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WHY SHOULD THE TAXPAYER FUND SCIENCE & RESEARCH?

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I received valuable comments and insights on an earlier draft from Rick Rylance of RCUK, David Sweeney of HEFCE, David Docherty and Aaron Porter of NCUB and Nicholas Tyndale of UCL. Agatha Ojugo provided invaluable assistance during the editorial process. I hope I have reflected their contributions in the final version. Any remaining errors or omissions are my responsibility alone.

Graeme Reid

01 INTRODUCTION

The UK research base is a wonderful success story. It is a magnet for global talent and investment, a feature of our country that is admired around the world, and a source of wide-ranging economic and social benefits.

Earlier achievements and current expertise enable us to live longer, enjoy a secure food chain, create the jobs of tomorrow, and appreciate the rich history on which our society is founded. The research base raises our understanding of ourselves, the planet on which we live and the universe in which our planet was formed. The respect in which UK research is held internationally gives our country influence in global debates on climate change, economics, health and telecommunications and other important areas.

But the UK research base is a fragile ecosystem. It is vulnerable to competitive global pressures, and critically dependent on government funding at a time of spending restraint. Relationships between the research base, government, businesses, medical research charities and international partners generate important discoveries, new intellectual challenges, additional resources and career opportunities. It is an interdependent web of activity. Perhaps the most vital element of this ecosystem is the taxpayers and their families, for whose benefit the whole endeavour takes place.

That is why politicians, civil servants and researchers have been wrestling with a number of questions for generations:

- **Why does the UK government spend taxpayers' money on science and research?**
- **What are science and research worth, and how much should government spend on them?**
- **What return on that investment should taxpayers expect, and over what timescales?**
- **What is the relationship between funding from taxpayers and that from business and charities?**
- **How can government spending on science and research attract support from a wide population?**

In April 2014, I moved to a career in academia from one in the civil service, most recently as Head of Research Funding in the Department of Business, Innovation & Skills. My new role, as Professor of Science and Research Policy at University College London, gives me the opportunity to reflect on these questions. In my inaugural lecture at UCL on 20 May 2014[1], I drew together some of the arguments and evidence relating to government funding of science and research in the UK, and explored the benefits that come back to taxpayers in return for their investment.

This paper has been developed from that lecture. I have updated some material, included a few points that were omitted from the lecture for brevity and some that arose in discussion after my presentation. As in the lecture, I have used the terms "science" and "research" to cover all academic disciplines, deliberately extending beyond the natural sciences. In places, I have used science and research interchangeably. I recognise that this approach is open to challenge, but it reflects the difficulty in categorising these activities.

Some material is well known, such as UK funding levels and citation performance, but I repeat it here to present a rounded picture. Other elements of the evidence and arguments are spread across a diverse literature. I have summarised key findings from that material into a coherent narrative, so as to make them accessible to a wider readership without undermining the rigour of the original work. I have, of course, added observations and arguments drawn from my own experience.

The case for public funding of science and research has developed significantly over the last 20 years or so. Objective evidence has been expanded and enriched by a growing stock of success stories that bring alive the abstract arguments. But the case is incomplete. The public can be in two minds: unnerved by advances in science and technology, such as fracking and genetic manipulation, while simultaneously applauding progress in the fight against cancer and the exploration of the universe. Answers to key questions are persuasive, but not unequivocal. Science and research can still appear remote to some of the people who pay for it. My hope is that, through this paper, we can spread the evidence, arguments and anecdotes a little wider and thereby engage a larger number of people in the debate.

[1] Graeme Reid, UCL Public Policy (2014), "Why should the taxpayer fund science and research?". <www.ucl.ac.uk/public-policy/events/Why-fund-research> [accessed 8 September 2014].

02 RESEARCH FUNDING IN THE UK: HISTORY, ECONOMICS AND POLICY

Government support for science and research has fallen into a high-level pattern that has remained consistent for more than two hundred years. Countless changes have taken place below that steady surface. In essence, two arguments for funding have co-existed over this period: one for public good and another for specific utility.

Figure 1 Statue of Adam Smith situated on Edinburgh's High Street

Adam Smith

In the eighteenth century, economist Adam Smith argued that: "The Sovereign has the duty to [...] maintain certain public works and certain public institutions, which can never be for the interest of any individual [...] because the profit could never repay the expense to any individual [...] though it may frequently do much more than repay it to a great society".[2] Those words have echoed along corridors of power ever since.

Figure 2 The White House

Vannevar Bush

Vannevar Bush, former head of the US government's Office of Scientific Research and Development: "There are areas of science in which the public interest is acute but which are likely to be cultivated inadequately if left without more support than will come from private sources. These areas [...] should be advanced by active government support".[3]

Figure 3 Gordon Brown

Gordon Brown

Gordon Brown, former British Prime Minister and Chancellor of the Exchequer: "The private sector generally does not have the incentive to invest in knowledge made publicly available because it could not earn a return. The government therefore funds this type of research, particularly the more fundamental, long-term research that is unlikely to have immediate application".[4]

[2] Adam Smith (1776), An Inquiry into the Nature and Causes of the Wealth of Nations, Book IV, Chapter 1. <www.econlib.org/library/Smith/smWN12.html#B.IV,%20Introduction> [accessed 1 October 2014] (NB land tax was already in place, income tax was introduced in 1799).

[3] Vannevar Bush (1945), "Science the Endless Frontier". <www.nsf.gov/od/lpa/nsf50/vbush1945.htm> [accessed 1 October 2014].

[4] Gordon Brown, Charles Clarke and Patricia Hewitt (2004), "Science and Innovation Investment Framework". <http://news.bbc.co.uk/nol/shared/bsp/hi/pdfs/science_innovation_120704.pdf > [accessed 1 October 2014].

Figure 5 The Royal Observatory

Ben Bernanke

Ben Bernanke, former chairman of the US Federal Reserve:

> **"The primary economic rationale for a government role in R&D is that, absent such intervention, the private market would not adequately supply certain types of research. The argument, which applies particularly strongly to basic or fundamental research, is that the full economic value of a scientific advance is unlikely to accrue to its discoverer, especially if the new knowledge can be replicated or disseminated at low cost."**[5]

In other words, the beneficiaries of progress are dispersed widely. People who discover new knowledge are unlikely to reap financial rewards from their research, because their discoveries may be communicated and replicated widely, both through peer-reviewed publications and through the collaborations that so often enable the advances in the first place. Government therefore intervenes on behalf of the beneficiaries, collecting their money through taxation and then paying for the science and research on their behalf.

Debates over the extent and conditions for government interventions in the economy provide careers for economists, journalists and politicians – not to mention civil servants. Arguments of varying strength are available on many sides of the debate[6&7]. In parallel, a further series of consistent arguments connect public spending on science and research to important national challenges, with each intervention by government directed at a specific economic or social objective.

Figure 4 Ben Bernanke

The Royal Observatory, Greenwich

For example, Charles II appointed John Flamsteed as his first Astronomer Royal in March 1675. The Royal Observatory was built to improve navigation at sea and "find the so-much desired longitude of places" – one's exact position east and west – while at sea and out of sight of land, by astronomical means.[8]

[5] Ben Bernanke (2011), "FRB: Bernanke, Promoting Research and Development: The Government's Role". <www.federalreserve.gov/newsevents/speech/bernanke20110516a.htm> [accessed 1 October 2014].

[6] Brian M. Reidl (2010), "Why Government Spending Does Not Stimulate Economic Growth: Answering the Critics", The Heritage Foundation. <www.heritage.org/research/reports/2010/01/why-government-spending-does-not-stimulate-economic-growth-answering-the-critics> [accessed 8 September 2014].

[7] Terence Kealey (2013) The Economic Laws of Scientific Research (Palgrave MacMillan, 1997) <www.amazon.co.uk/The-Economic-Laws-Scientific-Research/dp/0312173067>.

[8] Unknown, "History of the Royal Observatory : Our History in Greenwich". <www.rmg.co.uk/about/history/royal-observatory> [accessed 1 October 2014].

Figure 7 MRC Laboratory of Molecular Biology

© Courtesy of NPL

Figure 6 The National Physical Laboratory

© iStock.com / Peter Macdiarmid

Figure 8 George Osborne

The National Physical Laboratory, Middlesex

In 1900, the National Physical Laboratory (NPL) was founded as the "home" for the standardising of measurement. The Prince of Wales and future King George V opened the NPL with these words: "I believe that in the National Physical Laboratory we have the first instance of the State taking part in scientific research. The object of the scheme is, I understand, to bring scientific knowledge to bear practically on our everyday industrial and commercial life; to break down the barrier between theory and practice; to effect a union between science and commerce."[9]

MRC Laboratory of Molecular Biology, Cambridge

The National Insurance Act 1911, introduced by David Lloyd George as Chancellor of the Exchequer, put in place health and unemployment insurance. It enabled sanatorium treatment for cases of tuberculosis and for "purposes of research". This created a national fund for medical research equivalent to around £4 million today. The Medical Research Council was born from this initiative.[10]

George Osborne

In a speech to parliament, announcing the outcome of the 2013 Spending Round, the current Chancellor of the Exchequer George Osborne brought together his support for the dual rationale of public good and specific utility:

> **"Scientific discovery is first and foremost an expression of the relentless human search to know more about the world but it is also an enormous strength for a modern economy. From synthetic biology to graphene – Britain is very good at it. And I am going to keep it that way."**[11]

[9] The Prince of Wales (1902), "Welcome to the Home of Measurement", National Physical Laboratory. <www.npl.co.uk/content/conWebDoc/8805> [accessed 1 October 2014].

[10] Unknown (2011), "Early roots of the British Welfare State: Lloyd George 'People's Budget' 1909", Cambridge Forecast Group Blog. <http://cambridgeforecast.wordpress.com/2011/01/19/early-roots-of-the-british-welfare-state-lloyd-george-peoples-budget-1909/> [accessed 1 October 2014].

[11] George Osborne (2013), House of Commons, Hansard, 26 June 2013, Columns 310-311. As quoted by Jonathan Amos, "BBC News - UK Science Spending to Remain 'Flat'", BBC News, 26 June 2013. <www.bbc.co.uk/news/science-environment-23065763> [accessed 1 October 2014].

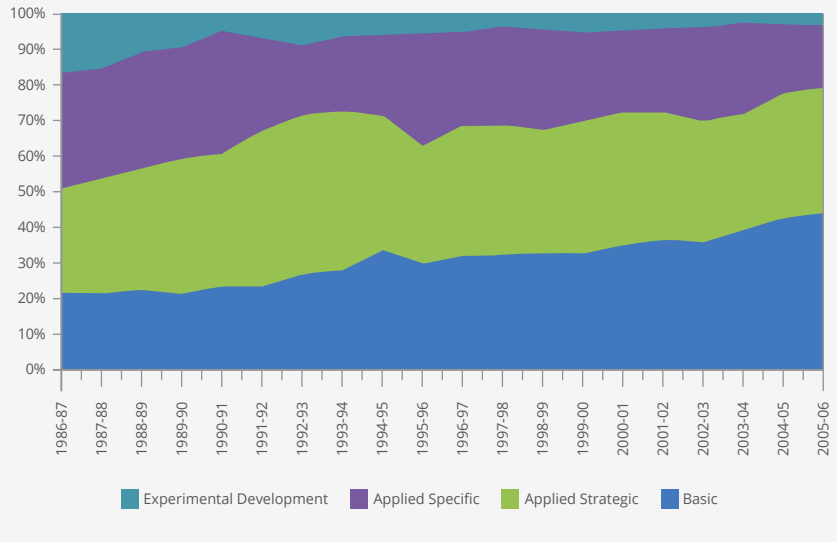
[12] Nils Roll-Hansen (2009), Why the Distinction between Basic (theoretical) and Applied (practical) Research Is Important in the Politics of Science, London School of Economics and Political Science, Contingency and Dissent in Science Project. <www.lse.ac.uk/CPNSS/research/concludedResearchProjects/ContingencyDissentInScience/DP/DPRoll-HansenOnline0409.pdf> [accessed 8 September 2014].

Pure vs applied research

If there are two complementary rationales for government funding of research, then there is an inevitable temptation to look for an optimal balance between them. This often takes the shape of a debate over funding for pure vs applied research. Such a model of resource allocation may be underpinned by the notion of a pipeline in which pure research brings intellectual advances, which are then turned into economic benefit through an adjacent process of applied research. There are examples of the model working well, often in medical research. Yet it misses many of the pathways between research and the economy, and is more likely to mislead than inform a sophisticated understanding of the relationships between science, research and the economy. The concepts of pure and applied research are useful in abstract discussion[12] but categorising real-world science and research along these lines should be attempted only with caution. The Prime Minister's Council for Science and Technology argue that:

> **"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."**[13]

Figure 9 Types of publicly funded science.[16]



Funders may support science and research for the primary purpose of public good, but they are unlikely to object if unforeseen benefits to the economy arise from the work. Indeed, the university funding system in the UK now creates specific incentives and rewards for academics to identify such impacts from all excellent research and nurture them as they begin to take effect in the public, private or charitable sectors. Similarly, public funding might be directed at a specific societal or economic challenge, but a savvy funder will welcome unforeseen advances in scientific knowledge.

Alongside the strong agenda on economic impact, UK Research Council funding for "responsive mode" - or curiosity-driven research - has not declined over the last 20 years or so [14&15] **(see Figure 9)**. During this period, research councils have developed extensive direct links with business alongside their more recent collaborations with the Technology Strategy Board (now renamed Innovate UK).

Research funding through the Higher Education Funding Council for England (HEFCE) has continued to be allocated to universities without reference to pure or applied research. This is hardly surprising, since it is so often the objective "excellence" of research that enables it to have an impact, rather than its place on an imaginary scale of pure and applied activity. We shall return to impact in section 6.

[13] Prime Minister's Council for Science and Technology (2010), "A Vision for UK Research" p.10 <www.gov.uk/government/uploads/system/uploads/attachment_data/file/225373/10-584-vision-uk-research.pdf> [accessed 8 September 2014].

[14] Annex to "House of Lords - Setting Priorities for Publicly Funded Research - Science and Technology Committee". <www.parliament.the-stationery-office.co.uk/pa/ld200910/ldselect/ldsctech/104/10402.htm> [accessed 8 September 2014].

[15] The Royal Society (2010), The Scientific Century: Securing Our Future Prosperity, <https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/2010/4294970126.pdf> [accessed 8 September 2014].

[16] From The Royal Society (2010), The Scientific Century: Securing Our Future Prosperity, Figure 1.7, p. 15. NB: More recent data was submitted by RCUK to a parliamentary enquiry.

The ring-fence around the science and research budget

In its 2010 Spending Review, following the general election earlier that year, the Treasury reported:

> **"[...] departmental budgets other than health and overseas aid will be cut by an average of 19 per cent over four years, the same pace as planned by the previous Government.**[17]
>
> **[...] A ring-fence will be maintained to ensure continuity of investment in science and research."**[18]

In one model for resource allocation, each government department decides how much of its budget should be allocated to science and research, with a degree of oversight from the government's Chief Scientific Advisor. The budget for the nation's science and research base is held by a host department (the Department of Business, Innovation & Skills since 2009) and has been ring-fenced by successive governments against pressures from elsewhere in the host department. The size of the science and research budget is determined by the Treasury [19&20] and allocated separately from the rest of the BIS budget[21&22]. BIS's mission-driven funding, through the Technology Strategy Board (Innovate UK) and the National Physical Laboratory, can then be tensioned against the wider BIS agenda, along similar lines to the decisions on research funding in other government departments. Broadly speaking, that approach has been followed over the last 20 years.

Research councils, funding councils and universities then develop programmes of their own, supported by the ring-fenced budget. Many of these programmes are in collaboration with government departments, including (but not confined to) BIS.

Budget pressures and other realities of government sometimes complicate this simple model. That is hardly surprising. But the ring-fence has remained in place as responsibility for the science and research has moved from one government department to another over the last 25 years (during which time, government responsibility for science and research has been in the Department for Education and Science, the Cabinet Office, the Department of Trade and Industry, the Department of Innovation, Universities & Skills and the Department of Business, Innovation & Skills). Ring-fencing has provided confidence and stability for long-term science at times of economic turbulence and organisational change. It has created an environment in which businesses and charities from around the world often choose to invest in long-term strategic relationships with the UK science base in preference to other countries.

If the efficiency of the science and research community increases (though, say, the better sharing of facilities) then the Treasury may agree that the cost savings can be redeployed within the ring-fenced budget. The Office of National Statistics reports UK government spending on science, engineering and technology separately from other departmental spending. Parliamentary scrutiny of the science and research budget takes place through select committees for science and technology in both the House of Commons and the House of Lords, while parliament has separate arrangements for scrutinising government departments.

[17] HM Treasury, 'Spending Review 2010', p. 5 <hwww.gov.uk/government/publications/spending-review-2010> [accessed 8 September 2014].

[18] HM Treasury, 'Spending Review 2010', p. 23, para 1.35.

[19] HM Treasury, 'Spending Review 2010'.

[20] Great Britain and H. M. Treasury (2013), Spending Round 2013, <http://goo.gl/5aUDMn> [accessed 8 September 2014].

03. HOW MUCH DOES THE GOVERNMENT SPEND ON SCIENCE AND RESEARCH?

The short answer is around £10bn per annum. That equates to about £3 per week for each person in the UK. But the longer answer depends on what is meant by "spend" and what is meant by "science and research".

The Office of National Statistics provide data[23] on UK public spending in the science and research base, government departments and devolved funding bodies. The UK's contribution to the European Union includes elements that are recycled back into UK science and research through explicit science and innovation routes, such as the European Research Council[24], the European Space Agency[25] and Horizon 2020.[26] The EU also recycles money back to the UK through regional development funding, some of which relates to science and business innovation.[27] The UK contribution to the EU is not hypothecated (funds are not earmarked for specific activities), so there is no definitive science element in the UK contribution. However, a reasonable estimate can be calculated from the size of the UK contribution and the proportion of EU expenditure dedicated to science and research. The ONS puts that figure at £0.7bn during 2012.[28]

In addition to public spending, HMRC[29] provides businesses with relief on corporation tax through the R&D tax credit. That, in effect, costs the Treasury more than £1bn annually in support of business R&D. Of course, medical research charities also benefit from tax reliefs and exemptions.

The Campaign for Science and Engineering used ONS data to prepare the graph at **Figure 10**. This gives an overview of the public spending pattern

[23] Office of National Statistics (2012), "Statistical bulletin: 'UK Government Expenditure on Science, Engineering and Technology, 2012" <www.ons.gov.uk/ons/rel/rdit1/science--engineering-and-technology-statistics/2012/stb-set-2012.html> [accessed 8 September 2014].

[24] See: <http://erc.europa.eu/> [accessed 8 September 2014].

[25] See: <www.esa.int/ESA> [accessed 8 September 2014].

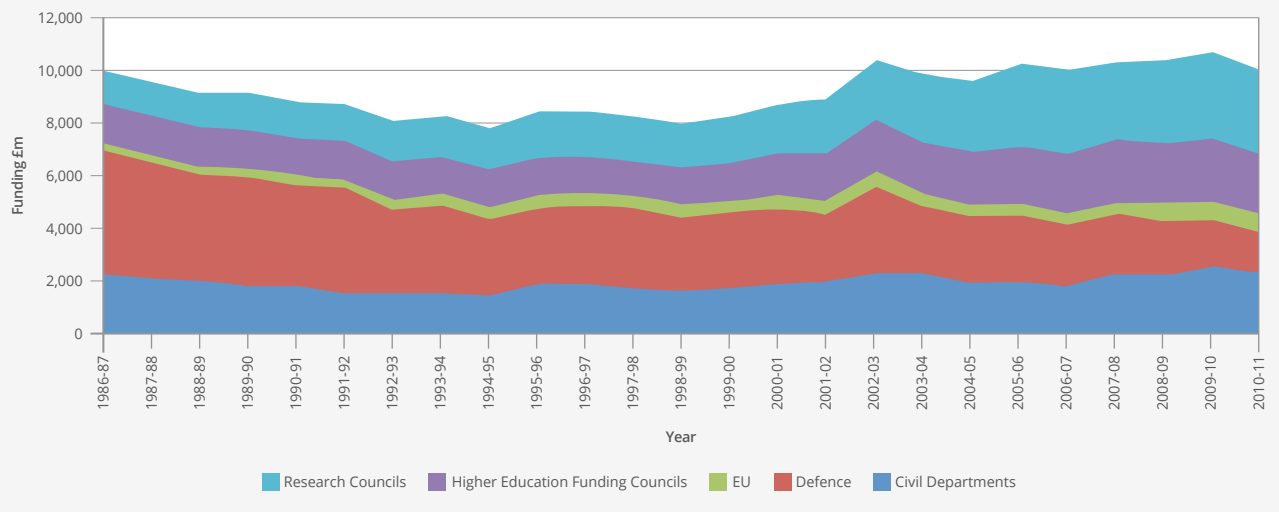
[26] See: <http://ec.europa.eu/programmes/horizon2020/> [accessed 8 September 2014].

[27] See: <www.europeanfundingne.co.uk/european-regional-development-fund-erdf.html> [accessed 8 September 2014].

[28] Office of National Statistics (2012), Statistical bulletin: 'UK Government Expenditure on Science, Engineering and Technology, 2012'.

[29] 'Research and Development Tax Credits Statistics: August 2014 - Publications - GOV.UK' <www.gov.uk/government/statistics/research-and-development-tax-credits-statistics-august-2013> [accessed 8 September 2014].

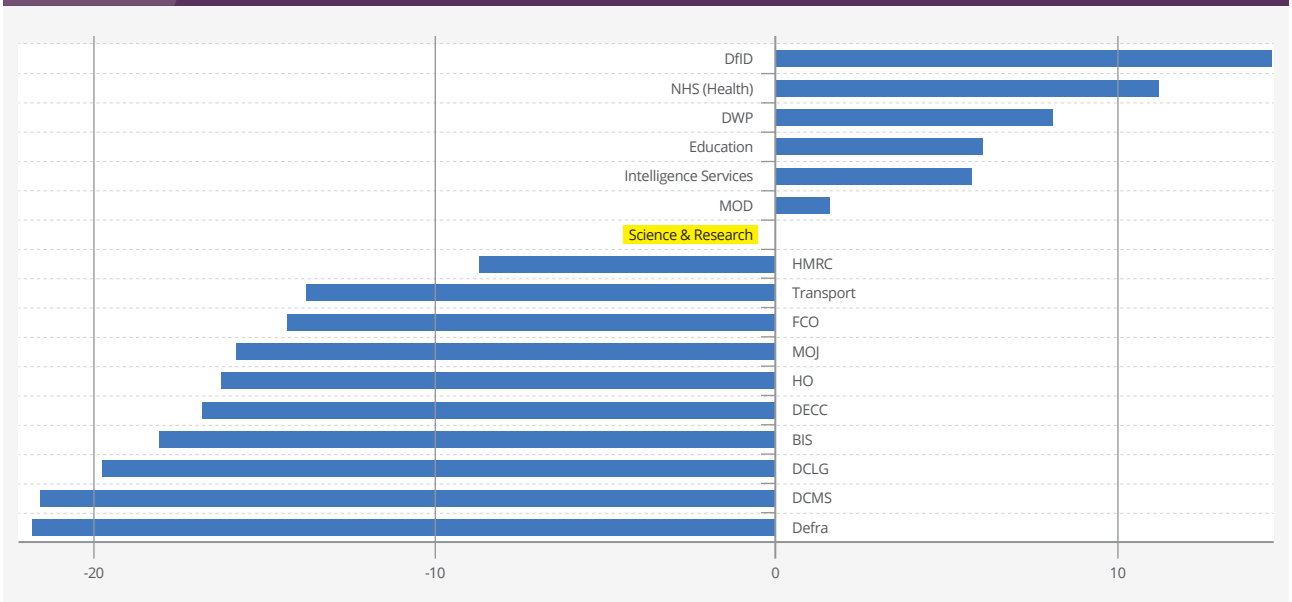
Figure 10 **Historic distribution of public spending on science and research.**[30]



over some 25 years. Two striking trends are the shrinkage in defence spending and the growth in funding for research councils and higher education funding councils, which between them make up a large proportion of the science and research base.

Data from recent Treasury spending reviews[31&32] allows a comparison of how science and research have been handled in comparison with other major areas of public spending. **Figure 11** shows the percentage change announced in the 2010 Spending Review as to the budgets of various government departments, with the ring fenced science and research budget highlighted in yellow.

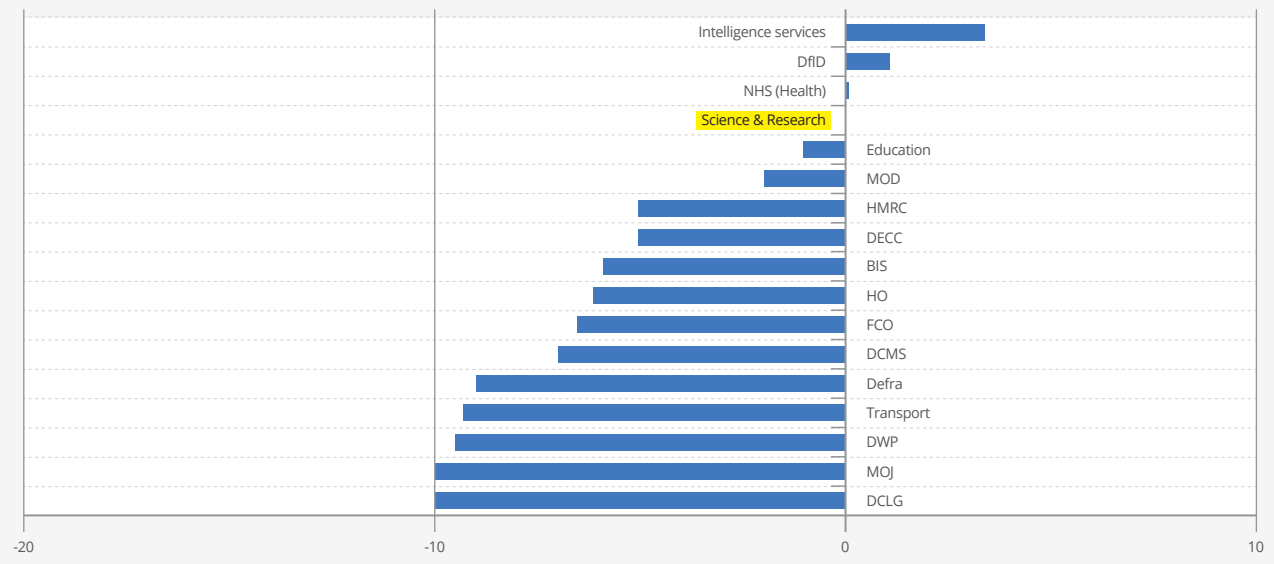
Figure 11 **Percentage change in departmental budgets, including the science and research budget, announced at the 2010 Spending Review.**[33]



[30] Source: 'The Campaign for Science & Engineering' <http://sciencecampaign.org.uk> [accessed 21 October 2014].
[31] HM Treasury (2010). [32] Britain and HM Treasury (2013). [33] Source: HM Treasury (2010).

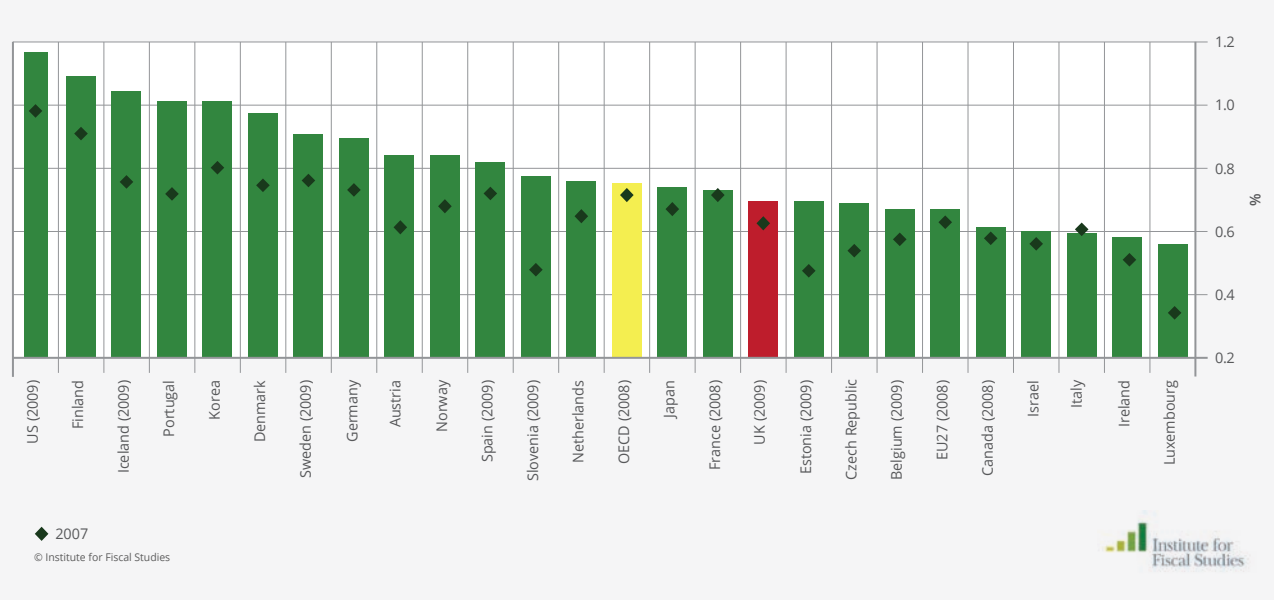
Figure 12 shows a similar list for the 2013 Spending Review. These demonstrate the government's willingness to make tough spending decisions at a time when public finances are under intense pressure. They also demonstrate the distinctive, and arguably preferential treatment given to the science and research budget.

Figure 12 Percentage change in departmental budgets, including the science and research budget, announced at the 2013 Spending Review.[34]



Turning to international comparisons, it is clear from the data in **Figure 13** that the UK spends a smaller proportion of GDP on R&D than countries with which we like to compare ourselves.

Figure 13 Government budget appropriations for R&D in 2010.[35]

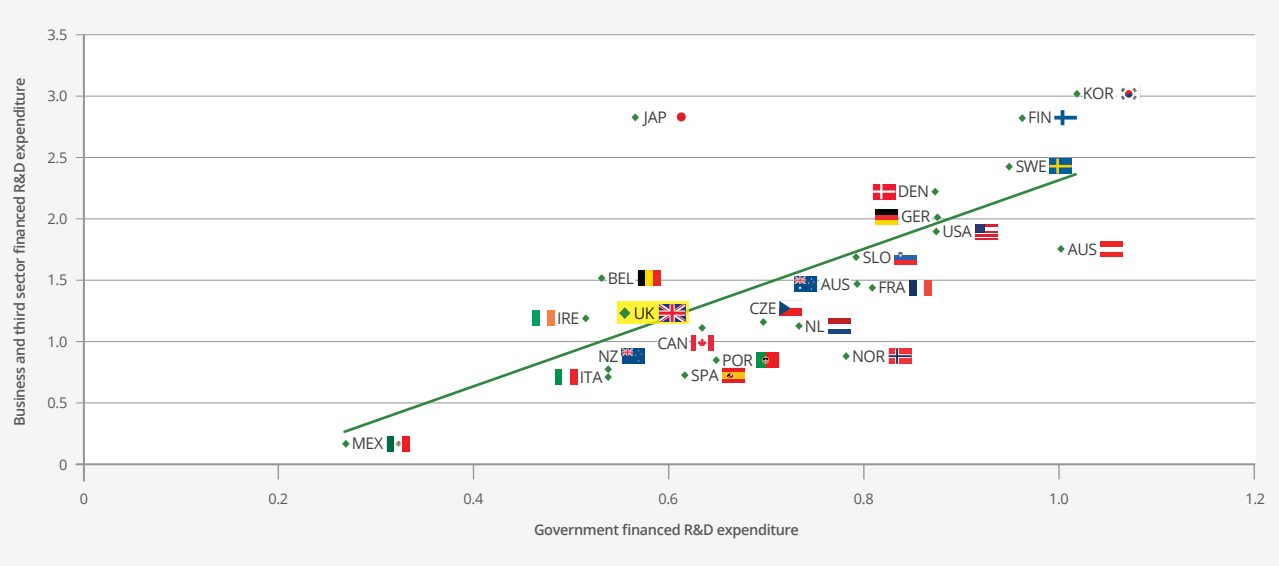


[34] Source: HM Treasury (2013). [35] Table prepared by the Institute of Fiscal Studies using data from OECD's Main Science and Technology Indicators (2012).

Tera Allas, until recently a Director General in BIS, reviewed recent OECD data which showed that UK government expenditure on R&D, as a percentage of GDP, would need to rise by 30 per cent to reach German levels and 50 per cent to reach US levels (all 2011 figures).[36]

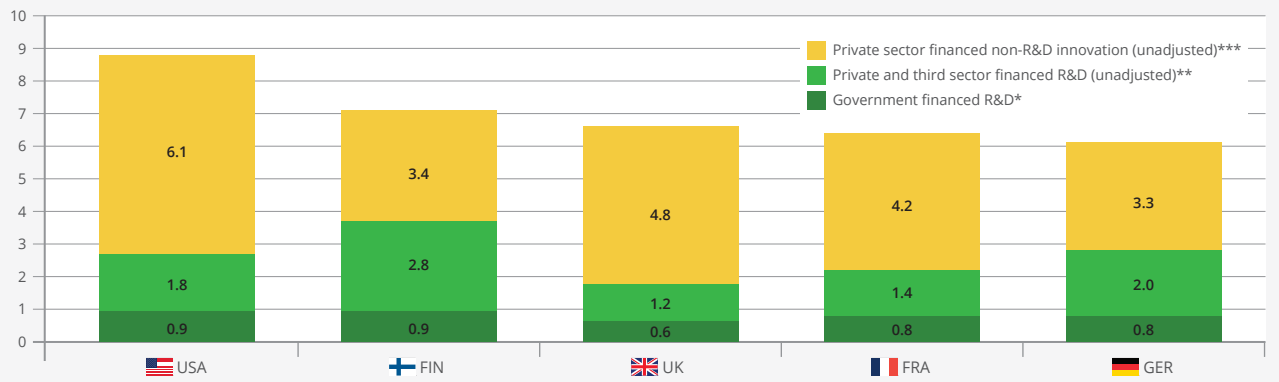
A similar pattern is evident in private-sector investment. This is consistent with the correlation between public and private expenditure on R&D shown in **Figure 14.**

Figure 14 Government vs business and third sector expenditure on R&D in 2011.[37]



Even if non-R&D innovation is taken into account (and leaving aside the definitional complexities of the term "innovation"), **Figure 15** shows that investment levels in the UK appear modest by international comparison.

Figure 15 Figure 15. Gross expenditure on R&D as a percentage of GDP in 2011.[38]



* Government funded Gross Expenditure on Research and Development (GERD); ** GERD minus Government funded GERD (unadjusted for industrial structure); *** See seperate methodological note (unadjusted for industrial structure). Source: OECD, IMF, Corrado et al 2010 data, BIS analysis.

[36] Tera Allas (2014), Insights from International Benchmarking of the UK Science and Innovation System, BIS Analysis Paper. <www.gov.uk/government/uploads/system/uploads/attachment_data/file/277090/bis-14-544-insights-from-international-benchmarking-of-the-UK-science-and-innovation-system-bis-analysis-paper-03.pdf> [accessed 8 September 2014].

[37] Allas, p. 30. [38] Allas, p. 37.

How much should government spend?

The figures above beg the question: if current levels of spending on R&D are low, then what is the optimum level?

Allas[39] observes more spend may be a worthwhile investment, stating:

> **"There is little evidence that comparator countries that spend more than the UK get poor returns on their investment. Indeed, most perceive significant positive value in continued investment and are aiming to increase their expenditure further."**

The optimum level of investment cannot be determined by analysis alone. Value judgements on public priorities will quite rightly be factored into decisions. However, it seems reasonable to suppose that there is some limit to the benefits of increasing investment. Allas points to work by Mario Coccia[40], who uses a mathematical model to derive an optimum total (private, public and charitable) for national spending on R&D of between 2.3 and 2.6 per cent of GDP, close to US and German levels. US economist, Paula Stephan questions whether these levels are high enough.[41] Even if Coccia and Stephan overestimate the optimum level, it is so far above current expenditure in the UK (1.8 per cent of GDP) that there is little risk of this country overspending on science and research.

[39] Allas, p. 30.

[40] Mario Coccia (2009), "What Is the Optimal Rate of R&D Investment to Maximize Productivity Growth?', Technological Forecasting and Social Change" <http://dx.doi.org/10.1016/j.techfore.2008.02.008> [accessed 8 September 2014].

[41] Paula E. Stephan (2012), "How Economics Shapes Science". <http://library.wur.nl/WebQuery/clc/1993059> [accessed 22 October 2014].

04. IS THE UK COMPETITIVE IN SCIENCE AND RESEARCH INTERNATIONALLY?

A litany of statistics have frequently been rehearsed to answer this question.[42] The UK has:

- **0.9 per cent** of the world's population;
- **3.2 per cent** of global research funding;
- **4.1 per cent** of the global population of researchers;
- **9.5 per cent** of downloaded world publications;
- **11.6 per cent** of world citations;
- **15.9 per cent** of the world's most highly cited papers.

That level of performance makes the UK one of the world's strongest scientific nations, second only to the USA in most disciplines. The UK's performance is holding up well, and improving, against growing levels of investment from China, India and Brazil.

Of course, citation figures reveal only past performance: there is an inevitable time lag between the execution of the research and its acquisition of a citation record. But that imperfection can be weighed against the advantage (compared to most other areas of public spending) of a performance appraisal method that is based on good-quality data and commands respect internationally. Being able to quantify citations doesn't make them a perfect measure of success (and introduces risks of over-interpretation), but they provide important insights into research performance if treated with appropriate care.

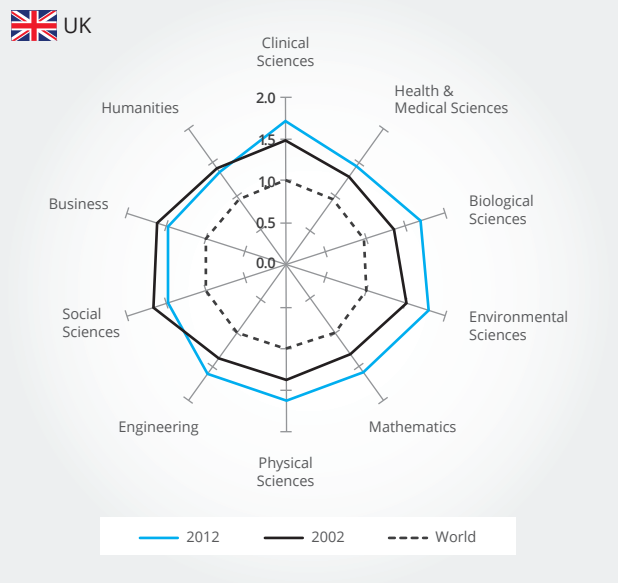
In its 2013 report for BIS[43], Elsevier illustrate the comparative performance of nations by weighting the citations in each research field to allow for the variation of researchers' propensity to cite one another's work. The resulting Field Weighted Citation Impact (FWCI) score is then normalised against a world average of one for each research field.

[42] Elsevier (2013), "International Comparative Performance of the UK Research Base, A Report by Elsevier for the UK's Department of Business, Innovation & Skills (BIS)" <www.elsevier.com/__data/assets/pdf_file/0018/171711/Elsevier_BIS_2013_web_Dec2013-2.pdf> [accessed 8 September 2014].

[43] Elsevier (2013).

Figure 16 – from the Elsevier report – shows the UK's FWCI score in ten disciplinary domains in 2002 and 2012.

Figure 16 UK research performance in ten research fields.[44]



Elsevier state that:

> "The UK is a well rounded research nation with activity and multidisciplinary competencies across all major research fields. The UK's field-weighted citation impact continues to rise and now ranks 1st among comparator nations." [45]

Figure 17 shows data from the US (a) demonstrating a broad span of excellence, and Germany (b) moving to a more rounded performance and increasing the FWCI scores in every field.

Figure 17a US research performance in ten research fields.[46]

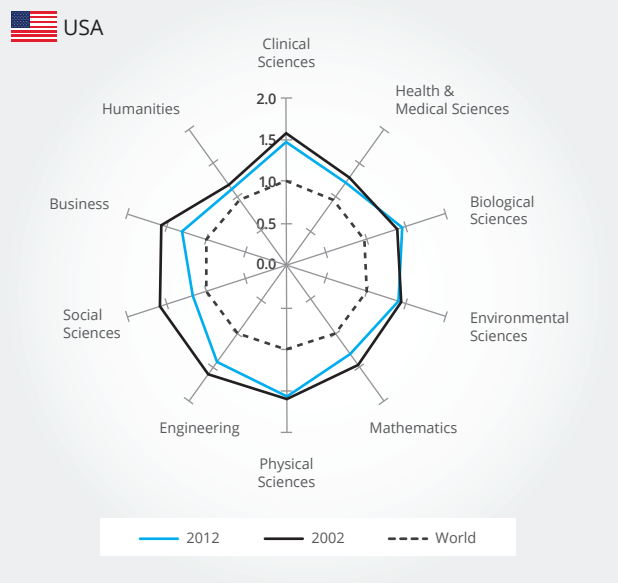
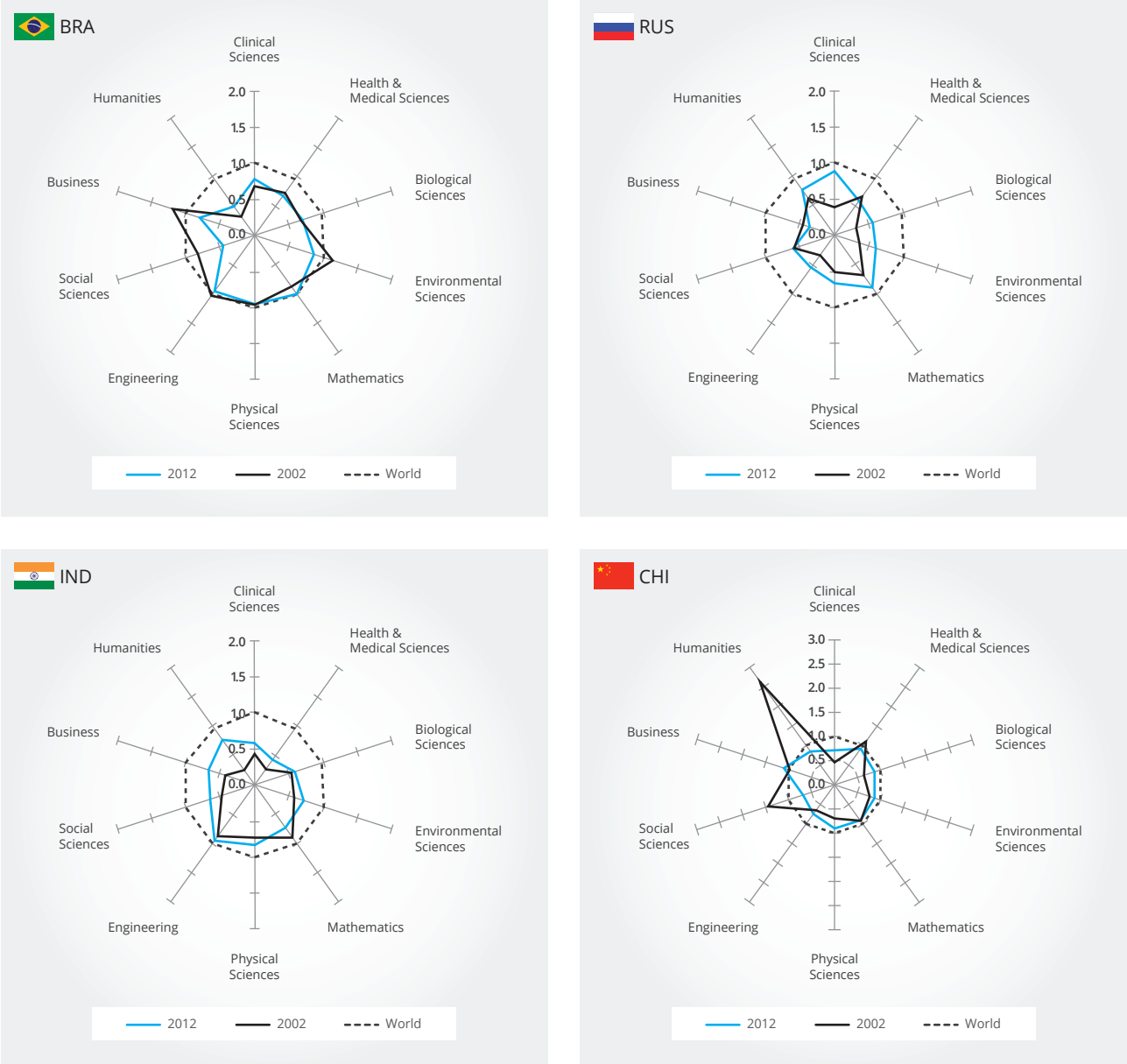


Figure 17b German research performance in ten research fields.[47]

[44] Elsevier (2013), p44 - (UK figure).
[45] Elsevier (2013), p32 - quote.
[46] Elsevier (2013), p45 (USA figure). [47] Elsevier (2013), p44 (DEU figure).

Figure 18 show the equivalent data for Brazil (a), Russia (b), India (c) and China (d), in each case showing greater levels of variation in FWCI between fields. China shows a striking move towards a more uniform performance in the years from 2002-12, albeit by reducing its performance in humanities and social sciences.

Figure 18 Research performance of the BRIC countries in ten research fields.[48]



[48] Elsevier (2013), p45 (BRA, RUS, IND, CHN figure).

A broad span of excellence

International comparison of citation performance reveals significant variations in the uniformity of FWCI scores from one country to another. Comparing the excellence of one field with another is far from straightforward, and probably unwise. Still, FWCI scores do allow a comparison between the performances of other nations in a given field. The UK compares well with other countries across a broad span of disciplines. Does this matter?

A broad span of excellence in individual disciplines is a prerequisite for many of the research challenges facing the world today. Only through a combination of expertise from many disciplines can a nation have the capability to address major new research challenges. Excellence across a comprehensive range of specialisms allows the UK, as a nation, to respond more effectively to global challenges than countries where research is concentrated in a smaller number of areas.

For example, UCL's Grand Challenges[49] in global health, sustainable cities, intercultural interaction and human wellbeing can only be addressed through a diversity of excellent research capability. Understanding and coping with climate change requires not only a grasp of the physics and chemistry of our planet, but also the economic, psychological and cultural factors that drive human behaviour. Advances in health care may require research strengths in engineering and statistics as well as in medicine.

Research fields that appear mono-disciplinary at first sight often reveal a more complicated picture. For example, the UK has recently joined several other nations in a project to build the Square Kilometre Array, the world's largest astronomical telescope.[50] Astronomers will not collect a single data point from that facility until mechanical and software engineers, telecommunications experts and others advance the frontiers of knowledge in their fields.

Collaboration between the Arts & Humanities Research Council and the Engineering & Physical Sciences Research Council has opened up a new research programme on science and heritage, operating from the Centre for Sustainable Heritage.[51]

These are exciting, ground-breaking areas of science and research. They capture the imagination of nations. And they each require innovative collaborations between scientists and researchers from broad spans of expertise.

[49] UCL Office of the Vice Provost for Research (2012), "UCL Grand Challenges: Progress to Date 2010/2011 to 2011/2012". <www.ucl.ac.uk/research/images/GC_report_2011_2012.pdf> [accessed 8 September 2014].

[50] Science and Technology Facilities Council (2014), "£265M Science Investment for Largest Telescope and Biggest Microscope" <www.stfc.ac.uk/3055.aspx> [accessed 8 September 2014].

[51] See: <www.heritagescience.ac.uk/Final_event> [accessed 8 September 2014].

05 DOES UK SCIENCE AND RESEARCH MAKE EFFICIENT USE OF PUBLIC FUNDS?

Terms like "productivity", "performance targets" and "efficiency" may not feel comfortable to scientists and researchers working at the frontiers of knowledge. It is easy to mock attempts by government to apply management rigours to exploratory research. However, if the science and research community is going to receive several billion pounds of taxpayers' money each year then government will - and should - ask if community is making good use of the money.

The efficiency of the science and research base is surely a reasonable component of that question.

In practice, the science and research community has worked with successive governments to reconcile these issues, not only developing pragmatic compromises to the conflicting goals of researchers and accountants, but also creating a shared agenda and working together to use scarce funding more effectively. Questions about efficiency have made helpful contributions to debates about the benefits of the research base to the business community, the sharing of capital facilities between institutions, and the UK's comparative advantage internationally. Furthermore, an ability to improve efficiency within the ring-fenced budget provides the science and research community with a financial reward.

What shapes can this sort of efficiency take? The Research Pooling initiative in Scotland[52] stimulated collaboration and interaction in 14 fields, originating with capital-intensive subjects such as physics before spreading across the natural sciences and engineering. Research Pools in economics and Gaelic languages have now been formed. The N8 Research Partnership of universities in the north of England has developed methods of sharing publicly-funded research assets.[53] A similar initiative is underway in the English midlands[54] and other universities groupings now share expensive facilities in growing numbers.

[52] See: <www.sfc.ac.uk/research/researchpools/researchpools.aspx> [accessed 8 September 2014].

[53] See: <www.n8equipment.org.uk/> [accessed 8 September 2014]. [54] See: <www.m5universities.ac.uk/facilities/> [accessed 8 September 2014].

[55] Sir William Wakeman (2010), "Financial Sustainability and Efficiency in Full Economic Costing of Research in UK Higher Education Institutions", Universities UK. <www.universitiesuk.ac.uk/highereducation/Documents/2010/FinancialSustainabilityAndEfficiency.pd> [accessed 8 September 2014].

[56] Research Councils UK (2011), "Efficiency 2011-15: Ensuring Excellence with Impact", <www.rcuk.ac.uk/research/efficiency/efficiency2011/> [accessed 8 September 2014].

In parallel, the 2010 Wakeham Review[55] of the financial sustainability and efficiency of university research provided a quantitative analysis of universities' research costs, and set out stretching ambitions for future efficiencies. RCUK subsequently produced a plan for delivering Sir William Wakeham's recommendations.[56]

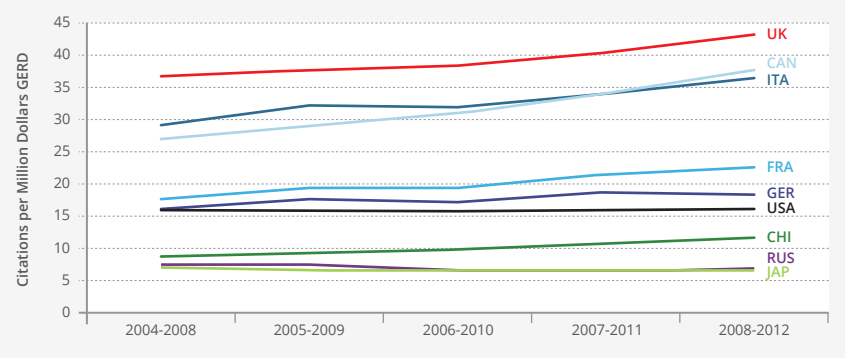
This marked two advances in the debate on efficiency. First, the academic sector and the funding agencies took the lead, putting quantified proposals to government for future efficiency savings in science and research. Second, the Treasury was good to its word and agreed that efficiency savings could be recycled within the ring-fenced budget for science and research.

By international comparison, this country spends modestly on science and research. The cost of doing science in the UK - inclusive of accommodation, salary levels, energy bills and more - is not strikingly lower than elsewhere in competitor nations. In her 2013 Review for BIS, Sarah Jackson[57] reported over £1.7bn of efficiency savings in university research over a period of nearly ten years, identifying two key drivers of efficiency that arguably make a wider contribution to research performance: "a. increasing domestic and international competition" and "b. science ring fence, allowing reinvestment of savings to increase world class performance of universities".

These are deeply embedded features of the funding system in the UK. It is difficult to separate them, and the persistent focus on efficiency, from the UK's research performance and the attractiveness of the UK research base to business collaborators. For instance:

- **The UK has the highest number of citations per unit of R&D expenditure in the G8 group of nations.[58] Figure 19 shows that this performance has persisted over several years.**

Figure 19 International comparison of citations per unit of Gross Domestic Expenditure on R&D (GERD).[59]



- **UK universities have grown their external income by over 40 per cent in the last decade and now generate over £3.4bn pa through that route.[60] It seems that businesses are attracted to efficient academic institutions.**

- **The UK is consistently regarded as one of the best places in the world for university-business collaboration.[61] The UK is now in the top five of around 160 countries covered by the World Economic Forum's "Global Competiveness" survey, having risen to that position during the last decade.**

This work is not over. Pursuit of even greater efficiencies is taking place under the leadership of Sir Ian Diamond, Chair of the Universities UK Modernisation and Efficiency Task Group[62], now focused on connecting the existing progress on research efficiency with related work on other areas of higher education. The Creation of the National Centre for Universities and Business in 2013[63], underpinned by support from HE funding councils, research councils and the Technology Strategies Board (Innovate UK), aims to further improve the environment for university–business interaction.

[57] Sarah Jackson (2013), "MAKING THE BEST BETTER: UK Research and Innovation: More Efficient and Effective for the Global Economy, A Report for Department of Business, Innovation & Skills". <www.n8research.org.uk/assets/files/EfficiencyReportFinal.pdf> [accessed 8 September 2014].

[58] Elsevier (2013). [59] Elsevier (2013), p. 82.

[60] HEFCE (2013), "Higher Education – Business and Community Interaction Survey 2012-13", <www.hefce.ac.uk/media/hefce/content/pubs/2014/201410/HEFCE2014_10.pdf> [accessed 8 September 2014].

[61] World Economic Forum (2013), "The Global Competitiveness Report 2013 - 2014". <www.weforum.org/reports/global-competitiveness-report-2013-2014> [accessed 8 September 2014].

[62] Universities UK (2011), "Efficiency and Effectiveness in Higher Education: A Report by the Universities UK Efficiency and Modernisation Task Group (UUK)". <www.universitiesuk.ac.uk/highereducation/Documents/2011/EfficiencyinHigherEducation.pdf> [accessed 8 September 2014].

[63] <See: <www.ncub.co.uk/> [accessed 8 September 2014].

06 THE IMPACT OF RESEARCH ON THE ECONOMY AND SOCIETY

Long-running attempts to raise the impact of publicly-funded research gathered momentum in 2006 when Peter Warry delivered his report[64] on the impact of research councils to the Department of Trade and Industry.

Warry's findings were absorbed quickly into government and research council policy. Reforms to the Research Assessment Exercise followed soon after[65], leading to the creation of the Research Excellence Framework, complete with incentives and rewards for excellent research with high impact. Meanwhile the Higher Education Innovation Fund, which rewards universities for their interaction with business, almost doubled in size to £150m pa[66]. This added up to a significant shift in policy and funding over a period of two or three years, following decades of rhetoric and debate. It set the ground rules for the spending reviews that followed.

By coincidence, after a period of uninterrupted growth in many economies, 2008 brought the credit crunch, banking failures and a severe economic downturn. Government turned to the science and research community as one source of future growth in the economy. While the debate about impact within the academic community would have several years to run, many universities and academics responded enthusiastically. The impact agenda endorsed what they had been doing for decades, and gave it recognition and reward. Overall, the science and research community rose to the challenge of playing a stronger role in the economy of the future, not by diluting the emphasis on excellent research or by shifting the emphasis from pure to applied, but by adding a new dimension to excellent research.

Since then there have been numerous publications, conferences and reviews on impact **(see Figure 20)**. The level of return on public funding has been estimated from different vantage points.[67–72]

[64] Peter Warry (2006), "Increasing the Economic Impact of the Research Councils". <www.rcuk.ac.uk/RCUK-prod/assets/documents/publications/ktactionplan.pdf> [accessed 8 September 2014].

[65] eComms Team HM Treasury, "Science & Innovation Investment Framework 2004-2014: Next Steps". <http://webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/spending_sr04_science.htm> [accessed 8 September 2014].

[66] Department of Innovation, Universities and Skills (December 2007), "The Allocations of the Science Budget 2008/09 to 2010/11". <http://webarchive.nationalarchives.gov.uk/tna/+/http:/www.dius.gov.uk/publications/URN07114.pdf/> [accessed 8 September 2014].

[67] Cancer Research UK (2013/14), "A Report for Cancer Research UK, Saving Lives Through Research: ONE DAY WE WILL BEAT CANCER. THROUGH RESEARCH WE CAN MAKE IT SOONER, Annual Report 2013/2014". <www.cancerresearchuk.org/sites/default/files/annual_report_and_accounts_2013-14.pdf> [accessed 8 September 2014].

Figure 20 **Some of the many reports on the impact of science and research that have been published during the last few years.**

There has been visible progress in understanding how to translate high level concepts about impact into actionable steps for researchers and analysts. Research councils have published impact reports.[73–79] National academies[80&81], professional institutions[82–84], university mission groups[85&86], think tanks[87] and NCUB[88] have all made valuable contributions to understanding the complicated and subtle processes by which the science and research base has impact on the economy and society.

Data from HEFCE[89] gives progressively stronger quantitative information about university-business relationships, PraxisUnico[90] nurtures a community of knowledge exchange practitioners, while the NCUB provides a forum for business and university leaders to forge a common agenda. Further reinforcement will be available when impact case studies from the 2014 Research Excellence Framework are published.

> Claims that this country is good at science, but poor at exploiting it, are no longer consistent with the evidence.

[68] Office of Health Economics, RAND Europe, and the Health Economics Research Group (2008), "Medical Research: What's It Worth? Estimating the Economic Benefits from Medical Research in the UK" . <www.wellcome.ac.uk/stellent/groups/corporatesite/@sitestudioobjects/documents/web_document/wtx052110.pdf> [accessed 8 September 2014].

[69] Arik Mordoh, Jon Sussex and Martina Garau (2011), "A Report for Cancer Research UK, Exploring the Interdependency between Public and Charitable Medical Research", <www.cancerresearchuk.org/prod_consump/groups/cr_common/@nre/@pol/documents/generalcontent/cr_071922.pdf> [accessed 8 September 2014].

[70] Alan Hughes, Elif Bascavusoglu-Moreau and Jonathan Haskel (2014), "The Economic Significance of the UK Science Base, A REPORT FOR THE CAMPAIGN FOR SCIENCE AND ENGINEERING". <http://sciencecampaign.org.uk/UKScienceBase.pdf> [accessed 8 September 2014].

[71] Alan Hughes and Ben Martin (2012), "Enhancing Impact" <www.cbr.cam.ac.uk/pdf/Impact%20Report%20-%20webversion.pdf> [accessed 8 September 2014].

[72] ESRC 2009), "Measuring the impact of ESRC funding, A REPORT PREPARED FOR THE ECONOMIC AND SOCIAL RESEARCH COUNCIL". <www.esrc.ac.uk/_images/Measuring_the_Impact_of_ESRC_Funding_tcm8-4549.pdf> [accessed 8 September 2014].

[73] AHRC (2012/13), "Impact of AHRC Research (AHRC)". <www.ahrc.ac.uk/News-and-Events/Publications/Documents/AHRC%20Impact%20Report%202013%20(A).pdf> [accessed 8 September 2014].

[74] BBSRC (2013), "BBSRC Impact Report 2013". <www.bbsrc.ac.uk/publications/planning/bbsrc-delivery-plan.aspx> [accessed 8 September 2014].

[75] EPSRC (2012/13), "EPSRC Research Performance and Economic Impact Report 2012 - 2013". <www.epsrc.ac.uk/newsevents/news/impactreport2013/> [accessed 8 September 2014].

[76] ESRC (2013), "Economic Impact Reports". <www.esrc.ac.uk/research/evaluation-impact/impact-evaluation/economic-impact-reports.aspx> [accessed 1 October 2014].

[77] MRC (2013), "Economic Impact Report 2012/13". <www.mrc.ac.uk/news-events/publications/economic-impact-report-2012-13/> [accessed 8 September 2014].

[78] NERC (2013), "Impact Report 2013, The Business of the Environment". <www.nerc.ac.uk/about/perform/reporting/reports/impactreport2013.pdf> [accessed 8 September 2014].

[79] STFC (2013), "Impact Report 2013". <www.stfc.ac.uk/resources/pdf/lrimpact_report_2013.pdf> [accessed 8 September 2014].

[80] The Royal Society (2010), "The Scientific Century: Securing Our Future Prosperity.

Does public spending on science and research displace investment from private and charitable sources?

Public, private and charitable organisations each invest in science and research, often in close collaborations and often in pursuit of similar goals. The impact agenda can bring these goals even closer together. It is therefore reasonable to question the relationship between these sources of funding and, in particular, to question whether public funding displaces or "crowds out" funds from other sources.

There is clear correlation between public and private investment, as shown in Figure 14. Is there a causal connection? If public spending for science and research was reduced, would private and charitable funding increase to take its place, or would it move elsewhere in pursuit of a more favourable environment? If public spending increased, would it stimulate accompanying increases from business and charities or would it cause them to scale back investment and let government pay the bill?

Perhaps the answers will always be open to debate but these questions have prompted several recent studies.[91] Haskel, Hughes and Bascavusoglu-Moreau review the literature on the specific question of whether the research base attracts investment from multinational business and conclude that:

> **"The general evidence of the international location of R&D suggests that the UK's outstanding research base should be a strong attractor of overseas funding of R&D in the private sector and the location of R&D activity in the UK. There is support for this proposition on both qualitative and quantitative grounds. On that basis public sector funding 'crowds in' private sector R&D from abroad."**[92]

This is consistent with empirical evidence. It would be difficult to understand why some of the world's most research-intensive companies choose to invest in Cambridge – a medium-sized community set in agricultural surroundings – were it not for the presence of one of the world's best universities with an outstanding record of attracting public investment in science and research. Some of the global businesses drawn to Cambridge are shown in **Figure 21**. Similar investment patterns are visible in many other parts of the UK, albeit on a smaller scale.

The government's Research Partnership Investment Fund (RPIF)[94] attracted some £800m of private and charitable investment in research infrastructure from consortia who were attracted by £300m of public-sector funding.

Figure 21 Some of the global businesses concentrated around Cambridge.[93]

[81] British Academy (2010), "Past Present and Future, The Public Value of the Humanities & Social Sciences" <www.britac.ac.uk/news/bulletin/BAPPF.pdf> [accessed 8 September 2014].

[82] Deloitte (2012), "The Importance of Physics to the UK Economy: A Report Prepared for the Institute of Physics by Deloitte" <www.iop.org/publications/iop/2012/file_58713.pdf> [accessed 8 September 2014].

[83] The Institute of Mathematics (2014), "IMA Mathematics Matters". <www.ima.org.uk/i_love_maths/mathematics_matters.cfm.html> [accessed 8 September 2014].

[84] EPSRC (2012), "Mathematical Sciences Research: Leading the Way to UK Economic Growth". <www.epsrc.ac.uk/newsevents/news/mathsciresearch/> [accessed 1 October 2014].

Medical research charities make a combined investment of over £1bn annually in UK research.[95] That investment is underpinned by public spending in universities to provide research infrastructure and to provide a specific incentive (the Charities Research Support Fund) for universities to work with charities. The Association of Medical Research Charities claims that:

> **"Charities choose to fund research in UK universities because of the world class research environments they provide. The Charity Research Support Fund [...] enables Government funding to leverage funding from the charity sector."**[96]

This claim is consistent with data from HEFCE, shown in **Figure 22**, showing increases in spending from medical research charities as the publicly funded incentive increases in scale.

Within the UK's national portfolio of research funding, there will be many complicated and nuanced relationships between funding sources. But the balance of evidence from academic studies and empirical observation supports the argument that public funding leverages additional investment from the private and charitable sectors. Leverage amplifies changes in government funding. Increases in public funding stimulate accompanying increases in spending from the private and charitable sectors (RPIF provides a vivid illustration of this process) with a corresponding increase in impact[98]. Decreases in public funding for science and research reduce the attractiveness of the UK research base to businesses and charities, putting downward pressure on their levels of investment in the this country.

Figure 22 **Comparison of research spending from medical charities with level of support from HEFCE's Charity Research Support Fund.**[97]

Data from HEFCE Quality Related data for units of assessment 1-15.

[85] The Russell Group (2010), "The Economic Impact of Research at Russell Group Universities". <http://russellgroup.ac.uk/uploads/RG_ImpactOfResearch2.pdf> [accessed 8 September 2014].

[86] The Russell Group (2012), "The Social Impact of Research at Russell Group Universities". <http://russellgroup.ac.uk/uploads/SocialImpactOfResearch.pdf> [accessed 8 September 2014].

[87] Jonathan Haskel, Hughes and Bascavusoglu-Moreau (2014).

[88] NCUB (2012), "The Brighton Fuse" <www.ncub.co.uk/our-initiatives/brighton-fuse.html> [accessed 8 September 2014].

[89] Higher Education Statistics Agency (2013/14), "HE Business and Community Interaction Survey". <www.hesa.ac.uk/pubs/hebci> [accessed 1 October 2014].

[90] See: <www.praxisunico.org.uk/> [accessed 8 September 2014].

[91] Hughes and Martin (2012), p. 53–55.

[92] Jonathan Haskel, Hughes and Bascavusoglu-Moreau (2014), p. 16-20.

[93] Courtesy of Eoin O'Sullivan, University of Cambridge.[94] See: <www.hefce.ac.uk/whatwedo/rsrch/howfundr/ukrpif/> [accessed 8 September 2014].

[95] Press release (2012): "Government Investment Secures £1 Billion for University and Private Research" <www.gov.uk/government/news/government-investment-secures-1-billion-for-university-and-private-research--2> [accessed 8 September 2014].

[96] Association of Medical Research Charities (2010), "Government Support for Charity Funded Research in Universities: A Joint Statement from Universities and Charities in the UK | AMRC - Association of Medical Research Charities" <www.amrc.org.uk/publications/government-support-charity-funded-research-universities-joint-statement-universities> [accessed 8 September 2014].

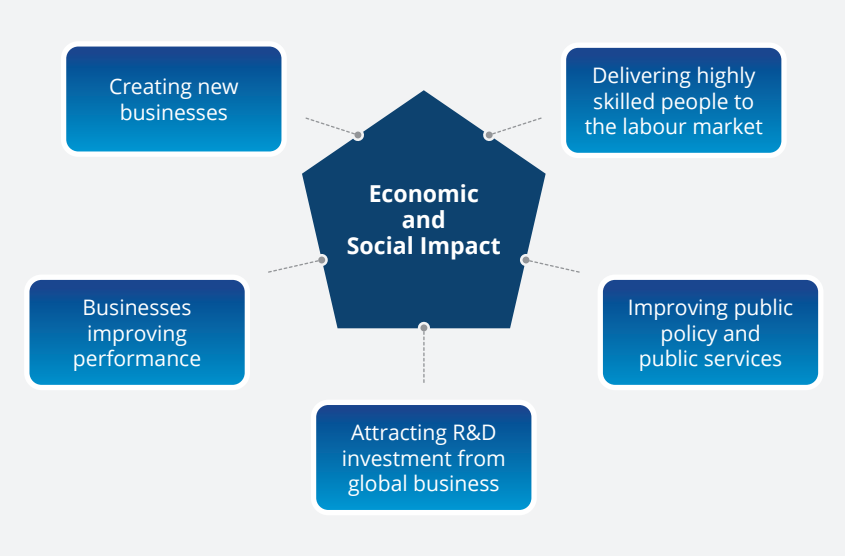
[97] Courtesy of the Association of Medical Research Charities.

[98] See: "UK Research Partnership Investment Fund - HEFCE" <www.hefce.ac.uk/whatwedo/rsrch/howfundr/ukrpif/> [accessed 8 September 2014].

Channels through which science and research contribute to the economy and society

Science and research are translated into economic and social benefit by long, complicated and unpredictable paths. Routes to impact are easier to understand after the event. **Figure 23** illustrates five paths from research to economic or social impact that, between them, cover most of the positive outcomes that beneficiaries in the UK harvest from the research base.

Figure 23 Routes, described in plain language, through which science and research delivers economic and social impact.[99]



I will expand upon these five categories in greater detail:

I. Delivering highly skilled people to the labour market

The Science and Innovation Investment Framework 2004-2014 recorded that:

> **"Perhaps the most significant forms of transfer of knowledge from the science and engineering base to business and the community is through the transfer of people."**[100]

This assertion is backed up by quantitative and qualitative evidence from Hughes and Martin.

In "The Scientific Century", The Royal Society illustrated more than 95 per cent of PhD graduates move outside academia at some point in their careers, with around 50 per cent doing so shortly after graduation, as shown in **Figure 24**.

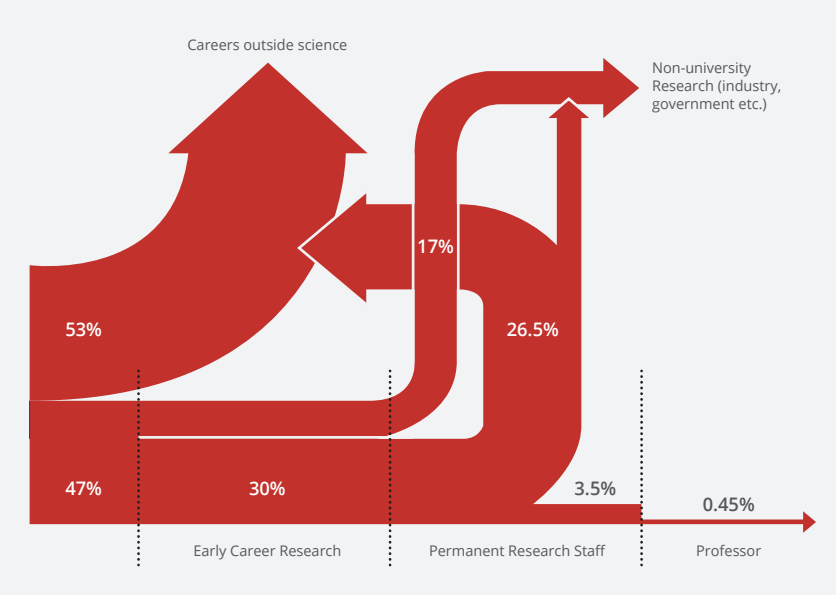
Some commentators equate this to a loss of talent from universities or an oversupply of PhDs[102]. The evidence suggests otherwise: this flow of talented, highly-qualified people into the wider labour market is a major contribution to the economy and society. Salter and Martin[103] reached this conclusion from a review of the evidence more than ten years ago. More recently, the National Centre for University and Business (NCUB) Brighton Fuse study examined the relationship between entrepreneurial business performance in the creative industries and the educational qualifications of the entrepreneurs. NCUB found that those with PhD qualifications clearly outperformed those with MBAs who, in turn outperformed those with first degree qualifications.[104]

[99] Graeme Reid, UCL Public Policy (2014), "Why Should the Taxpayer Fund Science and Research?".
[100] e-Comms Team HM Treasury, p.64.

The Goldman Sachs 10,000 Small Businesses programme[105] operates in partnership with five English Universities to give participating firms access to top quality training and introductions to business angels and investors. Over 75 per cent of the participants in the scheme at UCL go on to recruit new employees.

Knowledge Transfer Partnerships[106] are probably the longest established mechanism by which businesses make gains through exposure to postgraduates. Evaluation evidence suggests that each £1m of public money spent on KTPs, leads to an additional £4.25m profit before tax, over 100 new jobs and over 200 staff trained.

Figure 24 Career choices for PhD graduates.[101]



2. Creating new businesses

The ease with which business creation can be described to a lay audience (spot a good idea, patent it, form a business and get rich) led UK policy-makers in the early days of the impact agenda to place a strong emphasis on patents and spin out companies. This was classical research commercialisation, arguably at the expense of other important relationships between the research base and the economy.[107]

If government expects the direct commercialisation of research and the creation of spin-out companies to repay public investment in science and research then that government will be disappointed. Furthermore, a focus on direct commercialisation risks undervaluing the economic returns that are actually taking place. This vulnerability is not confined to the UK. A recent report from UNESCO into Higher Education in Asia[108] states that:

> **"The MoHE (Malaysian Ministry of Higher Education) sees commercialisation as a means by which the universities will be able to generate more of their own income as government funds are reduced [...] There is concern among faculty that government officials (in Thailand) hold unrealistic expectations of the return on investment through commercialisation."**

[101] The Royal Society, "The Scientific Century", p.14.

[102] The Economist (16 December 2010), "Doctoral Degrees: The Disposable Academic". <www.economist.com/node/17723223> [accessed 8 September 2014].

[103] Ammon J. Salter and Ben R. Martin (2001), "The Economic Benefits of Publicly Funded Basic Research: A Critical Review", Research policy, [accessed 8 September 2014]. p. 509–32.

[104] 'NCUB (2013), "The Brighton Fuse".

[105] See: "Goldman Sachs 10,000 Small Businesses Programme". <www.goldmansachs.com/citizenship/10000-small-businesses/UK/about-the-program/> [accessed 8 September 2014].

[106] See: "Knowledge Transfer Partnerships (KTP) - Accelerating Business Innovation". <www.ktponline.org.uk/> [accessed 8 September 2014].

[107] See: "Investing in Innovation: A Strategy for Science, Engineering and Technology - HM Treasury" (2002) p.70 <http://webarchive.nationalarchives.gov.uk + www.hm-treasury.gov.uk/spend_sr02_science.htm> [accessed 8 September 2014].

[108] UNESCO (2014), "HIGHER EDUCATION IN ASIA: Expanding Out, Expanding Up – The Rise of Graduate Education and University Research." <www.uis.unesco.org/Library/Documents/higher-education-asia-graduate-university-research-2014-en.pdf> [accessed 8 September 2014].

Current approaches to university spinouts and research commercialisation in the UK benefit from more than a decade of professional development and analysis but are still evolving. PraxisUnico and the Institute of Knowledge Transfer support a professional community dedicated to the commercialisation of university research. Some universities have built excellent professional teams to nurture new businesses and attract high quality managers and investors. Data from the annual survey of Higher Education, Business and Community Interaction (HEBCI)[109] shows that patents and licensing income makes up only 3-4 per cent of the external earnings (from business, charities etc.) for universities. Investors who take the majority of the financial risk should make the most of the direct financial returns from the commercialisation of research. Expectations in the UK are now more realistic, even if concerns still remain.[110]

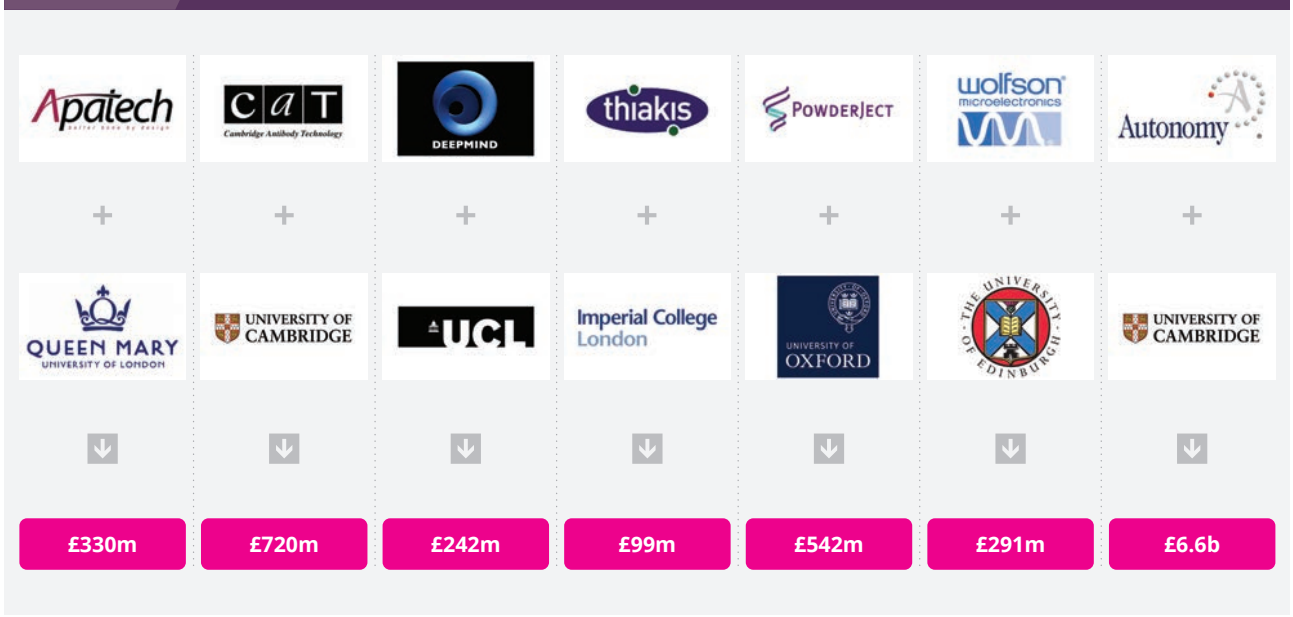
This realism attracts investors.

Investment manager Neil Woodford included two research commercialisation firms, Imperial Innovations plc and Allied Minds plc, in his newly launched unit trust for retail investors. Together, they made up more than 6 per cent of his fund at the time it was launched.[111]

Wonderful new businesses have grown from universities and their surrounding environments. Some of these firms continue to thrive independently while others have attracted new owners. **Figure 25** shows some examples of the values placed on such firms at the time of their sale to other corporations.

Spinouts UK[112] tracks companies that have spun out of universities, providing data on stock market flotation, mergers, trade sales and liquidations.

Figure 25 Values placed on a sample of companies that grew out of UK universities at the time those companies moved into new ownership.



[109] "HESA - Higher Education Statistics Agency".

[110] Holly Else (7 August 2014), "Overvaluations 'stifle' University Spin-Offs", Times Higher Education <www.timeshighereducation.co.uk/news/overvaluations-stifle-university-spin-offs/2015032.article> [accessed 8 September 2014].

[111] Mindful Money (14 July 2014), "Neil Woodford Publishes Entire Holdings of CF Woodford Equity Income Fund", <www.mindfulmoney.co.uk/investment-insight/neil-woodford-publishes-entire-holdings-of-cf-woodford-equity-income-fund%e2%80%8f/> [accessed 8 September 2014].

[112] See: "Spinouts UK" <www.spinoutsuk.co.uk/> [accessed 8 September 2014].

[113] See: "Higher Education Statistics Agency: Higher Education-Business and Community Interaction (HE-BCI)", HEFCE <www.hefce.ac.uk/whatwedo/kes/measureke/hebci/> [accessed 8 September 2014].

[114] NCUB (2014), "State of the Relationship 2014". <www.ncub.co.uk/reports/sor.html> [accessed 8 September 2014].

[115] Sir Richard Lambert (2003), "Lambert Review of Business-University Collaboration" <www.ncub.co.uk/index.php?option=com_docman&task=doc_download&gid=81&Itemid=> [accessed 8 September 2014].

[116] Herman Hauser (2010), "The Current and Future Role of Technology and Innovation Centres in the UK". <www.innovateuk.org/documents/1524978/2139688/The+Current+and+Future+Role+of+Technology+and+Innovation+Centres+in+the+UK/e1b5f4ae-fec8-495d-bbd5-28dacdfee186> [accessed 8 September 2014].

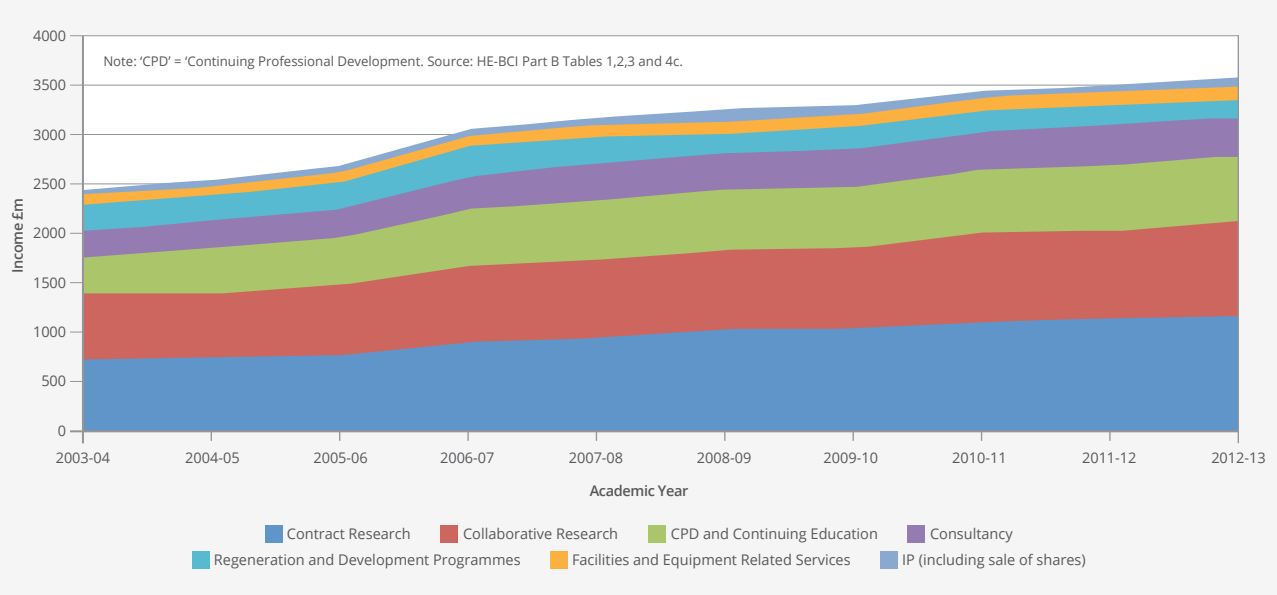
3. Businesses improving their performance

Many of the UK's great universities were founded on 19th century relationships between commerce and learning. Collaborations between universities and businesses have continued since then. Businesses thereby improve their performance by absorbing new skills, talented people and intellectual property, and by gaining access to facilities. Data on the level of university earnings from these relationships provide one indication on the financial value that businesses place on their relationships with higher education and research. This data is published annually by the Higher Education Statistics Agency (HESA).[113] The NCUB has published many case studies of university –business collaboration in its first State of the Relationship report.[114]

Relationships between universities and business have been examined frequently since Richard Lambert's seminal review of 2003.[115] The Lambert Review was followed by simplification and budget increases for the Higher Education Innovation Fund that, in turn, enabled transformational changes within universities. Hermann Hauser's 2010 review[116] of technology commercialisation guided the TSB's creation of Catapult Centres. Sir Tim Wilson's 2012 review[117] led to the creation of the NCUB. Sir Andrew Witty's 2013 review[118] clarified the relationship between national and regional agenda. The House of Commons Select Committee on Business Innovation and Skills is running an enquiry into university-business relations during 2014.

This included some £2.3bn in 2011-12 through a combination of collaborative research, contract research and consultancy. Universities earned a further £650m that year by providing continuing professional development. Large proportions of those figures come from business. Both lines of income have grown steadily over the last decade. Income from intellectual property has not grown significantly over that period, perhaps due to the effects of the recent downturn in the economy. Growth in the aggregate level of external earnings by universities is shown at **Figure 26**.

Figure 26 Growth in external earnings by UK universities.[119]



[117] Sir Tim Wilson (2012), "A Review of Business–University Collaboration", <www.gov.uk/government/publications/business-university-collaboration-the-wilson-review> [accessed 8 September 2014].

[118] Andrew Witty (2013), "Encouraging a British Invention Revolution: Sir Andrew Witty's Review of Universities and Growth, Final Report and Recommendations", <http://dera.ioe.ac.uk/18576/1/bis-13-1241-encouraging-a-british-invention-revolution-andrew-witty-review-R1.pdf> [accessed 8 September 2014].

[119] From HEFCE and the Higher Education Statistics Agency.

Figure 27 The Advanced Forming Research Centre at Strathclyde University.[123]

Figure 28 A new institute created jointly by Lloyds Register and the University of Southampton.[127]

Figure 29 The Warwick Manufacturing Group continues to grow.[130]

A growing number of strategic relationships are now emerging alongside the large number of individual transactions between businesses and universities.

Rolls Royce were one of the pioneers of strategic relationships through their University Technology Centres[120], developing over a 20 year period into an international network of 400 projects in more than 30 centres.

BP has created a portfolio of strategic collaborations with universities and research institutes[121] including its $100m International Centre for Advanced Materials, whose hub is at University of Manchester. The University of Strathclyde has created the Advanced Forming Research Centre[122], shown in **Figure 27**, in partnership with a wide network of high technology businesses.

This complements the University of Sheffield's Advanced Manufacturing Research Centre, founded in 2001 as a partnership with Boeing[124] and now involving over 70 businesses. The Strathclyde and Sheffield initiatives are each part of a wider network of Catapult Centres supported by the Technology Strategy Board.[125]

Lloyds Register is creating a Global Technology Centre on the campus of Southampton University.[126] The scale of that project is illustrated in **Figure 28**. Some 400 Lloyds Register employees will move into the new facility in 2014.

Jaguar Land Rover is one of many companies to have a long-standing alliance with the Warwick Manufacturing Group at Warwick University[128–129] whose extensive facilities are shown at **Figure 29**.

AstraZeneca has announced plans[131] to invest over £300m in a new global R&D centre in Cambridge, building on an existing presence near the university. UCL has a multi-faceted relationship with CISCO[132&133] spanning student internships, and a new Future Cities Centre (in partnership with Imperial College)[134&135], business incubations space, and visiting speakers.

Each of these examples reflects the desire of businesses to place their research and innovation activities close to top-quality university research. Much of the corporate activity will, quite rightly, remain within the business, suggesting that even the strong growth in university income from businesses understates substantially the scale of university-business relations.

[120] See: "UTC & Key Academic Partnerships - Rolls-Royce", Rolls Royce University Technology Centres <www.rolls-royce.com/about/technology/uni_research_centres/key_academic_partnerships.jsp> [accessed 8 September 2014].

[121] See: 'BP Major Research Collaborations' <www.bp.com/en/global/corporate/about-bp/bp-and-technology/our-approach/major-research-collaborations.html> [accessed 8 September 2014].

[122] See:"Advanced Forming Research Centre - University of Strathclyde" <www.strath.ac.uk/afrc/> [accessed 8 September 2014].

[123] Courtesy of the University of Strathclyde. [124] See: <www.amrc.co.uk/> [accessed 1 October 2014].

[125] See: <www.innovateuk.org/-/catapult-centres> [accessed 8 September 2014].

[126] See: <www.lr.org/en/research-and-innovation/global-technology-centres/southampton/> [accessed 8 September 2014].

[127] Courtesy of the University of Southampton.

[128] See: "Warwick Manufacturing Group" <www2.warwick.ac.uk/fac/sci/wmg/> [accessed 8 September 2014].

[129] See: "Jaguar Land Rover (JLR) Research and Development" <www.jaguarlandrover.com/gl/en/innovation/research-and-development/> [accessed 8 September 2014].

[130] Courtesy of the University of Warwick

[131] See: "AstraZeneca - Cambridge" <www.astrazeneca.co.uk/astrazeneca-in-uk/our-uk-sites/cambridge> [accessed 8 September 2014].

[132] See: "Cisco Named UCL Enterprise Corporate Partner of the Year 2013", UCL CISCO <www.ucl.ac.uk/enterprise/enterprise-news/cisco-award> [accessed 8 September 2014].

4. Attracting R&D investment from global businesses

UK-based corporations such as Rolls Royce and BP build research partnerships with the best universities in the world but, of course, businesses based overseas do the same. **Figure 30**, for example, shows the global distribution of R&D centres of the US consumer goods company P&G, including its research centres in Reading and Newcastle.

Figure 30 The global span of R&D in P&G.[136]

OECD and UN figures suggest that well over £100bn of business annual investment in R&D crosses international borders.[137&138] OECD data suggests that global BERD (Business Enterprise Research and Development) is around $600bn annually, and a survey by the United Nations Conference on Trade and Development[139] found about 28 per cent of R&D expenditure from its responding firms going abroad. The UK is in a global competition to win a share of that global flow of R&D investment. UK Trade and Investment revealed increasing numbers of inward investment projects "reported as involving R&D".[140]

The Office of National Statistics reports[141] that in 2011 almost half of the UK's annual business expenditure on R&D in the UK (£17.4bn) was from foreign-owned businesses and, as shown in **Figure 31**, that proportion has been growing for more than 15 years.

[133] See: "UCL Cisco" <www.ucl.ac.uk/enterprise/corporate-partnerships/partner-information/cisco> [accessed 8 September 2014].

[134] See: "Partnership with Cisco & Imperial in Tech City" <www.ucl.ac.uk/enterprise/enterprise-news/cp-archive/citiesofthefuture> [accessed 8 September 2014].

[135] See: "Imperial and UCL to Open Future Cities Centre" <www.ucl.ac.uk/enterprise/enterprise-news/imperial-and-ucl-to-open-future-cities-centre> [accessed 8 September 2014].

[136] Courtesy of P&G.

[137] Ove Granstrand, Lars Håkanson and Sören Sjölander (1993), "Internationalization of R&D — a Survey of Some Recent Research", Research Policy, 22. p. 413–30. <http://dx.doi.org/10.1016/0048-7333(93)90010-F> [accessed 8 September 2014].

[138] Maximilian von Zedtwitz and Oliver Gassmann (2002), "Market versus Technology Drive in R&D Internationalization: Four Different Patterns of Managing Research and Development", Research Policy, 31, p. 569–88. <http://dx.doi.org/10.1016/S0048-7333(01)00125-1>.

[139] United Nations (2005), "UNCTAD Survey on the Internationalization of Business R&D" <http://unctad.org/en/docs/webiteiia200512_en.pdf> [accessed 8 September 2014].

[140] See: "UKTI Inward Investment Report 2013-2014" p.11. <www.gov.uk/government/publications/ukti-inward-investment-report-2013-2014/ukti-inward-investment-report-2013-2014--2> [accessed 8 September 2014].

[141] UK Government Expenditure on Science, Engineering and Technology (Office for National Statistics, July 2012) <www.ons.gov.uk/ons/dcp171778_370646.pdf> [accessed 8 September 2014].

Figure 33 The Harwell research campus near Oxford will be the new home of the European Space Agency's innovation. centre.[144]

Figure 31 Business R&D expenditure in the UK in 1995 and 2011: distribution of business ownership.[142]

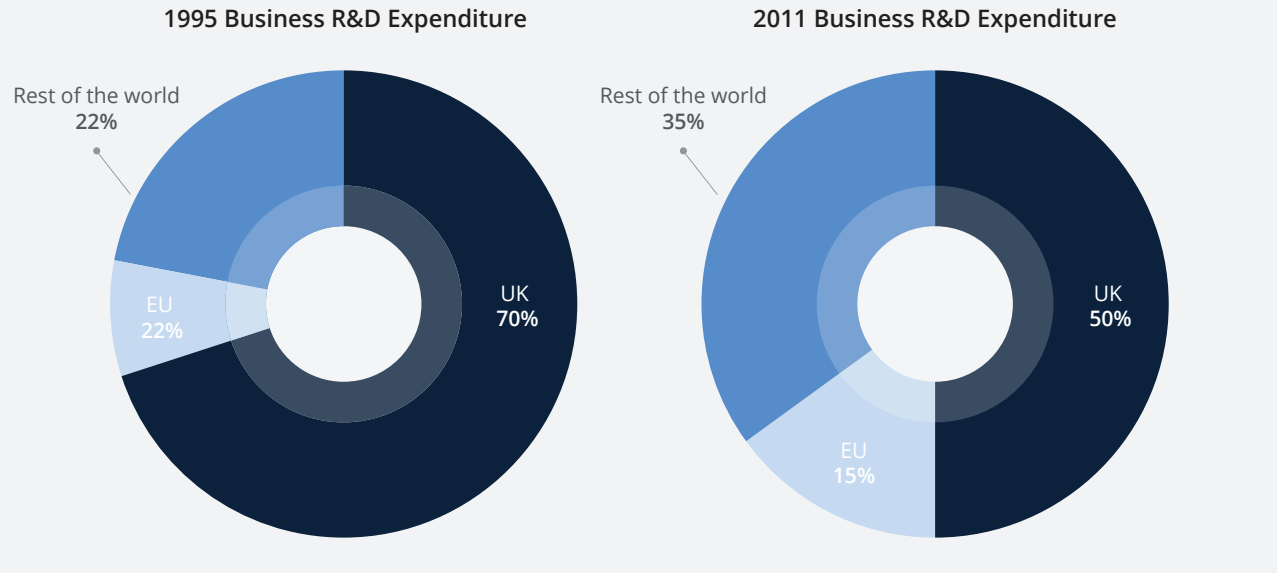
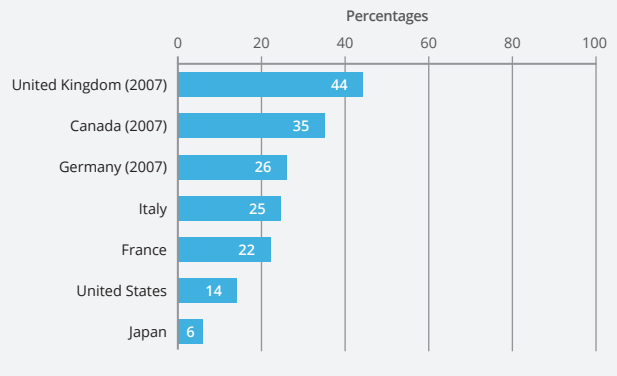


Figure 32 R&D expenditure generated in G7 countries by foreign controlled affiliates.[143]



The international comparison in **Figure 32** shows the UK as having the largest proportion of such R&D in the G7 Group of countries.

In other words, the UK delivers a strong performance in the global competition for business investment in R&D.

The contribution of public sector funding to the UK's attractiveness to overseas business R&D investors was described in the earlier section on leveraged investment. But the same characteristics of the UK are attractive to public sector investors, too. The European Space Agency (ESA) is relocating its innovation centre, and a significant number of high quality jobs, from the Netherlands to the Harwell Campus in Oxford, shown in **Figure 33**.

[142] From the Office of National Statistics.

[143] From data published by the ONS and the OECD.

[144] See: Research Complex at Harwell <www.rc-harwell.ac.uk/about-us.html> [accessed 21 October 2014].

This move allows ESA to co-locate its innovation activities with the TSB-funded Space Catapult Centre[145], the Research Councils' RAL Space organisation[146], and join ambitious plans for a cluster of space-related activities supported by the government's UK Space Agency.[147]

Foreign direct investment contributes directly to the bottom line of the UK's gross domestic product (GDP). A combination of historic and current public spending on science and research attracts that investment, and thereby makes a direct contribution to national wealth.

5. Improving public policy and public services

The existence of a Chief Scientific Advisor in every significant government department indicates the breadth of public policy and public services that draw upon evidence and expertise from the science and research community. Some government departments, such as health, have long established science and research agenda and a wide recognition of their role in the delivery of public services. Others, such as the Foreign and Commonwealth Office, have long had scientific capability embedded in the organisation but have appointed a Chief Scientific Advisor more recently. The UK government has an internal Government Science and Engineering (GSE) network with more than 3000 members.[148]

Quantifying the impact of science and research on public policy is not straightforward. Such quantification may well disguise, rather than reveal, the benefits accrued by the public sector and a wider population. It would place disproportionate value on those impacts that can be quantified. Until more sophisticated measurement techniques are available, we must rely on qualitative anecdotal descriptions.

Scientific advances have enabled profound changes in the criminal justice system through the widespread use of DNA fingerprinting, built on discoveries by Sir Alec Jeffreys in 1984 at the University of Leicester.[149] The discovery of the hole on the ozone layer of the atmosphere, shown in **Figure 34**, by scientists working at the British Antarctic Survey in 1985[150], led to the Montreal Protocol two years later.[151] Under the protocol, the production and use of ozone-depleting chemicals was controlled, thereby retaining the protection that the Earth's atmosphere gives against harmful radiation from the Sun.

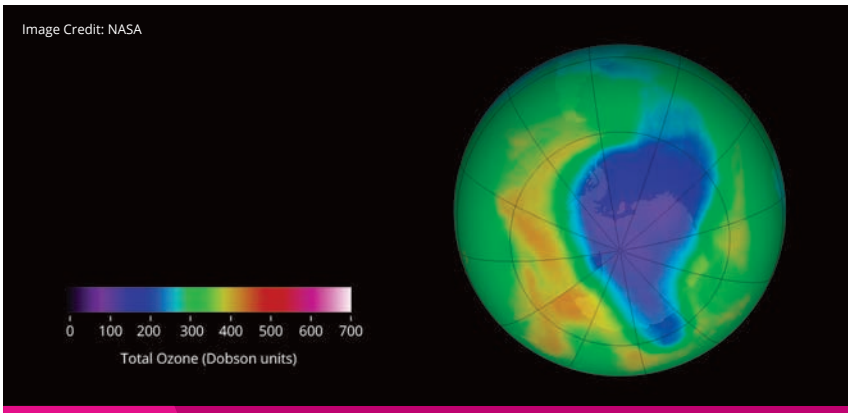


Figure 34 The hole on the ozone layer over Antarctica, discovered by scientists from the British Antarctic Survey (Dobson units describe the concentration of ozone in the atmosphere).

[145] See: "Satellite Applications Catapult Centre Ramps up for Business" <www.innovateuk.org/web/corporate1/press-release-display-page/-/asset_publisher/u5igfmj8gOAf/content/satellite-applications-catapult-centre-ramps-up-for-business> [accessed 8 September 2014].

[146] See: "Research Councils RAL SpaceOpsOgranisation". <www.stfc.ac.uk/RALSpace/Default.aspx> [accessed 8 September 2014].

[147] See: "UK Space Agency - GOV.UK" <www.gov.uk/government/organisations/uk-space-agency> [accessed 8 September 2014].

[148] See: "Government Science and Engineering (GSE)". <www.gov.uk/government/groups/government-science-and-engineering-gse> [accessed 8 September 2014].

[149] See: "Alec Jeffreys and Genetic Fingerprinting — University of Leicester". <www2.le.ac.uk/departments/genetics/jeffreys> [accessed 8 September 2014].

[150] British Antarctic Survey (2014), "Science Briefing – The Ozone Hole". <www.antarctica.ac.uk/press/journalists/resources/science/ozone.php> [accessed 8 September 2014].

[151] See: "UNITED NATIONS ENVIRONMENT PROGRAMME OZONE SECRETARIAT" <http://ozone.unep.org/new_site/en/montreal_protocol.php> [accessed 8 September 2014].

Figure 35 The summer of 2011 saw rioting and extensive damage to property in several parts of the UK.[152]

Researchers at UCL's Centre for Advanced Spatial Analysis helped the Metropolitan Police understand geographic patterns of behaviour among rioters during severe public disorder in London in the summer of 2011 **(Figure 35)**.

Also at UCL, the Pedestrian Accessibility Movement Environment Laboratory (PAMELA)[153] has been used in collaboration with rail and underground operators to understand and improve the experience of passengers.

The Drug Control Centre at Kings College London formed a partnership with GSK to deliver anti-doping facilities that operated round the clock during the 2012 Olympic and Paralympic Games in London.
Many universities across the UK have public policy operations. For instance, Edinburgh has an Academy of Government,[154] Cambridge has a Centre for Science and Policy,[155] UCL has a School of Public Policy,[156] a new Department of Science, Technology, Engineering

[153] See: "Pedestrian Accessibility Movement Environment Laboratory (PAMELA)". <www.research-equipment.ucl.ac.uk/item/pedestrian-accessibility-movement-environment-laboratory-pamela-/2507> [accessed 8 September 2014].

[154] See: "Academy of Government". <www.aog.ed.ac.uk/> [accessed 8 September 2014].

[155] See: "Centre for Science and Policy". <www.csap.cam.ac.uk/> [accessed 8 September 2014].

[156] See: "UCL School of Public Policy". <www.ucl.ac.uk/spp/> [accessed 8 September 2014].

[157] See: "Department of Science, Technology, Engineering and Public Policy (UCL STEaPP)". <www.ucl.ac.uk/steapp> [accessed 8 September 2014].

and Public Policy[157] and an Institutional agenda on Public Policy,[158] Sussex has the Science Policy Research Unit[159] and the Manchester has Policy@Manchester.[160] Research organisations such as the Institute for Fiscal Studies[161], the National Physical Laboratory[162] and the Institute of Animal Health[163] make essential contributions to public policy, based on publicly-funded research.

This movement towards greater use of research-based evidence in government is supported by the What Works Network, supported by the Economic and Social Research Council and others.[164] The network aims to improve the use of evidence in policy-making and public service delivery in areas such as social care, crime reduction and local economic growth.

Perhaps encouraged by the impact agenda, the science and research community is reaching out to government to offer research, consultancy, professional development and interchanges of people on a scale that appears larger than ever. Government, meanwhile, is committed to "Open Policy Making"[165] whereby civil servants engage more widely outside government as they prepare advice for ministers. Shrinking numbers of civil servants, coupled with growing ministerial demands for evidence-based advice, brings the research and public policy communities even closer together, not only in the traditional areas of government analysis (such as economics, law and statistics) but across a wide span of science and research disciplines.

Time lags between investment and impact

Those accountable for public money may ask: "how long does it take for research funding to deliver impact?" If that question is directed at individual research grants, then no generic answer is available. The question makes little sense at the level of an individual project. As the scope of enquiry is widened, clues to the answer begin to emerge. Jonathan Haskel and Gavin Wallis did ground-breaking work in 2010[166] describing signs of growth in UK market sectors that could be attributed to earlier science and research investments through research councils. In more recent work, Jonathan Haskell and Alan Hughes[167] have reported signs of an economic response as soon as three years after public funding goes into some research fields.

Of course, there is also a continual flow of benefit to the economy and society, one example being the movement of people into the wider labour market after they have acquired high-level skills in a strong research base. Concurrently, the attraction of foreign direct investment will deliver benefits to the economy daily. The latter two economic impacts are made possible by the science and research capabilities that have been built up in the UK following long sequences of public funding. It is not easy to measure the time lag between funding and these benefits.[168&169] But we do know that, day-by-day, the impacts of the stock of knowledge and expertise built up from past research has an impact on the economy.

[158] See: "Office of the Vice Provost for Research, Public Policy Team". <www.ucl.ac.uk/public-policy> [accessed 8 September 2014].

[159] See: "SPRU - Science Policy Research Unit : University of Sussex". <www.sussex.ac.uk/spru/> [accessed 8 September 2014].

[160] See: "Policy@Manchester, The University of Manchester". <www.policy.manchester.ac.uk/> [accessed 8 September 2014].

[161] See: "Institute For Fiscal Studies". <www.ifs.org.uk/> [accessed 8 September 2014].

[162] See: "National Physical Laboratory". <www.npl.co.uk/> [accessed 8 September 2014].

[163] See: "Institute of Animal Health". <www.pirbright.ac.uk/> [accessed 8 September 2014].

[164] See: "What Works Network", 2013 <www.gov.uk/what-works-network> [accessed 8 September 2014].

[165] Sir Jeremy Heywood (2014), "Sir Jeremy Heywood on Open Policy Making". <https://openpolicy.blog.gov.uk/2014/07/22/sir-jeremy-heywood-on-opm/> [accessed 8 September 2014].

[166] Jonathan Haskel and Gavin Wallis (2013), "Public Support for Innovation, Intangible Investment and Productivity Growth in the UK Market Sector", Economics Letters, 119. <http://dx.doi.org/10.1016/j.econlet.2013.02.011>. p.195–98.

[167] Jonathan Haskel, Hughes and Bascavusoglu-Moreau (2014).

[168] Bruce A. Weinberg and others (2014), 'Science Funding and Short-Term Economic Activity', Science, 344, 41–43 <http://dx.doi.org/10.1126/science.1250055>.

[169] Mitali Monalisa Tugrul Daim (2007), 'Time Lag Assessment between Research Funding and Output in Emerging Technologies', foresight, 9, 33–44 <http://dx.doi.org/10.1108/14636680710773812>.

07 PUBLIC OPINION

So, what about the most important part of our science and research ecosystem: the tax-paying public?

Even in an environment that values evidence and rigorous argument, public spending decisions will not be made on technocratic terms alone. Public attitudes and commentary from opinion-formers will rightly have an influence. Key decisions on overall funding levels and on the high-level allocation of resources between funding bodies will combine analysis with value judgements. A science and research community that receives several billion pounds each year from taxpayers should expect to maintain the support and engagement of the wider community. That is both in its own self-interest, and a public duty.

In the UK, we have experience of scientific innovation and public opinion getting out of alignment. The likelihood of such misalignment rises if an innovation provokes public unease, and the promoters of the innovation cannot prove unequivocally that it is free from risk. Of course such proof is seldom possible.

Science and research can make us wary. Public concern over genetically modified food ingredients, for example, co-exists with concerns about the security of the food chain.[170] A public debate is currently underway about the implications of fracking to extract shale gas from beneath parts of the UK.[171]

Of course, it can also delight and excite us. Take the examples in **Figure 36**: the discovery in 2010 of the Higgs Boson at CERN, as well as the 2013 discovery of the remains of Richard III in Leicester, generated much international news coverage and at least some wider awareness of scientific and research methods (indeed, part of the evidence supporting the identity of Richards III's remains came from DNA fingerprinting based on Sir Alec Jeffrey's work at the University of Leicester). The construction of a supersonic vehicle to challenge the land-speed record has attracted excitement and sponsorship from thousands of people.

Figure 36 opposite: (a) Richard Noble's attempt on the land speed record; (b) the discovery of the remains of Richard III; (c) the discovery of the Higgs Boson; and (d) the British Science Festival.

[170] Sarah Castell and others (2014), "Public Attitudes to Science 2014". <http://www.ipsos-mori.com/Assets/Docs/Polls/pas-2014-main-report.pdf> [accessed 8 September 2014].

[171] Castell and others (2014), Chapter 14.

Figure 36 **Examples of public engagement in science that have been supported through a broad span of initiatives.**

Medical research charities attract donations of more than £10 per month from nearly 10 million people in the UK.[172] Cancer Research UK and the British Heart Foundation are among the charities with national networks of high street shops. High profile fundraising by medical research charities increases public awareness of science and research in fields that attract popular support **(Figure 37)**.

Figure 37 **Millions of people in the UK support medical research charities through donations and fundraising events.**[173]

[172] See: "AMRC - Association of Medical Research Charities" <www.amrc.org.uk/> [accessed 8 September 2014].

[173] Courtesy of Cancer Research UK.

Survey evidence suggests strong public support for taxpayers' funding of research. Ipsos MORI Social Research Institute prepared a survey of Public Attitudes to Science in 2014.[174] Figure 38 shows 78 per cent of respondents support government funding of science, even when there are no immediate benefits. Ipsos MORI report that similar attitudes are found in surveys in Europe and the US[116], making a case for global support for investment.

Figure 38 Public attitudes to government funding for science.[175]

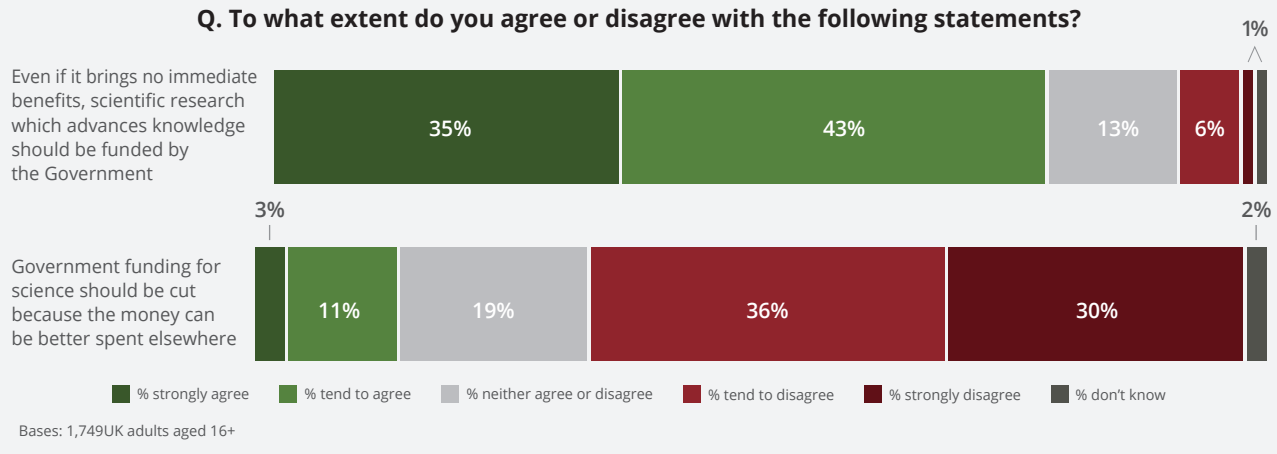
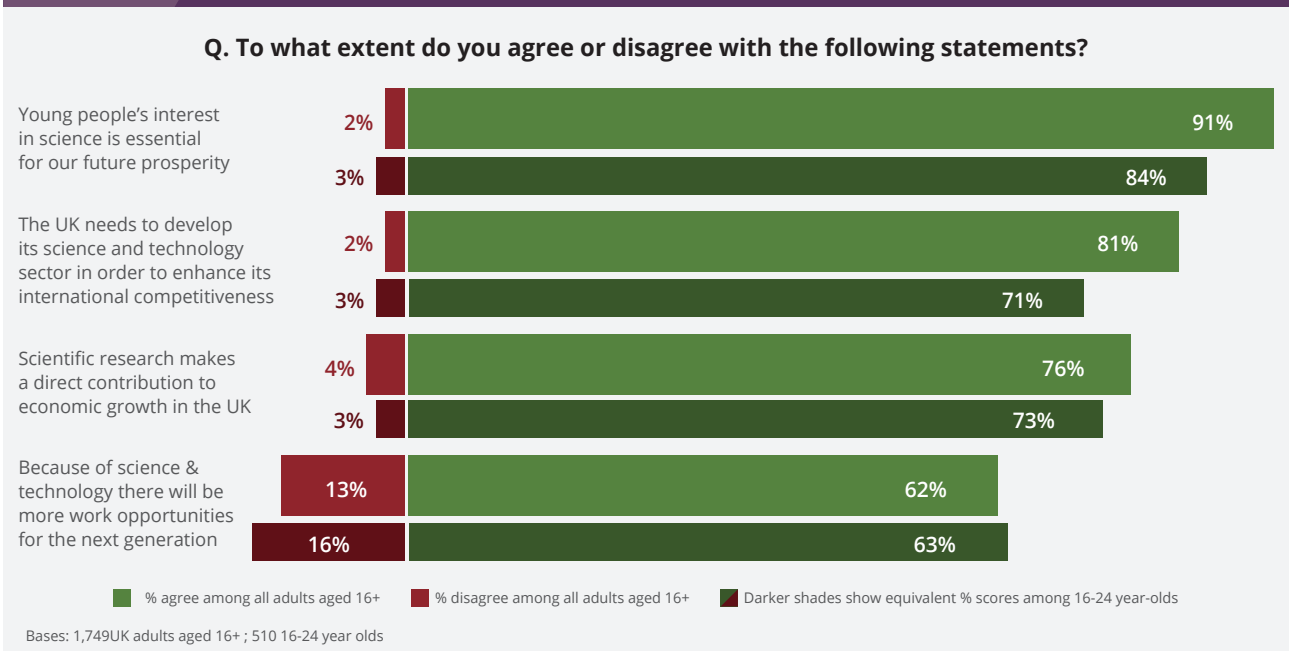


Figure 39 demonstrates that there is also a strong connection made by respondents between science and the economy. Respondents who felt more informed about science and about the way the economy works were more likely to feel positive about the contribution of science to the economy.

Figure 39 Public attitudes to the role of science in the economy.[176]



While recognising the risks of over-interpreting public opinion, this suggests close alignment between public attitudes to science and the policies of successive governments to support a strong science and research base in the UK.

[174] Castell and others (2014). [175] From the Ipsos MORI report for BIS, 2014. [176] From the Ipsos MORI report for BIS (2014).

08 SUMMARY AND CONCLUSIONS

Science and research is a success story for the UK. This country has an outstanding and well-founded reputation for scientific discovery that strengthens our position in many international forums. That reputation attracts talent and investment from around the world, further strengthening our capability and creating a virtuous circle that – so far – has enabled the UK to withstand challenges to our scientific leadership from both emerging nations and more established international competitors.

There have been steady improvements in understanding the relationship between science, research and the economy, both through analytical studies and empirical data. There are signs that we are, at last, escaping from the linear model of research and innovation: that misleading notion of a pipeline between science and wealth, in which fundamental science is only of value once it has been processed though a stage of applied science. Instead, there is a growing appreciation of the science and research base as a delicate ecosystem that delivers a multiplicity of benefits to the economy and society along many complicated, interconnected pathways.

Simultaneously, there has been a transformation in the relationship between universities and business. We still have some way to go on this journey, but already the UK is ranked independently as one of the best countries in the world for university-business relations. Many major firms have moved from individual transactions with UK universities into long-term strategic relationships. There has been progress in building effective relationships between smaller businesses and the science and research community, but many problems remain. These problems are widely recognised, much analysed, and still a long way from solutions.

The performance of the science and research ecosystem in the UK is understood today better than it ever has been, but several perennial questions remain. What makes a nation good at science (and what is meant by "good")? What is the optimum level of government funding for science? What benefits should taxpayers expect from science and research in return for their money? Are those expectations met by current experience?

Finally, there is a wide acceptance of the principle that science and research can only thrive with judicious support from government. The UK is passing through a period of modest investment in science and research, but the consequences of that shortfall are not yet visible. Citations and other performance data reveal our solid science and research achievements in the past. International comparisons present the UK as a scientific superpower. Could our future international position face a decline as a consequence of spending decisions being made now?

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