies intended to increase impact are often based on measures of prior impact or predictions of future impact. These should be applied with caution and not used to compare value across sectors. Different time scales, units of measurement, intangible gains, and levels of predictability make it hard to measure past performance, let alone assess the likely success of future work.

■ The breadth of research across science and engineering, ranging from basic to applied research, is one of the UK's competitive advantages. It enlarges the sectors that can attract internationally mobile industry investment, students, and researchers. It also enables the UK to gain more from research done overseas. A diversity of disciplines and approaches can foster innovation and provide the security to respond to unknown future challenges and opportunities. Any strategies to improve impact must not jeopardise this breadth.

■ Improving the "pull" through of research from users will improve impact. Pull from industry should increase with greater knowledge of ongoing work in the research base. It can also be advanced by various policy levers, including departmental R&D, procurement, regulation and taxation, and strategic support, such as through the Technology Strategy Board. These activities can be used to improve framework conditions in strategic areas likely to support economic growth.

The impact of the research base can be improved without undermining its role of providing the breadth of skills and knowledge across disciplines, the base upon which others can build. The current Science and Innovation Investment Framework has been effective in improving the sustainability of the science and engineering base. But it is now time to plan for the next ten years of science policy, putting decisions about the research base into a wider context that includes government departmental R&D, the work of research charities and factors affecting private investment in R&D. The government should commission evidence and analysis, including of the effectiveness of previous strategies, and engage in full consultation to improve future policies and investment.

Sponsored by:
IOP Institute of Physics

Benefits of the Research Base

Training the future workforce
Highly skilled scientists and engineers are one of the most predictable and rapid outputs of the research base and one that is highly prized by industry.[1] They carry with them tacit knowledge - skills and experience - which in turn creates impacts in public or private research and is highly-valued in other sectors too.

Enlarging the stock of useful knowledge
Codified knowledge can be quantified and the UK performs well, estimated to be second to the US with 9% of the world's publications, 12% of world citations, and 13% of most highly cited papers.[2,3] Although knowledge is often accrued fairly systematically, there are leaps in understanding which cannot be conveyed by numbers, nor do these measures capture the value of applications developed through engineering.

Giving breadth of research across disciplines
Multidisciplinary approaches are needed to address societal challenges such as climate change and breadth readies us for unexpected future challenges. Underpinning disciplines such as mathematics must be maintained and the range of disciplines produced brings the innovative potential that comes from different perspectives. If research funding is depleted in a particular area, it will become more difficult to provide the corresponding education. Breadth also expands the areas into which industry is likely to invest and in which the UK can gain from overseas research. The breadth of the UK's research excellence is a real strength; it ranks in the top three in seven out of nine research fields, as judged by citations per publication.[4,5]

Providing a public good
Private investors will under-invest in areas of research where there is uncertain anticipated utility. Even if the work is successful, the original researcher rarely gains from such research, because of the time scales involved, the open dissemination of knowledge and the development work required. The extent to which this is true varies across sectors with, for example, the basic research underlying drug development or biotechnological advances being more expensive and high risk than that in IT. Public funds are also needed for work that benefits society, for example in defence or health, but would not benefit private investors.

Enhancing industry
Overall, public research enhances and increases private investment in R&D (see page 6) in the following ways.[6]

- *Improving instrumentation and methodologies, and the performance of existing businesses.* Firms that are more innovative and high-value tend to work closely with universities.
- *Driving industry with the needs and findings of researchers.* Around a quarter of innovative UK businesses recognise their use of information from higher education institutions (HEIs) and a quarter use information from government or public research institutes. Public research encourages firms to engage in more collaborative R&D, intensifying existing partnerships and initiating new ones.[7]
- *Producing spin-out companies.* In 2006/07, 327 spin-offs were formed from publicly funded research. From 2003 to 2007, 31 HEI spin-offs were floated on stock exchanges with an initial public offering of £1.5 billion and 10 were acquired for a total of £1.9 billion.[8]
- *Forming international networks and stimulating interaction.* Researchers form an "invisible college" of peers, enabling knowledge exchange and providing a base of expertise that can be efficiently tapped by industry.

Increasing absorptive capacity
Researchers in the UK gain most from the work of others if they have developed their own skills and knowledge by conducting comparable research themselves. The fact that countries with higher R&D intensity are better able to gain from foreign R&D shows the importance of this absorptive capacity.[9]

Attracting students, researchers & investment
The research reputation of our HEIs attracts UK and overseas R&D investment and also overseas science, technology, engineering and mathematics (STEM) students - about 50,000 in 2006/07. These students bring a wide-range of cultural and scientific benefits and contribute billions to the economy.[10] The funding and freedom of the research base are key factors in attracting highly-mobile international researchers.

Quality of life
Research impacts across our lives, from health and well-being to defence and security. The cultural impact of knowledge ranges from pleasure derived from understanding the world around us, from the structure of DNA to images of the surface of Mars, to fascination at the historical path that scientific discovery has taken. Such knowledge can be highly motivating for students. In 2006/07, nearly 650,000 people attended free lectures at HEIs, around 110,000 paid to attend lectures, and over 1.4 million people attended performance and exhibition events.[11] Cultural enjoyment can also generate revenue, for instance, from entrance fees to events or sales of relevant TV programmes or books.

The government has a pre-eminent role in funding the research base to build up its strength and retain elements unlikely to be funded by other sources. The research base is so called for a reason; it provides the skills and knowledge across the disciplines, the base, for investors to build upon.

Investment in Research

The UK research base consists of research conducted in HEIs and other research institutes. It is just one fraction of R&D performed in the UK - 31% in 2005, compared with 62% by industry, 6% by government departments and 2% by charities.[12]

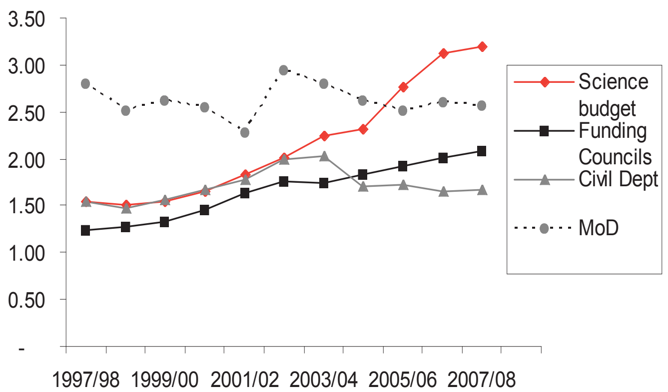
Government investment in the research base has been through the dual support system:
- Science Budget, mainly administered by research councils across the UK for specific projects - £2.9 billion in 2005/06 (including £200 million for arts, humanities, economic and social research). This has been guided by the Ten Year Science and Innovation Investment Framework (2004-14).
- Block grants from the regional higher education funding councils for research and infrastructure, £1.9 billion in 2005/06.

Non-government funding for the research base comes from a range of sources, including companies (£290 million in 2005/06), charities (£783 million in 2005/06), European Union (£280 million in 2005/06), and overseas (£213 million in 2005/06).

Growth in Research Funding

Figure 1 shows the pattern of government spending from 1997 to 2009. The doubling of the science budget over this period was vital following previous sustained under-investment - while not belittling the gains, it is important to appreciate that the baseline was low. Over the same period government departmental spending has been flat. While findings from the research base may feed into public policy, government departments should be funding much more research conducted primarily for this purpose.

Figure 1. *Net Government spending on R&D in real terms, £ billions.*



Source: SET Statistics DIUS, 2008, Table 3.2

The government has delivered sustained increased funding to the research base over the last ten years. However, departmental R&D spending has not gained. The roles of the different funding streams need to be clarified.

GDP Targets & International Comparisons

Other countries' spending should guide UK levels. The EU has a target of 3% GDP to be spent on R&D from all sources. The UK government has set a lower target of 2.5%, arguing that the UK has many industries that are typically low investors in R&D. But the situation is not helped by the fact that UK public investment is at the bottom of G7 levels, at 0.52-0.57% GDP over the decade up to 2005.

In 2006, the UK spent 1.78% GDP on R&D. This was second lowest out of the G7 countries, dwarfed by the 3.4% spent by Japan, 2.7% by the USA and 2.5% by Germany. This pattern will change with recent economic events as GDP changes and different countries invest in R&D to a greater or lesser extent. Earlier this year, the USA committed to spend 3% GDP on R&D and Australia increased its spending by 25%.

Public investment in R&D must increase to keep the UK up with its competitors. This will help maintain our attractiveness to internationally mobile researchers and business research investment. The government must work harder to achieve its goal of 2.5% GDP invested in R&D. OECD analyses suggest that increasing public funds can lift industry investment.

Investing in the Recession

Public research investment is even more important during the recession as R&D funds from charities and industry are falling.[13,14] OECD analyses of international responses to the economic crisis show how limited the UK's financial and revenue support for R&D is. The importance of funding long-term riskier research, start-ups, and research on societal challenges is noted.[15] The low success rate of grant applications to research councils (see page 4) suggests that more research could be funded without compromising on quality.

The government needs to build upon the breadth and excellence of the research base during the recession as other funding sources decline. Government funds are needed to support research that is unlikely to attract private money at this time.

Principles of Science Policy

Lord Drayson, Minister for Science, has outlined five principles for funding the science budget:
- Maintain the investment in science.
- Focus on excellence.
- Maintain investment in pure, fundamental science as well as in applied science.
- Maintain a broad base in science.
- Follow the Haldane principle.[16] Value peer review.

Research Council Funding Patterns

Research Council Grant Success Rates

Despite increased funds available, between 2003 and 2008 the success rate of grant applications halved from about 40% to about 20%.[17] This cannot apparently be wholly explained by higher numbers of applicants, more expensive grants, or the move to paying the full economic costs of grants. The decline in success rates is demoralising and means that it is hard to find funding for high-risk research. Low success rates may have led to the perception voiced by many academics that basic and responsive mode research is falling out of favour.

The research councils need to analyse why grant success rates have fallen so dramatically. They must be improved or only very safe research is likely to be funded and excellent researchers may work elsewhere.

Directed vs. Responsive Mode

Over recent years, the research councils have raised the profile of funding delivered in directed mode to particular challenges, rather than in responsive mode as proposed by researchers. Most recently, the research councils responded to the Treasury's grand challenges by setting up six cross-council funding programmes reflecting them: energy, security, ageing, living with environmental change, digital economy, and nanoscience. The 2008 science budget allocation was based on research councils' performances and on their delivery plans which included how they would invest in these programmes.

Data presented in Table 1 show that between 2004/05 and 2007/08 the proportion of funding spent in responsive mode dropped in two research councils - the Biotechnology and Biological Sciences Research Council (BBSRC) and the Engineering and Physical Sciences Research Council (EPSRC), but increased in the other two for which data are available: the Medical Research Council (MRC) and the Natural Environment Research Council (NERC). Between 2004/05 (or 2005/06 for MRC) and 2007/08 the overall allocation barely changed - from 67% to 66% responsive.

Table 1. *Funds (£ million) allocated by the STEM research councils in directed or responsive mode.*

		Directed	Responsive	%Responsive
BBSRC	2004/05	34.9	110	76
	2007/08	60.8	143	70
EPSRC	2004/05	171	230	57
	2007/08	263	310	54
MRC	2005/06[a]	24	133	85
	2007/08	14	176	93
NERC	2004/05	24.7	53.4	68
	2007/08	26.4	74.7	76

Source: Research Council annual reports collated by RCUK Strategy Unit, no data for Science and Technology Facilities Council.
[a]No data available for 2004/05.

Basic vs. Applied

Basic research is aimed at understanding the foundation of phenomena and observable facts, with little application in mind - it is also called curiosity-driven, blue skies, fundamental or pure research. In contrast, applied research is primarily directed towards a specific practical aim or objective, although these areas can overlap (see Table 2). According to Frascati definitions, in 2005/06, research councils spent 68% of their funds on basic research up from 60% in 1997/98, and this increase occurred in pure-basic research rising from 21% to 37% over that period (these data include non-STEM research).[18]

Either the data in both tables are misleading, or researchers perceive threats to responsive and basic research that are simply not there. In any case, interviews with scientists suggest that, to some extent, the terminology they use to describe their work changes more than the projects themselves.[19] Calling research basic can guard against demands for early results, but re-branding it to highlight any future potential for impact, can help secure funding.

Data on the funding of different sorts of research should be better monitored and communicated. There needs to be consistency and clarity in how terminology is applied. It is essential to maintain a broad portfolio of research.

Table 2. *Percentage of Research Council expenditure by research type*

Research type	Summary of Frascati definition	1997/98	2005/06
Pure-basic	No goal of long-term economic or social benefits, no effort made to apply results to practical problems or to transfer them others to apply	20.9%	37.1%
Orientated-basic	Intended to produce a broad knowledge base likely to form the background to the solution of known or expected problems or sibilities	38.9%	31.0%
Strategic-applied	Eventual applications cannot yet be clearly specified	31.2%	25.0%
Specific-applied	Aimed at specific and detailed products, processes, etc.	8.2%	6.0%

Source: SET Statistics Department for Innovation, Universities and Skills, 2008

The Economic Impact Agenda

The government is seeking a step change in the economic impact of the research base, based on the assumption that the UK, like most of Europe, is good at research but not at using it.[20]

The Treasury Green Book (2003) defined economic impact to include gains that were *"less quantifiable, such as effects on the environment, public health and quality of life"*. Unfortunately, this definition was not in the latest version.

The research councils describe impact as: *"the demonstrable contribution that excellent research makes to society and the economy... all the extremely diverse ways in which research-related knowledge and skills benefit individuals, organisations and nations by:*
- *fostering global economic performance, and specifically the economic competitiveness of the UK*
- *increasing the effectiveness of public services and policy*
- *enhancing quality of life, health and creative output."*

But the research councils lapse into different terminology for their Economic Impact Reporting Framework even though this includes both codified and tacit knowledge.

Using "economic impact" as an umbrella term can be confusing and divisive. Better to use "impacts" or specify the impacts more clearly.

It is entirely reasonable for the government to ask funders to monitor the impacts of their investment.

Demonstrating the worth of research can help to justify funding to the general public who invest either indirectly, in taxes or the revenues raised by companies, or directly, for example, through charities. Such justifications should also convince politicians of the case for the government funding of science and engineering. Better understanding of the processes by which impacts are achieved may indicate ways to improve them.

It is hard to quantify the value of preventative research even though such benefits can be huge. For instance, NERC notes that its data inform when to raise or lower the Thames Barrier saving an estimated £30 billion, plus the cost in human lives.[21] But these gains could be missed by most numerical analyses.

The value of research that prevents loss rather than produces gain must be recognised.

Measuring Impacts

Pathways to impact

The route from research to impact is not a linear "push", in which investment is transformed through research into new knowledge which leads to benefit through innovation, technological development or policy implementation. Many major breakthroughs have occurred through a combination of serendipitous observations and having researchers curious and free enough to explore them.

The inputs to research are funding and all the skills and knowledge generated from prior research. The impacts of research are said to "spillover" to benefit others that did not conduct the research in numerous ways. This breadth of inputs creates an attribution problem for any outcomes. Similarly, successful innovation depends upon many other conditions being met that have the potential to escalate or limit impact. There can also be a "demand-pull" from industry or research that is responding to particular needs.

These interwoven factors play-out in an international research environment, with UK research drawing upon and contributing to a global research effort.

It is extremely hard to quantify all the training, knowledge and funding inputs and final products of research to calculate a numerical return.

Government Measures

The government would like to know the impact of its research investment with the Treasury commissioning work on this from the Science and Technology Policy Research Unit.[22] The government now publishes figures on *Economic Impacts of Investment in Research & Innovation* many of which are cited in this report. Again, these "economic" indices include wider impacts.

Case Studies

The research councils now produce analyses of the impacts of their work, including many case studies.[23] These incorporate non-economic and global benefits.

A forthcoming Russell Group report describes the impacts of over 100 case studies from research-intensive universities.[24] The report argues that basic research produced greater financial benefits than applied. It highlights how hard it would have been to predict which work would yield the greatest financial gain let alone societal benefits that are less easy to quantify. In contrast, a report looking at more modern, less research-intensive universities emphasised their strengths in applied, practice-based, and policy research and their impressive level of interaction with, and income from, industry.[25]

Case studies often demonstrate the impressive outcomes that can be achieved from research but their selection criteria must be transparent.

Measuring Impacts continued

Sector Studies

A recent analysis of UK public and charity-funded medical research addressed many of the limitations of earlier work.[26] It compared investment from 1975-1992 with the reduced costs of care and increase in quality adjusted life years. The internal rate of return (IRR) for cardio-vascular research was estimated at 9% after 17 years (i.e., £1 invested gave an annual benefit of £0.09 for the foreseeable future) and for mental health, 7% after 12 years. A review of recent literature estimated an additional IRR of 30% (range 20-67%) from direct or indirect GDP gains, including spillover into other sectors or other parts of the economy, bringing the total IRRs up to 39% and 37%.

The methodologies for measuring impacts have improved but depend on many assumptions. These measures should not be used to compare performance across sectors with different benefits, assumptions, units of measurement, and timescales. Knowledge of past returns gives only limited insight about future returns because they occur in different research environments and wider contexts.

Impacts on Industry

Most evidence shows that public R&D helps generate private R&D, and vice versa, and that both have an independent effect on growth (as does foreign R&D).[27,28] Some studies have not found a positive correlation between public and private R&D leading to a fear that public R&D could "crowd-out" private, but these studies tend to have limitations.[29] The spillovers or social return of private R&D are around 30-40% (depending on sector, country etc.) but could be higher and seem to be greater than the rate of "private return" to the investors, of around 20-30%.

Publicly funded research can increase private investment, which in turn benefits the public more than the private investor. Regulation and incentives to enhance private investment, such as R&D tax credits, are thus well justified. Ensuring that there are plenty of skilled workers should help prevent crowding-out effects.

Analysis of the US pharmaceutical industry found that a 1% increase in public *clinical* research lifted industry R&D by 0.40% after 3 years; a 1% increase in public *basic* research lifted industry R&D by 1.69% after 8 years.[30] Given that industry spending was five times greater than public spending, this multiplied up to over 8%. Notably, the impact of basic research had a U-shaped relationship with time, greatest 1, 2, 7, and 8 years after it was done. The initial impact might reflect firms incorporating new information and building absorptive capacity, the decline may reflect market uncertainty with investment picking up when this had been resolved. Assessing the impact of basic research too early would have seriously underestimated it.

These data provide evidence for the argument that basic research has more impacts over time. It may take time to recognise or find a use for new findings - particularly for serendipitous discoveries - sometimes because the market does not exist at the time of discovery. Or it can take time to conduct the experimental and development work; it took an average of 9 years from an initial discovery to produce a license or other measurable impact (e.g., significant commercial investment in a spin-out company) in an analysis of over 100 UK case studies.[31] It is estimated to take 18 years for investment in basic pharmaceutical research to yield product approval in the US.[30]

Evidence shows that premature assessment of the impacts of research can lead to a lower evaluation of research that yields more long-term gains, typically basic research, even though it can be more beneficial in the long run.

CERN shows the ways in which science and engineering research can affect industry.[32,33] The spin-offs from this work on particle physics have yielded varied benefits and industries with CERN contracts have been estimated to gain triple the contract value in turnover and savings.

Participating in international projects benefits the UK by training and networking researchers, winning international contracts, and by the discoveries made. The government should take steps to ensure that international projects locate in the UK to bring more localised spill-over benefits.

International Aggregate Analyses

Multifactor productivity (MFP) reflects the extent to which an economy has increased its ability to derive GDP growth from a certain level of labour and capital. Research and innovation raises MFP in various ways, like improving the efficiency or the productivity and skills of the workforce. A 2004 OECD analysis estimated that a 1% increase in business R&D increases MFP by 0.13% and a 1% increase in public R&D increases MFP by 0.17%.[34] This sort of analysis should capture all the gains with any eventual economic impacts in the time period examined, however, it cannot tell us much about how these gains are reached.

The true impacts of the research base can be best conveyed by a narrative description supported by quantitative measures where appropriate. The goals of any more quantitative analyses should be clear and the resources allocated to such analyses should be proportionate. It may be sufficient to collect detailed data from just a sample of projects.

Strategies to Increase Impact:

1. Focus Funding on Priority Areas

In response to the recession, the government proposed focusing research funding into priority sectors. The exact implications of the proposal were never made clear, but discussion included the re-direction and concentration of funds rather than an injection of new money. Lord Drayson's proposed criteria for prioritisation were areas where:

- the UK has a competitive advantage,
- growth is anticipated over the next 20 years, and
- the UK has potential to be a world leader.

These criteria echo those of the Foresight project initiated by the Conservative government in 1993. More recently, the Council for Science and Technology looked at technology-priority setting in 2007. It argued that priority areas should not be supported at the expense of others. The 2009 budget announced that £106 million of research council efficiency savings would be re-invested into areas with economic potential. The areas identified were the same as those in the government's industrial strategy published a month earlier.

There has been little discussion of the trade-offs inherent in focusing research funding in some areas at the expense of others. The problems include:

■ It is hard to predict which areas of research will have greatest impact.
Using retrospective analyses to assess which areas have been high-impact in the past will draw money into areas that are easier to assess, often those that operate on shorter time scales. Even if a particular sector has done well in the past it does not mean that it will do so in the future as the context of research and the wider environment evolves. Identifying growth areas has not proved very successful in the past. For instance, in 1986, an advisory council to the government produced a list of research areas likely to produce key developments in communication technologies.[35] They did not identify particle physics research as one although it spawned the World Wide Web just a few years later, in 1989.

■ It is also hard to know in which sectors the UK can lead the world.
This is particularly true when the world is as economically unpredictable as it is now with emerging economies, such as China, and other countries, notably the US, spending funds that would dwarf the whole UK science budget even if the latter was entirely focused.

■ The research base needs breadth.
The current breadth of the research base gives the UK strength: it is better placed to address unexpected future challenges; it can attract students, researchers and investors in across a range of disciplines; and it advances innovation. Once resources drop in an area it is difficult to build them back up again to respond to emerging challenges or technological opportunities. For many researchers, their work is a passion and they will not respond to government incentives to change direction - if they cannot pursue their chosen work in the UK they may change country or career rather than research direction.

■ Students must not be discouraged from STEM.
Just when the numbers taking STEM are showing signs of improving, students must not be put off because they see little support for their area of interest. Many students are particularly excited by space and particle physics, areas perceived to be at threat by current spending plans.[36]

Even if it were possible to predict the research areas that would yield the greatest short-term economic return, reducing funding in other areas could bring significant long-term scientific and economic risk. The other functions of the research base, including training and the security to respond to unexpected future challenges, must be sustained.

It can be appropriate to have strategic efforts to achieve important research goals, for example, coding the human genome or understanding climate change. The research councils already focus efforts by direct funding to six cross-council programmes. It would be wise to see how effective the programmes are before reorganising further. We are not aware of evidence that further focusing is necessary or would be beneficial.

Indeed, an alternative approach might be to invest in weaker areas to increase the breadth of excellence and the potential for interdisciplinary collaborations. Interestingly, one of the goals of the Science and Innovation Investment Framework 2004-14 was to improve the health of key disciplines especially where the UK was relatively weak.

Any measures to try to improve short-term economic growth would be best placed upstream of the research base using a variety of levers such as procurement, regulation, facilitating collaborations and providing financial support for R&D investment, demonstration projects and public engagement. The Office of Life Sciences was developed to co-ordinate government efforts along these lines. If it proves successful the model should be rolled out to other sectors.

The government should analyse previous attempts to pursue a policy of concentrating resources and commission research from experts. There should be a proper debate, consultation and evidence gathered to examine the implications of different funding strategies in advance of spending reviews.

2. Funding Councils Invest in High Impact Departments

Another strategy to improve impacts might be to weight funding towards research groups with a proven record of high impact work. Anticipating these rewards should motivate current researchers to enhance their impact. Also, groups that had high impact in the past may be more likely to do so in the future. This approach is being developed in the Research Excellence Framework (REF), which will form the basis of how quality related money is distributed by funding councils to HEIs. The REF is intended to take greater account of the impacts of research than its predecessor, the Research Assessment Exercise (RAE).

The quality related money allocated following these assessments is intended for research as well as infrastructure although it is actually delivered as a block grant to each HEI to distribute among its departments as it sees fit.

In 2005/06, the quality related money distributed for natural or medical sciences or engineering across all the regions totalled £1,279 million out of £1,928 million for all subjects.

The Research Assessment Exercise
The quality of departmental research has been assessed periodically through the RAE. Assessment of research outputs has been done by disciplinary panels that mostly looked at published papers in the sciences with greater emphasis on other outputs in engineering and computer science.

The RAE process has been a driving factor in shaping researcher and institutional behaviour. For instance, publication in internationally acclaimed journals is highly rewarded and has therefore been encouraged. This means that research has needed to engage an international audience, possibly discouraging researchers from looking at problems more relevant to their local area. It may also mean that research is published in journals that do not reach practioners in the field.

There are other issues. The need to bring a track record of publications makes it hard for researchers to move between industry and academia. The pressure to publish has also meant that other activities like engaging with policymakers, industry or the public became less rewarded. Also, the need to produce outputs within the assessment cycle favoured incremental projects. It has been estimated to take around six years for investment to fully impact on the number of publications and seven years for citations.[37] Other outputs and impacts may take much longer. For instance, the mean time between publication and incorporation in UK clinical guidelines is eight years, with a quarter of papers being over ten years old, and 4% being more than 25 years old.[38]

The Research Excellence Framework
The REF will be considered here although it is still under development. It is set to assess contributions to economic, social, public policy, cultural and quality of life impacts as well making greater use of metrics than the RAE. It is to be welcomed that impact will be judged in these broad terms. Which of these elements are employed, and the balance between them, should vary across subjects but departments will be expected to submit a portfolio of research that includes work with demonstrable socio-economic benefits.

Using retrospective assessment to reward those who have acheived impact may be a good strategy. Measures must be fully adapted to individual disciplines, allowing for different time scales as well as different outputs. The exercise should not be extrapolated to compare value across disciplines. Expert judgement should ultimately be used to interpret metrics and other information submitted.

It is proposed that departments will provide a narrative backed by indicators and case studies of the impacts achieved in the assessment period. The impacts must be linked to high quality research and its application, but that research could have been done in the given department at any time (even if the researcher has moved on). The linking of impacts to high quality research seems to require assessment of research quality outside the timeframe of the given period - it is not yet clear how this will be achieved. Note that under current proposals very high impact work that is not recognisably excellent would not be valued in the impact assessment. Having the departments rather than the researchers receive credit for impacts must not lead to departments discouraging their current researchers from deriving impact from work that they had previously conducted elsewhere.

Expert groups will include user representation to consider the impacts. The make-up of these users will clearly be critical and they must be able to appreciate the breadth of impacts to be assessed.

New policies must be fully analysed to make sure that they will not create unwanted behaviours, do not conflict with other goals, and do not cause an administrative burden greater than their gain.

It is promising that some of the problems with the RAE may have be addressed in the formulation of the REF. These include explicit recognition of a broader range of impacts and flexibility for these to be included over a longer time period of assessment.

3. Research Councils Fund Projects on Impact Characteristics

RCUK, the umbrella body for UK research councils, has embarked on a number of efforts to facilitate knowledge exchange and increase impact. The Warry report of 2006 initiated many of these, including the somewhat contentious recommendation that economic impact (as defined in page 5) should be taken into account for funding decisions and that peer review panels should include experts at assessing this.[39]

More recently, in its 2008 Statement of Expectation for Societal and Economic Impact, RCUK argued that researchers and universities have *"considerable flexibility and autonomy"* and should demonstrate a range of impacts in return including the following.[40]

- engage with the public about research and its implications
- identify potential benefits and beneficiaries through the full project life cycle
- publish results widely to academic, user and public audiences
- exploit results to secure social and economic return to the UK
- develop staff and student skills
- curation, management and exploitation of data

By April 2009, all the research councils required grant applicants to produce an Impact Summary, and some a longer impact plan, answering the following questions:

- Who will benefit from this research?
- How will they benefit?
- What will you do to ensure benefit?

This is separate from the academic summary which explains how the research contributes to knowledge. Review panels, which include end-users, will consider *"whether plans to increase impact are appropriate and justified given the nature of the proposed research"* looking at *"both excellence and impact characteristics when prioritizing research proposals for funding".*

This approach raised concerns that researchers were being asked to predict the outcome of their research, despite the fact that many research outcomes are highly unexpected. It seemed likely that projects with unknown outcomes would be disadvantaged.

However, closer reading suggests that the research councils are looking for a match between anticipated outcomes and impact activities. If research has clear potential for application, then researchers should propose to seek input from potential users, for example. The question is whether or not research that is truly basic in nature, with apparently limited opportunities for activities promoting impact, could become relatively under-funded. RCUK has emphasised that basic research should not suffer, stating in January 2009 that *"excellent research without obvious or immediate impact will continue to be funded by the Research Councils and will not be disadvantaged within the assessment process"* and that the goal is a *"better application of research, not more applied research".*[41] The research councils need to publish funding statistics by research type (see page 4), especially considering the Frascati definition of pure-basic research as having *"no positive efforts being made to apply the results to practical problems or to transfer the results".*

It is positive that funding for impact activities is available through project funding, but research councils need to communicate their intentions more clearly. Research councils need to gain the trust of researchers that research with few foreseen impacts will continue to be supported.

Research councils are trying to change behaviour by imposing funding requirements, but it can be counter-productive to try to achieve cultural change by imposing rules.

There are further problems with these proposals. First, they depend upon the assumption that the outcome of research can be predicted from research proposals - this is what the proposed impact activities are matched to. We are not aware of any work that validates this approach, such as a comparison of the potential of research made at the time of application and later performance. In fact, there may be some areas where outcome can be predicted fairly well, but they should not receive more funding simply because of this. With uncertain outcomes, it is hard to know which end-users should be reviewing the proposals, and they and the applicants would need to develop considerable expertise. Finally, the wording of "plans to *increase* impact" suggests a baseline to compare against.

It is questionable whether or not it is possible to predict the impact of individual research projects in order to know what sort of impact activities are appropriate. It is vital that unpredictable projects, or projects that lead to unanticipated outcomes are not penalised as they can turn out to have major impacts.

Other OECD countries are also involving a broader range of stake-holders in priority setting and evaluation of relevance as well as excellence. However, the OECD has noted the importance of monitoring the effects of these changes before going further. It cautions that there is a risk of government rather than market failure *"where a lack of policy clarity, continuity, and coherence deters private investment in innovation".*[42]

4. Achieve a Culture of Knowledge Exchange

Governments have typically used incentives, legislation or regulation to change behaviours, but achieving a cultural shift can be as effective and may not have the downsides.[43] Cultural change can be reached through support, recognising success, enabling a diversity of approaches, and making sure that people feel engaged in the processes and not dictated to. To be successful, cultural influences, incentives, and policy decisions must be harmonised.

It is appropriate to ask researchers to try to maximise the impacts of their work. Implementing targets or funding requirements to shape researchers' behaviours may bring short-lived gains but they should be regularly reviewed as later gains can be outweighed by administrative burden or lead to unintended consequences. This approach also antagonises many. It would be much better to build a culture that encourages and supports impact activities and then trust most researchers to engage.

Such an approach may not permeate all, but it may not be necessary or indeed efficient to do so. The public may not want or benefit from all researchers engaging them, and policy-makers would probably gain most from a research overview rather than a project-by-project account.

Researchers should be encouraged and helped to derive impact from relevant findings, either themselves or through others. All researchers should not be required to engage in a prescriptive set of activities whether or not their findings or skill-set warrant it.

Improving Communication & Collaboration

Many of the stumbling blocks to innovation identified by OECD analyses concern knowledge exchange: poor communication, asymmetric information, and limited networking or mobility of personnel.[44] Thus, one of the most effective ways to increase impact is to improve knowledge flows around different sectors.

Speeding up knowledge circulation could greatly increase impacts. Any strategies used to speed up impact must be carefully evaluated to make sure that they do not simply prioritise later-stage research.

The movement of the skilled and experienced people that embody tacit knowledge is very beneficial. Proximity effects show the importance of interpersonal interactions. Spillovers from research often form local clusters of applied high-tech companies around research universities. The UK's 60 science parks often use this model and companies within them grow more quickly. Generally, company patents cite local publicly funded research and small firms are more innovative if they are near relevant public researchers.[45] A recent UK analysis found that being close to a highly ranked chemistry department doubled the number of private pharmaceutical R&D labs, tripled the number that were foreign-owned, and increased the number of chemical industries.[46] Proximity to centres of knowledge can affect location decisions especially in more applied research areas which highly value tacit knowledge.

Many programmes and initiatives already foster collaboration. Research councils are placing academics in industry and vice versa, enabling those involved to gain from new perspectives and increase understanding of the others' methods and needs. The cross-council challenges engage other partners including government departments and agencies. Various regional funds support a range of knowledge exchange activities in HEIs, like the Higher Education Innovation Fund. Nearly all universities have technology transfer offices, employing almost 4000 staff. The Technology Strategy Board brings people and organisations together in the hope of sparking new ideas, and provides support to bring innovations closer to market.

The research charities can also be important partners. For instance, the UK Centre for Medical Research and Innovation will house researchers from Cancer Research UK, the Wellcome Trust, the MRC and University College London with the intention of enhanced sharing of knowledge and expertise.

Communication needs to be sought with the public and policymakers. Engaging with the public enables them to make more informed personal choices and to participate in public debates about scientific direction. It can also inspire students to further study. In order to fully reap the benefits of research, policymakers and the public must be receptive to innovations and able to engage in informed consideration of new technologies.

There is already much support for scientists and engineers to engage and collaborate with each other and the private and charity sector, the public and policy-makers. It is important to evaluate the success of different programmes and not to expect results overnight.

Learned societies can play an important role in facilitating and rewarding knowledge exchange within their disciplines.

Rewarding Impact

In the past, researchers have received little recognition for knowledge exchange. New funding strategies may improve this but need to be carefully considered to guard against conflicting systems and perverse consequences. Institutes housing researchers are well placed to judge their impacts and can reward them through awards, honours and career progression.

Host institutions promote impact and may well monitor it in the REF so they may be best placed to encourage and reward knowledge transfer.

5. Improve Wider Framework Conditions

Research provides the skills, variety and capacity to innovate but a range of other framework conditions must be met, many of which the government can advance. Some countries have invested heavily in R&D without apparent increases in growth, probably due to adverse framework conditions.[47]

User Interaction
The gap between academic research and company innovation needs to be closed. Sir John Chisholm recently argued that this should be done by *"encouraging the private sector to look more assiduously at the opportunities coming out of science rather [than] seeking to turn universities into industrial lookalikes".*[48] Companies can enhance their knowledge of HEIs by using more of their facilities, capabilities and services, by shared appointments, by working with intermediate organisations, or by supporting the uptake of HEI research.

Improving innovation should come from increasing the "pull" from companies through more interaction with and knowledge of the research base - universities have already moved sufficiently in a commercial direction.

There is already considerable investment and activity to encourage the utilisation and commercialisation of research in universities.

Making sure that potential users are aware of the opportunities being thrown up by researchers should help improve the "pull" through of innovative products and ideas.

Intellectual Property Rights (IPRs) & Patenting
IPRs can stimulate innovation by protecting investment and therefore encouraging more of it. On the other hand, IPRs could produce monopolies and delay publication to enable patenting. There have been concerns that pressure to achieve more IPRs may deter academics from work unlikely to generate it, such as finding new uses for current drugs, or simply bias them to more applied research. While it is vital that these risks are monitored, evidence suggests that they are as yet unfounded.[49] A recent report by Professor Paul Wellings observed that there are often time-consuming and obstructive debates about the ownership, recognition and return of IPR for projects with many partners, although the government's model contracts, the Lambert Agreements, have been helpful.[50] University IP was judged to be generally immature, fragmented, and overvalued by its originators. If gain essentially benefits the UK as a whole it is unhelpful if all parties believe that they must derive financial benefit. He concluded that pushing universities to maximise financial returns is *"doomed to fail in the long run".*

The purpose of research commercialisation for HEIs and funding agencies should be clarified.

Economic Issues & Financing

Economic conditions for innovation include macro-economic stability, openness to trade, competitive markets, and financing for translational research. The US and Canada had the best developed venture capital markets in the OECD before investment plummeted during the recession. Funders are now trying to save their current investments rather than funding new ventures. Because of the relatively high cost of both starting up a business and of failure through bankruptcy, the UK typically invests in safer start-ups. In contrast, the US had viewed failure as part of the learning process.[51]

The UK government is working to improve financing. The 2009 Budget included a Strategic Investment Fund of £750 million over two years for advanced industrial projects. June 2009 saw the creation of the UK Innovation Investment Fund to invest in high-tech businesses with high growth potential. The £150 million fund is intended to stimulate private sector investment and will focus on growing small businesses, start-ups and spin-outs. The Treasury has said that it will look at potential taxation reforms to help encourage companies to locate R&D and register IPR in the UK. OECD analysts suggest that the role for government in the recession is not necessarily propping up ventures that are failing but in enabling new ventures to seize the opportunities opened up.[52]

Now is the time for the UK to change its approach to start-ups by reducing the initial administrative costs and the price of failure, developing alternatives for bankruptcy and fewer penalties resulting from it.

Skills & an International Outlook
Innovation gains from a flexible and mobile workforce with access to retraining.[53] The most important factor affecting where companies locate their R&D is access to skilled staff. Over a fifth of firms regard lack of skilled workers as a factor of medium to high importance constraining their innovation.[54]

STEM education must improve to continue to grow the workforce, particularly in certain strategic subjects.

Research is a global affair. The UK needs to welcome international students and researchers, collaborate in international research programmes and help capacity building projects overseas. Recent changes to the immigration system have threatened the ability of STEM workers and students to come to the UK.

The impacts of UK research can be increased by making sure that it is communicated internationally. The UK will gain most from overseas research by conducting comparable work in the UK. The UK's immigration policies must be efficient and appropriate.

Conclusions from Strategies to Increase Impact

The government's economic impact agenda has been implemented in a piecemeal manner. Policies to increase the impact of the research base should be informed by evidence and be developed strategically.

Some of the strategies to increase impact are based on the assumption that it is possible to predict impact by looking at measures of past performance or by hypothesising about the future. But there is little evidence underlying these assumptions and there are trade-offs and risks involved.

It is vital that any strategies implemented to improve impact do not risk the breadth and excellence of the science and engineering research base. Given the difficulty in assessing impact, any measures of impacts are likely to be surrogates and should not drive behaviour.

The research environment should value and support impact and be facilitated by enabling framework conditions. Much of the burden of increasing impact has fallen to researchers, but they have only limited opportunities to influence impacts. In particular, industry and government departments need to improve their knowledge of the work of researchers.

The government has a range of policy levers to make strategic interventions to support emerging technologies, through departmental R&D spending, procurement, and supportive regulation and taxation.

The US has a new federal Science of Science Policy which is developing rigorous tools, methods, data and analysis to enable policymakers to develop better informed investment strategies.

The UK government should build the evidence base necessary to inform its thinking on the impacts of the research base. Government policy options for increasing impact should be better articulated and more fully debated prior to the next spending review. The Treasury should appoint a Chief Scientific Adviser to work on this.

Campaign for Science & Engineering in the UK

29-30 Tavistock Square, London, WC1H 9QU
Tel: 020 7679 4995
E-mail: info@sciencecampaign.org.uk

References & Footnotes

1 Salter, A. et al. (2000). *Talent, not Technology: publicly funded research and innovation in the UK*. SPRU.
2,4,6 *Science and Innovation Investment Framework, 2001-2014. Economic Impacts of Investment in Research & Innovation, 2008.*
3,5 These data may have an English language bias.
7 *Government R&D Funding and Company Behaviour: Measuring Behavioural Additionality.* OECD, 2006.
8 UNICO data.
9,28,34 Guellec, D. & van Pottelsberghe, B. (2001). *R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries*, OECD.
10,54 *International Excellence: Valuing International Scientists and Engineers.* CaSE Policy report, 2008.
11 *Higher Education - Business and Community Interaction Survey, 2006-07.* HEFCE, 2008.
12 *SET Statistics.* DIUS, 2008
13 *Briefing Paper: Medical research charities and the economic downturn.* Association of Medical Research Charities, 2009.
14,15,52 *Policy responses to the economic crisis: Investing for long-term growth.* OECD, 2009.
16 This states that the funding decisions made by research councils should be independent of government.
17 *Review of the Impact of Full Economic Costing on the UK Higher Education Sector*. RCUK/UUK, 2009.
18 *The Measurement of Scientific Activities. The Frascati Manual.* OECD, 2002.
19 Calvert, J. (2006). *What's Special about Basic Research?* Science, Technology & Human Values, 31, 2, p199-220.
20 *Ten Year Science and Innovation Investment Framework*
21,23 *Excellence with Impact*. RCUK, 2007.
22,45 Martin, B. & Tang, P. (2006). *The Benefits of Publicly Funded Research*. SPRU, University of Sussex.
24,31 *The Impact of Research produced by Russell Group Universities.* Russell Group, unpublished paper.
25 *The Social and economic impact of publicly funded research in 35 participating universities*. Arthur D Little, 2006.
26,38 *Medical Research: What's it worth?* Health Economics Research, Office of Health Economics, & RAND Europe, 2008.
27,42,44,53 Box, S. (2009). *Work on Innovation - A stocktaking of Existing Work*. OECD.
28,30 Toole (2007). *Does public scientific research complement private investment in research and development in the pharmaceutical industry?* Journal of Law and Economics, 2007, 50, p81-104.
29,51 *Sources of Economic Growth in the OECD countries.* OECD, 2003.
32,36 *Particle physics - it matters.* IOP & STFC, 2009.
33 Llewelyn-Smith, C. (2009). *What's the Use of Basic Science?* Presentation at CaSE Opinion Forum.
35 *Exploitable Areas of Science*. ACARD, 1986.
37 Crespi, G. & Geuna, A. (2004) *The Productivity of Science*. SPRU, University of Sussex.
39 Warry, P., (2006). *Increasing the economic impact of Research Councils.* The Research Council Economic Impact Group.
40 Summarised from *Expectations for Societal and Economic Impact,* Research Councils UK, 2008.
41 Esler, P. (2009). *Excellence with Impact: A New Culture,* Presentation at CaSE Opinion Forum.
43 *Achieving Culture Change: A Policy Framework*, The Cabinet Office, 2008.
46 Abramovsky L., et al. (2007). *University Research and the Location of Business R&D.* Economic Journal, 117, p114–41.
47 Lane, J. (2009). *Assessing the Impact of Science Funding.* Science, 324, 1273-1275.
48 Chisholm, J. (2009).*Universities and Industry: A perspective on the 21st century Relationship.* Report for DIUS.
49 Van Looy, B. et al. (2006). *Publication and patent behaviour of academic researchers.* Research Policy, 35, p596-608.
50 Wellings, P. (2008). Intellectual property & research benefits.