PA Consulting Group

Research Councils UK

Study on the economic impact of the Research Councils

PART I: Summary

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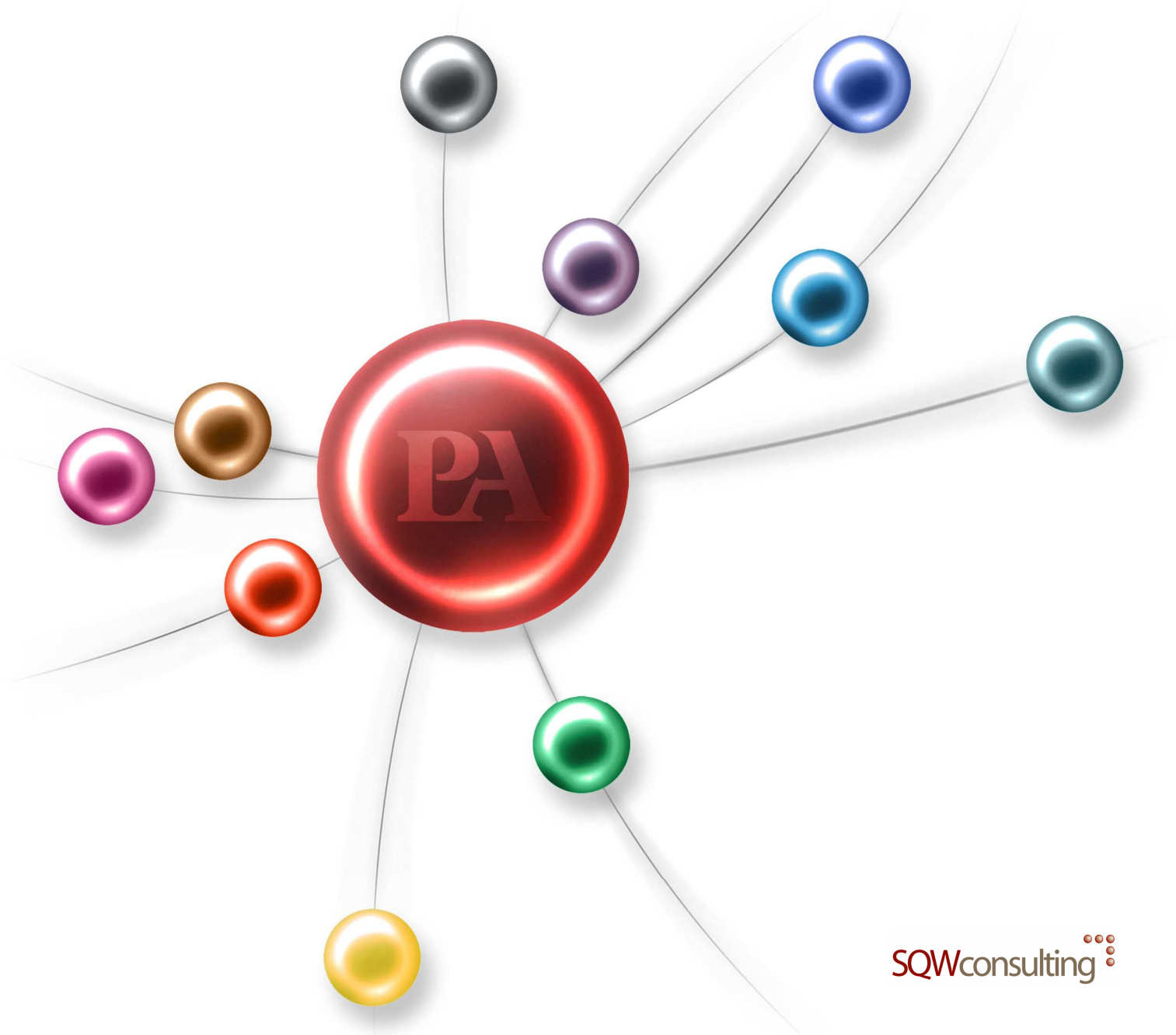

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Executive summary

This report sets out the findings of PA Consulting Group/SQW Consulting on the economic impact of the Research Councils. This work was commissioned by the Research Councils as part of their response to the Warry Report[1] which recommends that 'Research Councils should describe the economic impact of the investment in their field in a one-off report, setting a baseline[2] against which further economic impacts can be assessed and reported on an annual basis'. A further report, to be published later in 2007, sets out the methodological lessons for the future assessment of economic impact.

What is being attempted in this study and its companion is unique. Case studies of the impact of research funded by Research Councils exist, as do attempts to codify methodologies for measuring research impact more broadly. However, undertaking these activities within a single exercise across all Research Councils is new and challenging.

The findings in this report are based on eighteen case studies covering aspects of the work of all Research Councils, supplemented by a broader understanding of the evidence base on the economic impact of research and data from the Research Councils' Output Frameworks[3]. Given the well-understood challenges in assessing impact our findings are partial in their nature and cannot hope to present more than a glimpse of the full impact of the Research Councils. Despite the breadth of our research it has not yet been possible to establish a baseline which will enable a judgement on the extent to which impacts in future years have risen or fallen. This challenge remains to be addressed in the further report.

Nevertheless our analysis points clearly to numerous examples of actual or potential impact and we feel that progress has been made in developing understanding in this area.

This study is divided into 3 parts:

Part I introduces the study and provides an extended summary of impacts derived from our research

Part II details each of the case studies

Part III provides detailed reference material in the form of appendices.

This document is Part I.

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[1] Increasing the economic impact of Research Councils, http://www.dti.gov.uk/files/file32802.pdf

[2] The terms of reference for this report added 'It is anticipated that the baseline will be a descriptive baseline supported by metrics where possible and relevant (which will most likely vary between the Research Councils)'

[3] Office of Science and innovation (2006). Annual Report on Output Frameworks www.berr.gov.uk/files/file34325.doc

Research Council funding has led to a wide range of economic impacts

In 2006/07 the Research Councils received an allocation of around £2,600 million[4] to invest in research covering the full spectrum of academic disciplines from the medical and biological sciences to astronomy, physics, chemistry and engineering, environmental and social sciences, economics, and the arts and humanities. This investment funds research, facilities and people throughout the UK and comprises about 80% of the UK's science budget.

In undertaking this study we looked at work funded by the Arts and Humanities Research Council (AHRC), Biotechnology and Biological Sciences Research Council (BBSRC), Council for the Central Laboratory Research Council (CCLRC), Economic and Social Research Council (ESRC), Engineering and Physical Sciences Research Council (EPSRC), Medical Research Council (MRC), Natural Environment Research Council (NERC), Particle Physics and Astronomy Research Council (PPARC). CCLRC and PPARC recently merged to form the Science and Technology Facilities Council (STFC).

This study reveals many ways in which Research Council-funded activities translate research into impacts. From the evidence we found in the case studies, these can be grouped under the headings[5]:

- 'Development of human capital' (primarily through the acquisition of skills which accompanies the research process)
- 'Business and commercial' (dealing with the commercial adoption of research and exploitation of intellectual property)
- 'Policy' (the impact that research has on the creation and application of, primarily, government policy)
- 'Quality of life' (which looks more broadly at the diverse impacts which manifest themselves in benefits such as improved environment, social welfare, health and cultural advances).

We illustrate each of these impacts through examples taken from case studies and data from the Output Frameworks where this is relevant.

What is striking is the diversity of impacts which emerge from research funding. Furthermore, in a large number of the case studies we found impacts which were not necessarily part of the original rationale for the specific investment. This (along with other factors such as the diffuse nature of research outputs) strongly suggests that our findings are likely to under-represent the full range of impacts. In practical terms, without a comprehensive study of beneficiaries, case studies are only ever to likely capture a small proportion of those who have benefited from the results of a particular investment.

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[4] Science Budget Allocations 2005/6-2007/08 DTI 2005, http://www.berr.gov.uk/files/file14994.pdf. Allocations rose from £2,210,199 in 2004/05 to £2,791,943 in 2007/08. Actual spend may differ from allocations.

[5] This is a simplified version of the groups of impact described in section 4.1 where we also identify publications leading to the codification and dissemination as a category of impact. All case studies provided examples of publications as an output, but their impact will be covered by one or more of the categories listed here

Development of human capital

The training, and migration, of skilled graduates, PhDs and post-graduate researchers is a major impact channel from investment in research. Impacts can be gained through the movement of skilled researchers into industry - raising absorptive capacity and assisting the dissemination and deployment of research results - and also the movement of skilled researchers to other research organisations. The value of this impact is measured in terms of additional salary benefits to individuals, This is the best proxy of the value which employers place on higher skills and, therefore, their contribution to the economy.[6]

Two of the case studies (EPSRC's Engineering Doctorate (EngD) programme and PPARC studentships) were specifically concerned with PhD outputs:

- We found that EngD graduates, relative to other PhD graduates in similar disciplines, enjoyed significantly higher salaries (between £100,000 and £300,000 over their careers) as a result of their training. The aggregate salary benefit resulting from EngD over the case study period therefore could be as much as £80 million, if all achieve the highest salary benefit, for an EPSRC investment of around £12 million
- PPARC PhDs follow a more standard training programme with a concentration on research in PPARC areas. The evidence suggests that average career salaries are around £70,000 higher than equivalent individuals with a first degree which is broadly comparable to the cost of their training even before consideration of broader research outputs.

In both case studies, students have the opportunity to develop personal and transferable skills as well as their research capabilities

In 2004/5, there were 119,450 higher degrees obtained in the UK, 15,775 of which were doctorates. In 2002, the UK was ranked 1st in the G8 for PhDs awarded per amount of R&D performed in the Public sectors and this carries through to productivity, being 2nd in the G8 for citations per researcher, and 4th overall in the world.[7]

Business and commercial impacts

Impacts from the innovation process arise in three ways and our case studies produced clear examples of business and commercial impacts from each:

- Knowledge transfer through collaboration (primarily between businesses and academics)
- Generation and exploitation of intellectual property and related outputs
- Creation of clusters and the impact that has on, for example, inward investment.

Knowledge transfer through collaboration

[6] See, for example, O'Leary & Sloan (2005)

7 Source: Office of Science and innovation (2006). The 2007 report was in production as this report was being published.

Several of the case studies involve direct collaboration between businesses and academics. These obviously include the LINK programmes, but also others such as Advanced Institute of Management (AIM), the EngD programme and the Protein Phosphorylation Unit (PPU) at the University of Dundee. These programmes have (to different degrees) supported business capabilities to undertake R&D through:

- Ensuring research is relevant to end users and keeping researchers up to date with issues affecting the user community. The EngD programme, for example, ensures that the training of skilled graduates is focused on the real-world challenges that businesses face
- Transfer of knowledge through interactions between academics and businesses. The knowledge transferred is both new techniques and research outputs. The AIM research initiative interacted with a wide range of businesses, including with 36 of the FTSE 100 companies through seminars and workshops. This resulted in the active sharing of research findings leading to changes in ways of approaching innovation in a number of the businesses involved. The LINK programme case studies leveraged more than 50% of funding from private sector contributors as part of the scheme's conditions. Commitments have often continued, with more than 30 businesses, many international, participating in membership based schemes arising from the Foresight Challenge and the Polymer Interdisciplinary Research Centre (IRC)
- The development of expertise or insight through the use of instrumentation and scientific facilities (most pronounced in relation to the Synchrotron Radiation Source (SRS) and Lasers for Science Facility (LSF) within the cases we studied).

Data covering 2003-04 for UK Higher Education Institutions (HEIs)[8] indicates:

- An 18% increase in income from contract research as compared to 1999-00. For Public Sector Research Establishments (PSREs) the second annual survey indicates a rise of 47% in income from business from 2003-04 to 2004-05
- The overall value of collaborative research has risen by 13 per cent in the UK, to £541 million and consultancy income to £211 million.

Intellectual property and other commercial outputs

Many of the case studies have generated, or are expecting to generate, Intellectual Property (IP) and other forms of direct commercial outputs. There is a very wide variation between them, in part reflecting subject area, and also timescales from completion of research, but the general picture is as follows:

- There have been a number of significant licensing deals (Bio-molecular Science Committee (BMS), Polymer Research and the PPU case studies)
- BMS, Polymer Research, Foresight Challenge and the PPU have generated spinouts which have raised substantial external investments

8 Source: Office of Science and innovation (2006). .

- One of the main outcomes of the AHRC Surrealism Centre was a major exhibition at London's Hayward Gallery which has generated significant expenditure impacts
- Similarly, books funded under the AHRC's Research Leave Scheme have seen direct commercial returns
- Of a rather different nature is the use of scientific facilities by industry. The SRS, for example, sells beam time to businesses. The direct revenue to SRS is likely to be dwarfed, however, by the wider impact arising from businesses' exploitation of knowledge that is developed by using the facilities.

Data covering 2003-04 for UK HEIs[9] indicate:

- An 86% increase in number of patent applications and 146% increase in number of patents granted annually as compared to 1999-00
- A 288% increase in number of licenses and options granted and 64% increase in gross income from IP since 1999-00. For PSREs the second annual survey indicates a fall of 53% in the number of licenses executed but a rise of 32% in the income from licensing from 2003-04 to 2004-05.

Clusters and inward investment

Research Council funding has helped to create, improve or sustain a number of clusters of research excellence. More generally, many of the case studies describe researchers working with multinational companies and these contacts will help to ensure that the UK is recognised as a centre of scientific excellence and considered in investment decisions as appropriate. For example:

- MRC funding of the PPU at Dundee has contributed to a Biotech cluster in Dundee area which received £50 million joint private-public sector investment
- The Foresight Challenge projects led to sustained centres of which at least one attracts inward investment on an ongoing membership basis from around 20 major companies; the EngD centres have resulted in other research centres with industry support
- The Daresbury Science and Innovation Campus, which encompasses the SRS, is being developed and has successfully attracted over 40 firms to co-locate on the Campus. The Daresbury Laboratory has supported around two thirds of those.[10]

Policy impacts

The impacts of research on policy arise in two ways:

- Production of a body of research over a period of time which influences ‘received wisdom’ (the 'General Enlightenment' model)
- Direct responses to specific requests for policy inputs, either through commissioned research or advice from individuals (the 'Direct Influence' model).

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9 Source: Office of Science and innovation (2006). The 2007 report was in production as this report was being published.

[10] A similar development is planned adjacent to the Rutherford Appleton Laboratory; the location of Diamond and ISIS.

The first impact channel is particularly difficult to track.

Two of the studies (Centre for the Analysis of Social Exclusion (CASE)[11] and the Tyndall Centre) described research which is specifically relevant to policy issues and two more (AIM and the Institute of Animal Health (IAH)) described research initiatives which have important policy dimensions to their work.

More specifically we can identify impacts in the case studies:

- There are frequent references to the work of the Tyndall Centre in Hansard which suggest it is having policy influence both in the UK and internationally. In addition, its consultancy activities are self-sustaining indicating a demand for its specialist expertise
- Interviewees report that "CASE research work enabled government to make better policy, and faster than would otherwise have been produced" and its contribution to the Sure Start programme is used as an illustration of the potential scale of impact
- AIM contributed to the DTI's innovation review[12] in 2003, by organising a strategic research forum in the review's early stages. The forum focussed on areas around innovation of importance to the DTI. AIM was also cited as having funded research on the subjects of 'ownership and productivity, research and development (private and university), the benefits of university collaboration and the impact of engagement in Far East economies.' Such work was regarded as influential in forming a much more sophisticated understanding of the factors holding back UK productivity growth
- The IAH is a reference laboratory for several diseases and receives samples of all new strains as they are encountered. IAH is central to surveillance and diagnostic duties, as well as research into the development of faster and more efficient ways of overcoming the challenges to animal health posed by infectious diseases which have a potentially huge cost to the UK economy
- The potential contribution of a book produced under the AHRC Research Leave Scheme to the Northern Ireland peace process.

Quality of life impacts

Research Council outputs, as described above, have improved the delivery of public services and this gives rise to a direct economic benefit in the form of cost savings to the exchequer and others. However, Research Council outputs also contribute directly to the quality of life and this generates social benefits over and above efficiency savings. They can often be the most difficult to value but are relatively easily identified.

They can be described in the following ways:

- Healthcare benefits which improve the quality of life for patients and carers
- Prediction of environmental impacts and how they might be addressed

[11] CASE is also a form of studentship sponsored by the Research Councils. To avoid confusion throughout the report "CASE studentship" is used to describe those and CASE refers the Centre.

[12] http://www.berr.gov.uk/files/file12093.pdf

- Social welfare benefits such as cohesion or enhanced security. These may often be the result of achieving policy goals
- Cultural advances. It is widely argued that improvements in cultural life generate benefits to society over and above those which are measured by willingness to pay. This is perhaps evident both in relation to arts and also humanities, and also in relation to research which improves our understanding of the fundamental laws of nature.

The case studies have produced examples of all four types of quality of life impact:

- Many of the case studies (particularly those of BBSRC, MRC and PPARC) are targeted, ultimately, at biomedical improvements which will enhance health care and potentially longevity of life
- The Tyndall Centre's objective is to focused on 'seeking, evaluating and facilitating sustainable solutions to climate change'. In addition, Foresight Challenge led to development of new materials that help reduce CO2 emissions in aero-engines and the EngD programme led to improvements in ways of reducing nuclear waste and other pollutants reduction
- The ESRC's CASE Centre carried out longitudinal research which led to understanding which factors contribute to social exclusion. This research then informed the development of government policies which sought to tackle issues such as early years provision. This in turn affects quality of life of those who benefit from the provision. Books produced under the AHRC Research Leave Scheme which were felt to have contributed to bringing the communities in Northern Ireland closer together and improving the understanding of the plight of children in conflict situations
- The Surrealism Centre which added new dimensions to the study of one of the most important art forms of the 20th Century.

Net outputs

In all cases we have tried to assess the extent to which the research, and ensuing outputs, would have occurred in the absence of Research Council funding.

The first question is whether another organisation might have funded the research. Charities are of course an alternative source of funding for many researchers but, with the exception of the Wellcome Trust, are much smaller than the Research Councils and do not invest in basic research to the same extent. If we take any single programme in isolation, then one of the charities might have supported it, indeed there are many examples of joint funding in the case studies, but this would inevitably have been at the expense of some other area, and in aggregate the charities cannot be considered a substitute for the Research Councils[13]. The other potential source is industry, but the fundamental nature of most of the activities we have examined means that in most cases, Research Council funding is genuinely additional.

[13] There is, of course, also the point that most would withdraw if they believed they were simply substituting for public funding.

Finally there is strong feedback from much of the co-funded programmes (LINK, EngD, Foresight) that there is a willingness to pay in partnership with Research Councils - and it is seen as an effective way of doing relevant research. In many cases, then, leverage is seen to be significant.

We have drawn much of our evidence from case studies

In Figure 1: below we set out, where possible, a range of impacts[14] [15] from the eighteen case studies we undertook. We note two factors which act in opposition when considering whether we have been conservative or liberal in our attribution of impacts:

- On one hand, the case study approach is likely to lead to a partial view of impacts - the need to limit the scope of the case studies and the number of interviewees means that impacts will almost certainly have not be captured comprehensively
- On the other, the impacts set out below include potential and illustrative impacts in addition to actual impacts identified. Potential and illustrative impacts are ways of presenting a fuller picture of impact given the time lags associated with much research and the difficulties in attributing impacts to specified activities and have been used in previous estimations of impact through case studies (see section 4.3).

One notable feature of the case study approach is that it paints a rich picture of impacts - recognising that the impacts resulting from a particular stream of Research Council funding are likely to cut across the range of impact categories defined above.

[14] For details on the robustness of each impact, see section 4.2 and individual case study chapters.

[15] Currency values are generally given in £sterling. Where other currencies are used this reflects the original research on which they were based in order to avoid confusion through currency adjustments.

Figure 1: Examples of impacts for each Research Council derived from case studies

Research Council	Case study	Key characteristics	Impact
AHRC	Centre for Surrealism	Funding for group of universities to undertake research in surrealism. The Centre has, inter alia, organised a number of exhibitions. AHRC input ~ £0.9 million (total).	Actual impacts include: 'Undercover Surrealism' exhibition generated economic impact of ~ £1 million (conservative estimate) Potential impacts include restoration of credibility of surrealism research and contribution to development of creative industries.
AHRC	Books and monographs (Research Leave Scheme)	Funding which provides time for researchers to write up research findings in book or monograph format. AHRC input < £50,000 (total).	Illustrative impacts may include: Savings from lower security costs in Northern Ireland ~ contribution to saving of £200 million annually Increased inward investment to Northern Ireland ~ contribution to increase of £150 million annually from US alone.
BBSRC	Institute for Animal Health	IAH undertakes basic research into animal diseases. It is also a reference laboratory for several diseases and undertakes tests and diagnoses. BBSRC input ~ £3.8 million (2005/06).	Actual impacts to which IAH has contributed include the eradication of Rinderpest, with a net economic benefit to Africa > $1,000 million annually and thereby supporting UK development policy goals.
BBSRC	Bimolecular Sciences Committee	Basic research across the boundaries of physical sciences and biology. BBSRC input ~ £22.5 million (2005/06). EPSRC contribution of 1/3rd of budget (1994 - 2002)	Actual impacts include early stage direct benefits arising from software licensing and establishment of new companies, including: External investment in companies of at least $600 million. Some were in part sponsored through the Applied Genomics programme Software licensing revenue ~£1 million (includes some SRS activity) Sales revenue ~ £15 million annually for the start up companies.

Research Council	Case study	Key characteristics	Impact
CCLRC	Lasers for Science Facility	Central resource for researchers. CCLRC input ~ Part of £8 million funding for whole Central Laser Facility of which LSF received ~£1 million (2005/6).	Actual impacts include: £0.25 million funding attracted for an early stage spin out £1 million total investment leveraged from EU and private sector sources. Illustrative impact from realising improvements in healthcare through new drug discovery could realise £multi-millions.
CCLRC	Protein crystallography at the SRS Daresbury	Use of the Synchrotron radiation source by academics and businesses. CCLRC input ~ £12.6 million (1995-2004).	Actual impacts include, for one new business user of SRS, the raising of ~ £50 million in funding. Software developed from SRS (and BBSRC funding) generates licensing revenue ~ £1 million annually. Illustrative impact on drug product revenues could range from $15-200 million annually.
EPSRC	Engineering Doctorates	Doctoral training programme designed to produce engineers with management skills. EPRSC input ~ £12 million (1992/3-1997/8).	Actual impacts include: Leverage around £30,000 per student from private sector Market capitalisation of company founded by EngD during studies >£100 million Contribution to innovations from EngD students including: a new test method estimated to have saved £ millions by reducing warranty returns; • a premium product with lower manufacturing overheads realising a total margin of £ tens of millions annually; a new lower environmental impact product that has become the world leader; • novel engine management techniques yielding significant fuel and cost savings, and lowervolumes of persistent pollutants with implications for climate change

Research Council	Case study	Key characteristics	Impact
			Salary benefits for cohort ~ £80 million (maximum) a proxy for economic impact.
EPSRC	Foresight Challenge	Collaborative research with businesses in the broad area of applications of ICT. EPSRC input ~ £8.6 million (1997-2000).	Actual impacts include: Leverage ~ £8-10 million funding from private sector Creation of new business, of which one, Parc Technologies was sold to a multinational, Cisco for $9 million in 2005 Impact of Mobile VCE estimated at many £ millions and has contributed to retaining multi-national telecommunications research capability in the UK, Potential benefits include a cost savings of ~ £5 million from more effective aero-engine development process due to improved insight into materials Illustrative benefit of new materials from potential contribution to more fuel efficient aviation ~ $828 million.
EPSRC	Basic research in polymer science	Mixture of responsive and directed mode funding. The case study sampled universities attracting around £16 million of funding from a total EPSRC input of around ~ £49 million (1992 - 1996).	Identified actual impacts include: New polymer licensed with an investment of ~ £10 million by the company exploiting the technology Cost savings through improved modelling processes ~ £0.1 million per product development project (products not specified) Spin-out company (CDT) recently merged with Sumitomo in a deal valued at $285m.
ESRC	Centre for Analysis of	A focus on one area of CASE's work: Generational	Contribution to development of evidence-based policy for Sure Start programme where Government currently spends £1,000 million per

Research Council	Case study	Key characteristics	Impact
	Social Exclusion	and Life Course dynamics. ESRC input ~ £1.2 million (97/98-05/06).	year. Potential broader impact from better, faster policy making in sphere of social exclusion.
ESRC	Advanced Institute of Management	AIM is a network of research fellows designed to address key management issues and to develop relationships between business schools and businesses. ESRC input ~ £21.8 million (2002-2007). EPSRC input ~ £3.2 million (2002-2007)	Illustrative impact of potential increase in turnover growth in AIM-associated companies ~ £4 - 20 million (current year). Potential to raise the impact of management theory on industry practice - including through high quality publications and associated activities.
MRC	Protein Phosphorylation Unit (Kinases research)	Protein Phosphorylation Unit at the University of Dundee, founded in 1990 MRC input ~ £16 million (total).	Actual impacts identified include: Leverage ~ £23.4 million (1999 - 2008) from private sector 22 licenses (undisclosed amount) Royalties ~ $1.1 million annually Biotech cluster in Dundee area received £50 million joint private-public sector investment (1997). Illustrative impact from accelerating drug discovery process ~ £ multi-millions.
MRC	DNA Technology	Aspects of DNA technology research. MRC input ~ £12.5 million (estimated) since 1974.	Actual impacts include two major spin-outs ~ $160 million market capitalisation for one. The other is a key contributor to the $600 million DNA micro-array market. Wider benefits include a contribution to the $2,000 million global biochip market.

Research Council	Case study	Key characteristics	Impact
			Illustrative impacts include a potential £47 million benefit from earlier detection and conviction through DNA fingerprinting.
NERC	Ocean Margins LINK programme	A LINK programme with the objective of developing a scientific understanding of effects in deep water oceans. NERC input ~ £9 million (2000 - 2007).	Actual impacts include leverage ~ £9 million from private sector. Potential impact expected in the short to medium term include improved risk mitigation and site prediction in oil drilling in Atlantic margins ~ £100 million. Illustrative wider impact includes the application of analytical techniques to drugs testing in sport ~ £10 million annually.
PPARC	PhD students	The subsequent career paths of PPARC funded PhD students. PPARC input ~ £65,000 per student.	Actual impacts include returns to individual ~ £70,000 average return per student (relative to those without a PhD), a proxy for econoic impact. A large spread of salary benefit identified, including a significant minority (~20%) with financial services salaries substantially more than double the average.
PPARC	Detectors research and its use for medical imaging	PPARC supports the development of leading edge detectors for use in major facilities. This case study looked at the transfer of these technologies to medical imaging devices. PPARC input ~ £2 million (but difficult to differentiate funding).	Nature of the dissemination of the codified knowledge from the research is such that direct impacts are difficult to identify. An illustration suggests that leading edge detectors have potential to contribute towards impact of improved medical applications, including ~ £1,000 - 10,000 million annually in avoidance of premature deaths
Cross-Councils	Tyndall Centre	Virtual Centre for interdisciplinary research into climate change. Centre established with core funding of £10m provided 50% NERC, 37.5% EPSRC, and 12.5%	Actual impacts identified include: Leverage of ~ 40% of funding from mix of private, public and charity sectors Self sustaining consultancy services

Research Council	Case study	Key characteristics	Impact
		ESRC.	Potential contribution to influence on UK and global policy- making addressing £310,000 million global warming challenge.
Cross-Council	Applied genomics research	A LINK programme sponsored by BBSRC, MRC and the DTI. Research Council inputs ~ £14 million (total).	Actual impacts identified include: Leverage ~ £14 million from private sector Six companies received further investment > £500 million. Some were in part sponsored by the work shown in the Biomolecular Sciences Committee case study. Illustrative impact from accelerating drug discovery process ~ £ multi-millions.

As part of this work we have reviewed existing studies of Research Council activities. These help flesh out our understanding of different sorts of impact and we present results in Figure 2. We note that these are not exhaustive. The full list of impact studies we have identified and analysed during this study is presented in section 4.3.

Figure 2: Actual and potential/illustrative impacts from existing studies of Research Council activities

Type of impact	Actual	Potential/illustrative
Business and commercial	Polynesian Visual Arts Exhibitions (AHRC) ~ £8 million in visitor expenditure. 'The past, present and future of flexible housing' (AHRC) ~ £0.1-4.2 million on housing maintenance savings and gross rental income increase of £0.03-1.3 million (in 2004-05). Raphael Exhibition (AHRC) ~ £30 million in visitor expenditure. Biotechnology Young Entrepreneurs Scheme (BBSRC) ~ £5 million investment raised by 3 entrepreneurs. Rothamsted Research (BBSRC) increased yield for 1500 farms in Uganda/Kenya by 20-50%. Bioscience Business Plan Competition (BBSRC) ~ £2.3 million investment raised for spin outs, £0.5 million license agreements, £1.2 million income from contracts (2003). 'Impact of EPSRC research' ~ £1,500 million raised by spin outs in 3 years.	Centre for Research in Intellectual Property and Technology (AHRC) ~ £8.3-11 million in projected revenues from education courses. 'Are transparent/translucent architectural structures possible?' (AHRC) ~ £2-3 million GVA and £0.5-1 million royalties over 25 years. Helping develop a UK marine biotechnology industry (NERC) ~ £224 - 1,222 million. Providing subsidence and ground instability data to insurers, developers and local authorities (NERC) ~ £70-270 million. Reducing the cost of gritting and salting icy roads (NERC) ~ £20 million. Discovering the hole in the ozone layer (NERC) ~£8-40 million. Flood Estimation Handbook (NERC) ~ £7-34 million. Lowland Catchment Research Programme (NERC) ~ £2-9 million.
Impacts on society (Includes policy and quality of life impacts as these are often difficult to dissociate in secondary research)	AHRC, 'Are translucent / transparent architectural structures possible?' Reductions to landfill. ESRC, A case study of the Future of Work programme, approach and analysis. Changes to employment legislation, families bill and maternity-paternity leave .	AHRC 'The past, present and future of flexible housing' Improved housing to suit changing lifestyles. BBSRC Making a difference – the past and future and societal impact of Rothamsted research. Environmental protection through reduction (£12 million) on fungicide spraying.

Type of impact	Actual	Potential/illustrative
	ESRC, Econometric modelling. More effective management of the national economy. MRC, Laboratory for Molecular Biology. Improved healthcare.	EPSRC, Connecting with business: The impact of EPSRC research on society and the economy. Buildings are responsible for 45% carbon emissions in the UK. Research is underway to construct 0% carbon buildings by 2016. NERC, Economic benefits of environmental science. Improved environmental monitoring and responses.
Human capital	Few of the Research Councils' own case studies explicitly address human capital issues. The main exceptions are the evaluation of the BBSRC modular training initiative and the Knowledge Transfer Partnership/TCS evaluations. Both are concerned, directly or indirectly, with enhancing business relevant skills and have been successful in this respect. However human capital impacts have been much wider than this: all research programmes have involved, and supported, PhD students other components of the literature review have found that non-academic partners in collaborative research have, generally, leant new skills and techniques form the collaboration PhDs involved in collaborative research have developed business relevant skills. Some of the specific programmes designed to promote knowledge transfer, for example the business plan competitions and the fellowship schemes, have had similar impacts.	

The evidence we have collected provides a practical way of assessing impact, but still has significant limitations

The method chosen for this study focused around the development of 18 case studies (including 2 cross-cutting studies) and a review of existing evidence. Case study fieldwork was undertaken in the period May to July 2007. Case studies were selected in discussion with Research Councils on the basis of an approach designed to optimise the coverage of a limited sample. Potential interviewees were also selected in discussion with Research Councils and thereafter often in discussion with the award holder(s). Evidence from stakeholder interviews was supplemented by data on case study inputs and by secondary research based on existing material.

It was intended that the results from these case studies would be presented both 'in their own right' and, potentially, as indicators of broader impact; the project has succeeded on both of these aims. This report provides many examples of how Research Council investment has resulted in realised or potential impacts, some of which we have been able to value. However, despite using all the relevant evidence available to us - output monitoring data, existing case studies and wider impact literature - we cannot robustly extrapolate from the case study findings to total spend. As a result, the findings do not of themselves provide a baseline against which future performance can be assessed.

This is partly a result of the limited number of case studies which are the focus of this report (the case studies chosen cover significantly less than 2% of Research Council expenditure in any one year.). Beyond this though, there will always be difficulties in valuing Research Council-related impacts. The first set of difficulties is methodological - in summary we are faced with problems of attribution, traceability, measurability and time lags. As an example, some major outputs, notably publications, are diffused widely and it is challenging to assess their impacts with any degree of confidence. The second set of difficulties is more practical - even where outputs are more targeted, for example collaborative research programmes, impacts can only be assessed through detailed surveys of collaborating businesses and other organisations and the resources required to cover a significant proportion of Research Councils' expenditure are unlikely to be available.

It was always intended that this report would pilot a methodology for assessing impact and that we would identify the challenges involved in applying this methodology. The preparation of a further report is underway which sets out in more detail these challenges and attempts to identify potential ways of overcoming them.

In conclusion

This summary has explored the ways in which Research Council-funded activities translate research into impacts and the range of impacts themselves. It has described the methodology used to identify these impacts and look at the challenges in making an assessment of impact.

The rest of the body of this Part I summary report is divided into 5 chapters:

- Chapter 1 introduces the study, its context and objectives and outlines the work of the Research Councils
- Chapter 2 describes how research generates impact
- Chapter 3 sets out the challenges with measuring impact and the methodology we have used in this study
- Chapter 4 sets out the evidence we have gathered in our study on the economic impact of Research Councils
- Chapter 5 sets out the extent to which this report provides a baseline for measuring economic impact and looks at the implications for the future.

References to supporting information can be found in Part II (Case Studies) and Part III (Appendices).

1 Introduction

This report sets out the findings of PA Consulting Group/SQW Consulting on the economic impact of the Research Councils. This work was commissioned by the Research Councils as part of their response to a recommendation in the Warry Report which recommends that 'Research Councils should describe the economic impact of the investment in their field in a one-off report, setting a baseline against which further economic impacts can be assessed and reported on an annual basis'.

This chapter sets out the report's context and its objectives.

1.1 Context for this report

At the request of the Director General of Science and Innovation, Sir Keith O'Nions, the Research Council Economic Impact Group made recommendations as to how Research Councils can deliver and demonstrate that they are delivering - a major increase in the economic impact of their investments. The group comprised of senior academics, a number of Research Council Chief Executives and business people. The recommendations were delivered in a report (the Warry report) published on 14th July 2006[16] and can be summarised in three key issues for Research Councils:

- Their leadership of the knowledge transfer agenda
- Their role in influencing knowledge transfer behaviour of universities and Research Council Institutes
- Increasing their engagement with user organisations.

The report recognises that Research Councils have pivotal roles, both as funding bodies and as leaders of the research base. It adds that Councils are already increasing their emphasis on knowledge transfer and the economic impact of their work but must increase this emphasis further without sacrificing the research excellence for which the UK is rightly admired.

[16] Increasing the economic impact of Research Councils, DTI 2006 http://www.dti.gov.uk/files/file32802.pdf

Around 80 percent of the Science Budget, some £2,600 million (in 2006/07), is delivered through the seven Research Councils[17]. In light of the Comprehensive Spending Review, this was an appropriate time to investigate the current economic impacts of Research Council activity and to recommend how these impacts can be substantially increased in the future. A much improved description of existing economic impact is clearly essential before improvements can be made and recognised.

One of the recommendations of the Warry Report was that Research Councils 'should make strenuous efforts to demonstrate more clearly the impact they already achieve from their investments'. A specific action to go some way to meeting this recommendation is stated as: *'Research Councils should describe the economic impact of the investment in their field in a one-off report, setting a baseline against which further economic impacts can be assessed and reported on an annual basis'.*

1.2 Objectives for this report

In order to attempt to meet the recommendation set out in the Warry Report, the Research Councils commissioned this study in March 2007. The terms of reference for this report stated that:

'The study will set a baseline in producing a repeatable methodology that will result in a description and broad assessment of the economic impact of the Councils' activities, against which future achievements can be assessed. It is anticipated that the baseline will be a descriptive baseline supported by metrics where possible and relevant (which will most likely vary between the Research Councils).'

This report therefore:

- Provides, by way of the case studies, many examples of how Research Council investment has resulted in realised or potential impacts, some of which we have been able to value
- Summarises outputs from the case studies (and previous reviews)
- Illustrates what sort of impacts might result from a given set of inputs in a particular context (although this will require some assumptions to be made which are not rigorously testable).

However, it does not provide a single figure or range of figures which identify impact at an aggregate level or levels. This is partly a result of the limited number of case studies which are the focus of this report (we have limited data covering a very small proportion of Research Council expenditure) and partly a result of the more general challenges involved in measuring economic impact which are set out below. The preparation of a further report is underway which sets out in more detail these challenges and attempts to identify potential ways of overcoming them.

[17] At the time this report was commissioned, the CCLRC and PPARC had recently merged into the Science and Technology Facilities Council (STFC). However, as the study is backward looking it was appropriate to recognise the two separate councils and we therefore studied the work of eight Councils.

1.3 The work of the Research Councils

Research Councils are the public bodies charged with investing taxpayer's money in science and research in the UK in order to advance knowledge and generate new ideas which can be used to create wealth and drive improvements in quality of life.

Each Research Council funds research and training activities in a different area of research ranging across the arts and humanities, social sciences, engineering and physical sciences and the medical and life sciences. The Councils employ around 12,000 staff, and support around 30,000 researchers, including 15,500 doctoral students in UK universities and in their own Research Institutes.

There are currently seven Research Councils:

- Arts and Humanities Research Council (AHRC)
- Biotechnology and Biological Sciences Research Council (BBSRC)
- Engineering and Physical Sciences Research Council (EPSRC)
- Economic and Social Research Council (ESRC)
- Medical Research Council (MRC)
- Natural Environment Research Council (NERC)
- Science and Technology Facilities Council (STFC).

All are Non-Departmental Public Bodies (NDPBs), established by Royal Charter and are independent legal bodies outside of Government, accountable to Parliament.

The Research Councils have common objectives, which are to:

- fund basic, strategic and applied research
- support postgraduate training (PhDs and masters students and fellows)
- advance knowledge and technology and provide services and trained scientists and engineers to contribute to the economic competitiveness, the effectiveness of public services and policy, and quality of life
- support science in society activities.

The STFC owns and operates large facilities. These world-class institutions support the research community by providing access to advanced facilities and an extensive scientific and technical expertise.

Figure 3 below sets out a breakdown of funding by Research Council. Figure 4 sets out funding by major funding category (research, facilities and training).

Figure 3: Breakdown of Research Council funding (PA/SQW analysis. Source Research Council Annual Reports 2005-06)

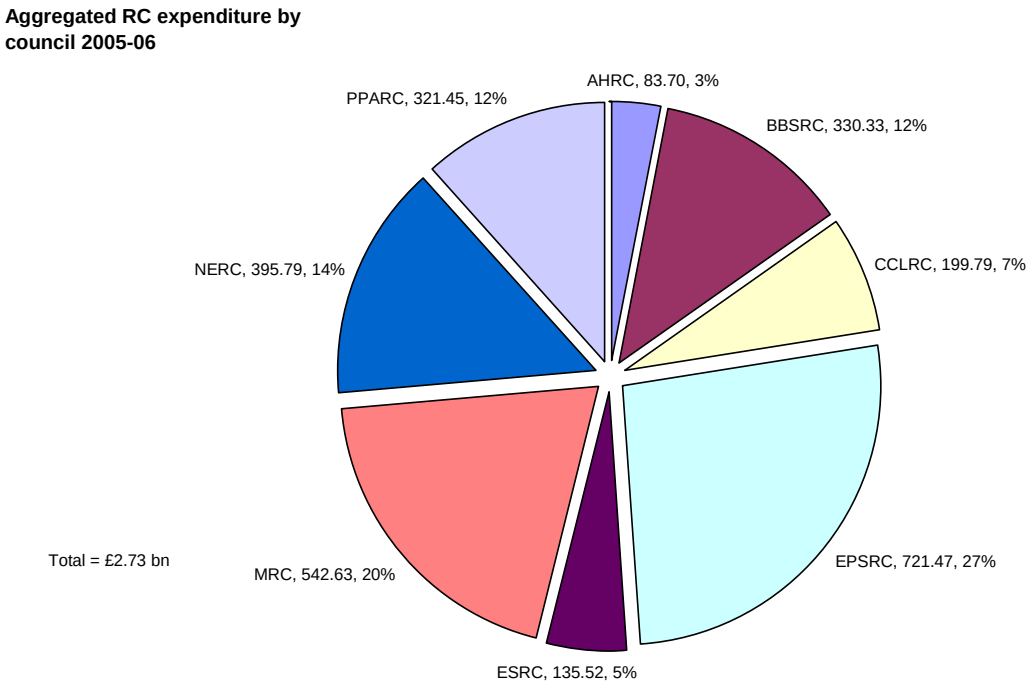
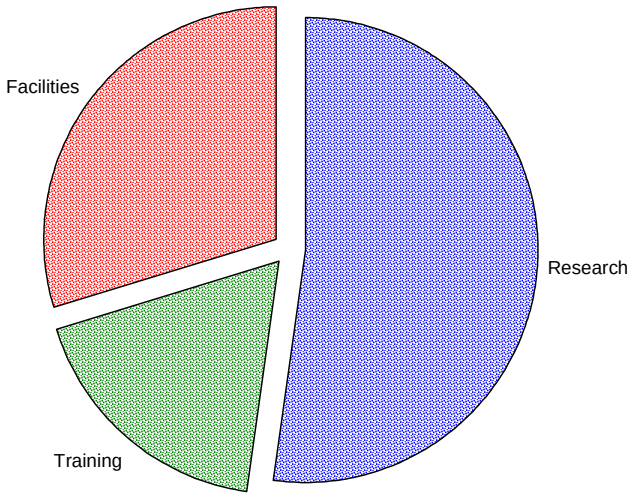


Figure 4: Breakdown of Research Council funding by category (PA/SQW analysis. Source Research Council Annual Reports 2005-06)



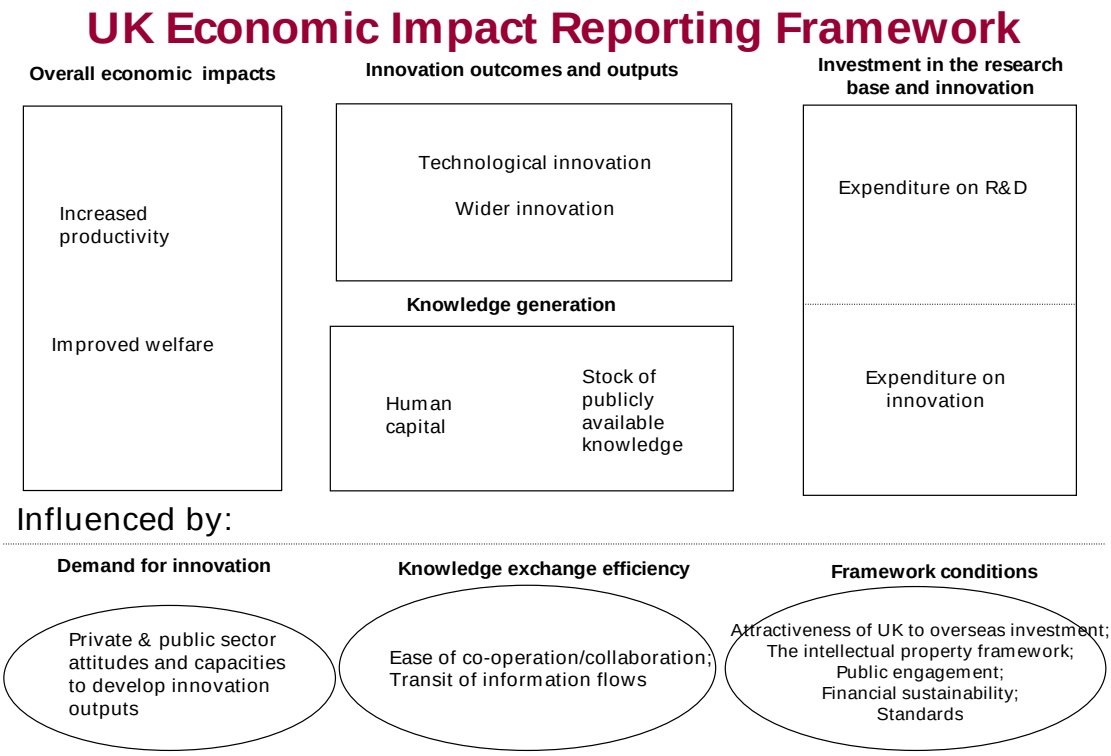
2 How does research generate impact?

This chapter sets out a definition of economic impact, the rationale for public funding of research and identifies the ways in which impacts arise.

2.1 What is economic impact?

As set out in the recent DTI paper[18], 'A policy action has an economic impact when it affects the welfare of consumers, the profits of firms or the revenue of government. Economic impacts range from those that are readily quantifiable, in terms of greater wealth, cheaper prices and more revenue, to those less easily quantifiable, such as effects on the environment, public health and quality of life. The economic impacts of science and innovation include the resulting contributions to long-term, sustainable economic growth and increased overall welfare.' Figure 5 sets out a picture of the contributors to impact, taken from this paper.

Figure 5: Schematic of UK Economic Impact Reporting Framework



[18] "Measuring economic impacts of investment in the research base and innovation – a new framework for measurement", DTI (2007)

2.2 Economic rationale for public support of research

2.2.1 Market failure

The traditional rationales for public funding of R&D derive from market failure arguments. A market failure arises when the price which economic agents pay for a good does not reflect the value of that good to society. As a result, non-optimal amounts of the good are produced and consumed. Market failures in relation to R&D arise because of the likelihood that investors in R&D are unable to appropriate all the benefits which society might derive from research outputs. This is a well established and robust rationale for much of the Research Councils' activities. It is also the underlying rationale for the intellectual property rights system which provides inventors with a temporary monopoly over their invention enabling them to charge higher prices and therefore appropriate more of the benefits than would otherwise be the case. For various reasons, however, the patent system cannot remedy all market failure problems.

2.2.2 Systems failures

Economic literature recognises that innovation must be perceived as a complex social process which contributes to the distributed nature of knowledge production and diffusion through the creation of greater agency linkages and mobility of human resources.

It follows that the impacts of public support for research extend beyond the direct outputs of the traditionally defined 'innovation process' and could also include system factors such as network development and linkages between knowledge producers and knowledge users as measures of value (Georghiou & Roessner, 2000). Along similar lines, Bozeman & Rogers (2002) propose a "pre-economic" approach to evaluating scientific knowledge which highlights the role of research collectives and networks engaged in knowledge production. In this way, increasing prominence has also been given to the non-economic benefits of public sector investment in research including the development of human capital, the development or improvement of research networks, and institutional development.

2.2.3 Cross-disciplinary research

One of the most striking features of recent years is the emergence of new scientific fields co-evolving from established disciplines. Again, the private sector can, and does, exploit these opportunities but the Research Councils are well placed to lead and initiate. Scientific and technological advancement increasingly comes from the re-combination of knowledge from different scientific and technological disciplines; so-called 'fusion' innovations (Miller & Morris,1999). Examples are biochemistry creating new opportunities for pharmaceuticals, and biotechnology and bio-informatics creating new avenues for health care services and diagnostic innovations. In the future, the fusion of nanotechnology and biotechnology- bio-nanotechnology- is predicted to create new scientific arenas with widespread applications[19].

2.2.4 Collaborative Research

As a consequence of converging scientific and technological fields, leading products are becoming more complex drawing on multiple scientific fields and embodying an increasing number of technologies. It becomes clear that the scope of technological knowledge required for many modern products is beyond the resources of many businesses. As a consequence, firms are adopting an 'Open Innovation' approach where the inputs to the innovation systems are delivered by a distributed network of partners (Chesbrough, 2003). Public sector research is a vital part of this architecture: the share of business funded R&D in universities across the OECD has increased from 1.4% to 1.7% over the last decade (OECD, 2002) and 7% of EU higher education R&D is financed by industry.

2.3 How do impacts arise from research?

There are many problems associated with measuring research impacts, which are described in section 3.1. However, steps have been taken to identify the potential channels of impact arising from basic research enabling us to establish an expected set of impacts from investment in research. In addition to different channels of impact, different recipients of impact have also been identified, namely:

- Impact on the scientific community
- Impact on the economy
- Impact on quality of life and social welfare.

The measurement of impact on the scientific community is well established and facilitated by a strong set of metrics including peer review, conference participation and citations. Essentially an intermediary impact, we do not address this further here.

[19] Perhaps most significant is its potential in the medical field where it has the potential to revolutionise disease diagnosis, drug delivery and molecular imagery.

Instead we are concerned with the wider economic and social impacts. Research, for example, may provide knowledge which enables businesses to reduce costs representing a benefit to GDP, or they may produce an innovative new process or product that provides a benefit to society. Although harder to measure, and subject to significant limitations as outlined above, a significant body of empirical and theoretical work now exists to identify the mechanisms through which research can impact upon the economy and society.

2.3.1 Impacts via the innovation process

The majority of work into assessing research impact has focused on the economic impact of research through the innovation process (Martin & Salter, 1996; Scott et al., 2001). The continuing validity of these channels has recently been reconfirmed by McMillan & Hamilton (2003) and Martin & Tang (2007). We set out each of these channels below.

Producing new scientific information (knowledge creation)

The role of the public sector in new knowledge creation is increasingly important as the private sector conducts less basic research in-house, preferring instead to invest in applied research and development activity where uncertainty is reduced and returns more accurately estimated (Calderini & Garrone 2001). Universities and research institutes therefore play a vital role in creating new knowledge to fill the 'innovation funnels' of innovating companies representing a major impact channel.

New knowledge is accessed by businesses in a number of ways, including publications (Arundale et al.,1995), trade-fairs and conferences, collaborations, on-campus research centres, student and PhD sponsorship through schemes such as CASE, and increasingly, through the purchase and licensing of patented university research outputs.

New knowledge can be identified and measured in a number of ways via patent counts, the value of licensing arrangements and bibliometric data such as publication and citation counts.

The UK is ranked 2nd globally in its share of total publication outputs (at 8%) and publications remain an important channel for knowledge diffusion, feeding into industry to advance innovations; whilst also encouraging networks and problem-solving capabilities. However, the use of such metrics as an indicator of impact must be treated with caution. It is important to note that publication rates vary dramatically between different scientific disciplines (McMillan & Hamilton, 2003) precluding the use of generic benchmarks across the Research Councils. In particular, researchers in the social sciences, and especially the arts and humanities, publish less frequently in journals than STEM researchers and relatively more frequently in books which are not covered by the standard citation data bases.

Another issue likely to impact upon the measurement of research impact through publication counts is the on-going Open Access movement. Articles self-archived by authors on the internet receive between 50-250% more citations than those that don't (Brody, 2006). There is as yet no effective way of capturing this broader dissemination, which is particularly likely to have positive influence on the wider dissemination of research outputs to businesses, which may not have access to traditional publication sources. In addition, citation indices do not necessarily capture the breadth of outputs across all disciplines (especially social sciences, arts and humanities) that are less oriented towards publishing in journals.

Patents also serve a similar dissemination purpose. In the US for example, 73% of scientific references cited within patents originate from the public science arena (Narin et al., 997) and, increasingly, universities are patenting their research outputs themselves. However, caution must be taken when attempting to measure the value of university patents. McMillan & Hamilton (2003) point out that universities have tended towards logging more patents as awareness of the monetary value of their research has grown. However, these are cited less heavily by other patents which may indicate lower commercial value.

Academic studies have tended to overlook the role in the UK that Research Council Institutes and Units (RCIs) play in exploiting intellectual property. Most IP generated on extramural grants to universities belongs to the host institution. In contrast, IP discovered in RCIs is normally owned by the Research Council concerned, and Research Councils have focused on exploiting this IP. For instance, in 2005/06 earnings from IP of the three Councils who run RCIs came to £36.5 million in 2005/06 (BBSRC £0.4 million; NERC £1.8 million; MRC[20] £34.3 million) exceeding the licensing income reported by UK universities through the Higher Education Business and Community Interaction Survey (HEBCI) data (discussed in Section 4.5).[21]

We would also note that research results can be disseminated in ways other than publications and patents. Research in the arts may support performances and exhibitions which generate economic impacts through visitors' and audiences' expenditure. These can be substantial. Glaister and Travers (2004), for example, highlight the important contribution made by the Natural History Museum to the local, national and international community and economy.

Training skilled graduates

The training, and migration, of skilled graduates and PhDs is a major impact channel from investment in research. Impacts can be gained through the movement of skilled researchers into industry – raising absorptive capacity and assisting the dissemination and deployment of research results – and also the movement of skilled researchers to other research organisations.

[20] Source: Annual Accounts 2005/06. MRC figure excludes exceptional one-off payment of £108 million

[21] There is also the Annual UNICO Survey on University Commercialisation Activities which gives data on university licensing income.

In 2002, the UK was ranked 1st in the G8 for PhDs awarded per amount of R&D performed in the Public sectors and this carries through to productivity with the UK 2nd in the G8 in citations per researcher. Graduate numbers have increased over 50% in the last decade and in 2003, the UK was ranked 6th equal in the G8 with 5.92 researchers per thousand workforce.[22]

With a higher trained population, absorptive capacity of individuals and organisations to exploit external knowledge is raised, which yields greater R&D flexibility in problem-solving. Graduates and Doctorates also act as knowledge networks between public and private sectors, science disciplines and geographic boundaries, which is actively promoted by the Research Councils themselves (Demeritt & Lees, 2005).

The migration of researchers between research teams, institutions and disciplines within the scientific community is also a potential source of impact. Such movement facilitates cross-disciplinary scientific development, which has been shown to be a major source of innovation and economic impact in recent years (Miller & Morris, 1999).

Expanding the capacity for problem-solving

Migrating into industry, new graduates bring with them knowledge and skills that are both specific and generic, as well as both tacit and codified In particular, impact can be generated through an expansion of the capacity for problem solving.

As a by-product of increasing the nation's graduate pool, the capacity for problem-solving is increased; not through direct knowledge solutions, but through knowledge manipulation and analytical skills enhanced through graduate training. Specific knowledge of recent research findings and techniques are complemented by more generic skills; the ability to solve complex problems, the skills to perform research and the ability to develop new ideas (Martin & Tang, 2007). Senker (1995) suggests that graduates bring into industry an 'attitude of the mind' and a 'tacit ability' to acquire and use knowledge in useful new ways. Such abilities are highly valued by industry; analytical problem-solving in basic science is a desirable skill which is recognised by business communities (Demeritt & Lees, 2005).

This capacity is further increased with the greater network reach of individual researchers and organisations. In addition to possessing the capacity to produce knowledge, skilled graduates also have the capacity to disseminate new knowledge (Bozeman, Dietz & Gaughan, 2001). This combination of individual endowments and abilities with social ties and network links is a fundamental source of impact.

[22] Source: Office of Science and innovation (2006). Annual Report on Output Frameworks.

Promoting new networks and linkages

The importance of networks and linkages has been identified through the more systemic understanding of the innovation process, discussed previously. In the first instance, networks facilitate cross-disciplinary research and the combination of complementary, specialist capabilities. In the second, they provided the necessary combination of capabilities to facilitate distributed, or 'open', innovation processes. Extending beyond the academic research base, these must also capture industry partners, end users and sources of finance.

Rather than stimulating additional research inputs (input additionality) and associated increases in research outputs (output additionality) research impact here is most likely to occur due to the behavioural changes triggered by research funding, so-called behavioural additionality (Buisseret et al. , 1995).

Lockett et al. (2003) have also confirmed the importance of networks in maximising the impact of specific technology transfer mechanisms. They found that the more successful university technology transfer offices had a stronger working relationship with venture capital investors and were connected into a greater number of industry networks.

Networks and linkages are catalysed by university-industry sponsored programmes, such as the LINK programme, or the CASE awards through the Research Councils in the UK (Demeritt & Lees, 2005). The high level of internationalisation of scientific R&D also contributes to further network benefits in both global reach and professional standing of collaborators and is fostered through numerous programmes (Georghiou, 1999). A review of evaluations of the European Framework Programmes, now in their 7th round, found that in addition to directly extending networks through the funded programme, it also led to an increase in participants' non-framework programme international networking (Arnold, 2005).

The funding of basic research also promotes communication channels for personal and knowledge networks for scientific research. The primary channels are conferences, publications and other informal interactions that engage both public and private sectors, rather than formalised channels (e.g. by licensing or cooperative ventures), with benefits derived from greater knowledge diffusion. Often local in nature, such linkages are emphasised through the growth of science parks, to maximise localised knowledge spillovers between universities and companies.

Producing new instrumentation, methodologies and techniques

Another impact channel identified in the original Salter et al. paper (2001) is the production of new instrumentation, methodologies and techniques.

Commercialisation of new instrumentation often originates from basic research studies and is applicable to a broader spectrum of science disciplines and applications. Subsequently, advances in instrumentation stimulate collaborations and linkages between scientific disciplines, to the extent of promoting trans/multi-disciplinary researchers. However, such holistic impacts generally have very long lead times (of decades). This continued advancement of instrumentation innovation feeds back into 'new' basic research environments and further catalyses this cyclic process between public and private sector R&D.

Indeed, Arora & Gambardella (1994) argue that such advances in instrumentation, methodologies and techniques are changing the character of technological change itself. Despite increasing complexity, advances in scientific instrumentation and techniques have led to an enhanced capability to simulate problems and have facilitated the development of increasingly generic data frameworks and categories. This in turn has facilitated greater codification of knowledge making information comprehensible in a wider array of circumstances and to a wider array of users.

Ultimately, such codification has led to the increasing commodification[23] of knowledge (Arora et al., 2002) and has helped to facilitate the open innovation system within which research impacts are created today.

Creating new firms

Increasing attention has been paid to the role of new firm creation, or university spin-outs, in disseminating and deploying new research outputs and they have become a focus of interest of many universities (Feldman et al., 2002).

Whilst universities have certainly entered the commercial arena, with spin-off companies found at all major universities in the UK over the last 25 years. The longevity of many of these ventures has been variable and some evidence suggests that spin-outs have very little impact on the economy or job creation (Harmon et al., 1997). In some instances the success of spin-outs has also been jeopardised by over enthusiastic technology transfer offices, keen to capitalise on a new revenue stream for universities. Technology push spin-outs from universities are less likely to generate impact, than those that have a strong commercial pull.

University spin-outs have also faced criticism from academics and economists, concerned about potential conflict with the basic knowledge creation role of the university (Lee, 1996; Rogers, 1986) and about potentially negative impacts upon the rules and conventions under which research takes place (Dasgupta & David, 1994).

[23] Commodification of knowledge requires transforming tacit into explicit, unstandardised into standardised, uncodified into codified knowledge and shifting emphasis from its use value to its exchange value. At the same time this type of knowledge needs special protection such as patents and other intellectual property rights to prevent unauthorised use and assure individual appropriation of its exchange value.

Whilst the success of spin-outs in generating economic value has been questioned, according to UNICO, the University Companies Association, between 2004 and 2006, 25 UK university spin-out companies floated on the stock market at a value of £1,500 million. The value adding potential of university spin-outs has also been confirmed by Bray & Lee (2000) who found that spinning-out is a significantly more effective technology transfer mechanism compared to licensing, creating 10 times higher income.

Research Councils have been active in setting up spin-out companies. BBSRC's seven Institutes alone have created 16 spin-outs that were still trading in 2005/06; MRC spin-outs employed over 1,200 people in 2006, excluding Celltech.[24]

In the life science sector, there is evidence that when account is taken of the net present value of income generated over the whole income life cycle generated by a patent, licensing generates considerably more income for the inventing agency than selling off a spin-out company with its IP. For instance MRC earned about £30 million from equity held in CAT and Domantis, compared to over £260 million from licensing two major antibody patents.[25]

There is also a sectoral dimension to the importance and role of university spin-outs that it will be important to acknowledge in identifying potential research impacts. Fontes (2005) found that spin-outs in the biotechnology sector have been an important mode of dissemination of research results to industry and Zucker & Darby (2005) find similar evidence in the nanotechnology and nanoscience sectors. In other sectors, the role has been less significant.

Research also generates benefits for society which are not mediated through business innovation or not captured fully by such processes. They are considered below.

2.3.2 Policy impacts

All research areas have the potential to contribute to policy making and this is reflected in the Government Guidelines for Scientific Advice includes as a source "discussions with those in the Research Councils, industry, academia and elsewhere". These discussions are likely to be most fruitful when held against the basis of long-standing relationships developed with departments.[26] Research users are not, of course, restricted to central government but also include non-departmental organisations, regional and local government and NGOs. Also important is the role that research plays in the standard-setting work of professional bodies and regulators.

Georghiou, Rigby, Cameron (2002) characterise the direct impacts on policy as improved understanding in the short-term and problem solving in the long-term. They also cite indirect impacts of increased awareness of the problem. The impacts are manifested through reductions in the cost of public provision and higher quality provision, which may have a societal value over and above cost savings.

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[24] BBSRC Annual Report 2005/06; MRC Outputs Framework 2005/06

[25] Personal Communication: Mike Dalrymple, CEO, MRC Technology

[26] Department for Business Enterprise and Regulatory Reform (2000)

The linkages between researchers and policy makers are different to those with the business community and in particular research outputs may be mediated by other parties before they are considered in the policy debate. However, skilled people are also important in this domain. Public bodies need to act as well informed customers for any research they directly commission and they need to have the capability to translate research outputs, from whatever source, into policy terms. In this sense, there are similarities with business innovation and research, although the transmission mechanisms may differ radically in other respects. Various documents have drawn attention to the importance of 'in-house' skills in this respect, for example Select Committee on Science and Technology (2007) and Commission on the Social Sciences (2003).

The Select Committee on Science and Technology (2007) noted the importance of the STEM research capability to address issues such as BSE, foot and mouth disease and GM crops. More generally, medical and biological research make major inputs to the identification of health related issues and environmental concerns, globally, have been driven by the scientific community. The social sciences are also important in this respect. The Commission on the Social Sciences (2003) described a number of examples where it considered research inputs to have informed policy and practice including: gender segregation in the labour market; equal pay; domestic violence; educational achievement and globalisation. It also drew attention to the underpinning role economics has played in developing an understanding of the economy and appropriate policy responses.

A similar point concerning economics was also made by the British Academy (2004). The same report also drew attention to the role of arts and humanities research in informing policy debates by contributing to a greater understanding of major UK and global challenges

2.3.3 Quality of life and social welfare impacts

Contributions to (successful) policy development will enhance the quality of life, perhaps most tangibly in relation to health care, but also arising from social, economic and environmental developments. Research outputs may, however, have an intrinsic value over and above enabling society to undertake existing activities more efficiently or new activities altogether. The British Academy (2004) identified the function of the arts, humanities and the social sciences. Their function included economic, social and policy contributions, but also contributions to cultural and intellectual enrichment through:

- Cultural performance, exhibition and enlightenment, through both teaching and research
- Providing crucial expertise to support museum and gallery collections, as well as the historic environment
- Leading the way in promoting understanding of the nation’s history and other cultures, religions and societies, thereby helping to sustain national identity, multicultural tolerance and interaction
- Fostering public debate and enhance public engagement with the complexities of modern life, especially those which involve conflicting moralities, traditions and beliefs

- Providing, through their commitment to analytical rigour and humane values, crucial support for civic virtues and open, accessible government, on which any civilised society depends.

Significant work has been undertaken in the sphere of medical research, including in the work of Buxton and Hanney (1996), who have created a 'payback' framework model that captures a wide range of economic benefits arising from medical research, including gains in quality of life and social welfare. This methodology has been applied to social science research funding through the ESRC's policy and practice impact case study of the 'Future of Work' programme.

In the environmental sphere, a recent report by the RSPB[27] on the economic impact of preserving wild nature concluded that 'the major benefits associated with retaining systems more-or-less intact were non-marketed services such as storm protection and carbon sequestration, which accrue to society as a whole'. A separate RSPB report[28] notes the link between well-being and wildlife, including

- Access to natural green space improving our physical and mental health
- Nature giving us green infrastructure, which contributes to the sustainable regeneration of communities
- The environment supporting substantial economic activity, and wildlife can generate significant benefits for local economies.

[27] http://www.rspb.org.uk/ourwork/science/process/2002/economicvalue.asp

[28] http://www.rspb.org.uk/ourwork/policy/economicdevelopment/wellbeing.asp

3 Measuring economic impact

In this chapter we set out the theoretical and practical challenges in measuring economic impact and the approach we have taken in attempting to overcome these challenges.

3.1 The inherent difficulties of impact assessment

The Warry report recognises that 'it is difficult to measure the economic impact of innovations which may be delayed in time and indirect in consequence' and indeed the consensus in the economics literature[29] is that measuring the economic impacts of science, innovation and research funding is highly problematic. Although there are a number of well established methods for assessing impact within parts of the research community (peer review, citations etc)[30], assessing wider impact is far more problematic. Citations may provide a strong indication of impact within the research community however; they do little to indicate end-user benefit and impact beyond. As noted by SPRU[31], 'attempts to add up all the economic and social benefits and to relate them to the initial investments in research are doomed to failure'.

The challenges to assessing the impact of research are both methodological and practical. Below we summarise five key challenges:

- Systems and multipliers
- Attribution
- Timing
- Project fallacy
- Identifying impacts on society.

3.1.1 Systems and multipliers

The linear model of innovation assumes that the outputs from research are created autonomously and then passed on to the users of research to develop and exploit. In theory, the benefit of this model, which splits the innovation process into discrete stages, is that value creation can be tracked.

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[29] SPRU, 2006, provides a comprehensive literature review of the literature in measuring economic impact. SPRU, 2006, "The benefits of publicly funded research," July 2006.

[30] Although these tend to be less helpful in the field of social science, arts and humanities.

[31] ibid.

However, a number of problems exist. In the first instance, linear models of innovation have now been superseded by a systemic understanding of innovation. Rather than being a linear input – output process, innovation is founded upon a complex set of interactions and feedback loops between multiple institutions including firms, public sector research institutes, policy making bodies, universities, users and consumers. In this way, the process of impact attribution along the linear model becomes problematic. It is conceptually difficult to establish the extent to which a particular technological development contributed to a particular innovation, and further, the extent to which a particular research output contributed to that particular technological development leading to a 'chain of escalating uncertainty' (Martin & Tang, 2007).

Whilst the scientific impact of research can be gauged through peer review and citations the inherent complexity of the innovation system means that many of the wider societal impacts arising from research are affected by a host of external, interacting factors (multipliers) beyond the control of the research base. The dissemination and deployment of research outputs are largely conducted by other players (Camarinha-Matosa & Afsarmanesh, 2007) and it is not realistic to expect that, for example, a research institute can, by itself, cause a significant impact on society.

Businesses are identified as one of the main impact multipliers, providing the mechanisms through which research outputs can be transformed into products and processes that impact upon society. However, there are methodological problems with measuring this conversion process. Business spin-outs are one conversion method, however simply counting the number and value of such spin-outs in the short term is problematic because many have failed in the longer term. Technology transfer mechanisms, initiated through government sponsored schemes such as HEIF and Knowledge Transfer Networks also have a role to play. However, impact is generated through the effective operation of such networks, rather than simply their existence. Counting such business linkages, is therefore insufficient to establish the value creation links from research outputs to societal value. Businesses also rely heavily on scientific publications as a source of information on the science base (PACE Survey, Arundel et al., 1995) but there is no way of measuring this intermediary impact.

Furthermore, the quality of the research outputs is not necessarily an accurate predictor of societal impact. Research with high impact within the scientific community will have wider societal value only once it is effectively disseminated and deployed. Multipliers, typically businesses, therefore have the potential to not only multiply, but also limit impact. In the first instance, businesses must have the necessary skills, or absorptive capacity (Cohen & Levinthal, 1990), with which to use research impact to its full potential, in the second, they must be motivated to use the research outputs. As McMillan & Hamilton (2003) point out, public goods are freely available but not free in the cost of using them. In this way, research impact is strongly influenced by the ability and willingness of businesses to convert research outputs into products and processes of value to society, and consequently difficult to predict.

3.1.2 Attribution

Innovation, and the economic and social benefits it generates, is not just a technical issue. Martin and Tang (2007) draw attention to the importance of other inputs typically provided by the firm, for example market research and marketing and of course the organisation of the production process. Indeed, if such inputs were not important it would be difficult in many cases to see why market advantages from innovation were not lost to competitors relatively quickly. It has, however, difficult to separate out the relative contribution of technical and non-technical factors.[32]

3.1.3 Timing

The potential time lag between research inputs and eventual outcomes also causes significant problems for those wishing to assess the impact of research. Whilst the quality and relevance of research can be gauged within the scientific community in shorter time scales, wider societal benefits often take decades to materialise. In this way, full research impacts certainly cannot be measured during the duration of research projects, and arguably should not be assessed before the 5 – 10 year time scale.

Instead, the quality, relevance and management of research outputs can be assessed as rough predictors of future usefulness or impact potential. Labelled 'pre-impact indicators' by Camarinha-Matos & Afsarmanesh (2007) they reflect the seed for future impact. However, as we have already discussed above, tracking the value creation process, predicting and attributing future impact is extremely problematic in the complex value creation system.

3.1.4 Project fallacy

In addition to the problem of attributing impacts to research outputs within the wider system of innovation and value creation, there is also a problem of attributing specific research outputs to discrete research projects (and inputs). 'Project fallacy' is a recognised problem when trying to attribute impacts to specific research projects (Georghiou, 2002). It occurs when evaluators assume that the stated parameters and deliverables of a research project are the same as the real parameters and deliverables. Often, this is not the case; research projects are often part of a wider portfolio of projects which interact with each other and research outputs and impacts are often cumulative over series of projects. In this way, eventual societal impacts should often be attributed to a series of research projects and programmes. Similarly, research is increasingly conducted within large international consortiums and attributing impact to individual partners within these is highly problematic (Martin & Tang, 2007).

[32] Some recent work has addressed the methodological issues in relation to plant breeding. See for example Morriss and Heisey (2003).

3.1.5 Impacts on society

Innovation and economic impacts are also societal impacts but research outputs also impact on society in other ways which raise additional assessment issues. Two issues are of especially problematic. The first concerns contribution to policy making. Policy makers draw on research outputs for decision making and policy formulation and this has become increasingly important in the UK with the emphasis given to evidence-based policy. There are, however, real difficulties in identifying the impact of research on policy. If a business adopts new technology it may be possible, given sufficient interviews with appropriate staff in the business, to identify the role of the science base in developing and disseminating the research, at least where the new technology is of some significance to the firm. Policy impacts are different, however, in that research outputs are often one of many influences on policy makers and those that are influenced may not be aware of the source of new insights since other bodies and individuals mediate in the transfer of information. As such, surveys are often of limited value.

The second concerns the valuation of impacts arising from research which contributes to outputs for which markets either do not exist or only reflect imperfectly the value to society of an output. These include:

- Defence, environmental improvements and so on where consumption by one individual does not reduce availability to others; known as public goods
- Outputs which have some intrinsic value over and above what might be revealed by market behaviour. This would include, for example, cultural advances; exhibitions and books generate tangible economic benefits through sales and visitors' expenditure but most governments would attribute a greater societal value to cultural activities than the direct and indirect expenditure they generate. It also applies to many other areas. An educated population, for example, has a higher value to society than the enhanced productivity it generates and, for reasons of equity, programmes which improve the employment prospects of disadvantaged sections of the community are more valuable than any increase in GDP they may give rise to.

Where market prices are absent, the literature (including the Green Book[33]) suggests a willingness to pay (WTP), or a willingness to pay to avoid something happening approach[34]. This is simply trying to estimate what individuals would pay even though they are not required to. This is typically estimated through surveys which are often problematic. WTP approaches have been used to assess major investments where some individuals would experience significant costs or benefits, for example a new dam which might displace housing. Although some examples exist of the successful use of WTP (e.g. the economic impact of an art exhibition), the more general difficulty is the very limited data on WTP in circumstances which might be relevant to the Research Councils. Throsby (2003) discusses some of the difficulties associated with WTP approaches.

[33] http://greenbook.treasury.gov.uk/

[34] Sometimes known as contingent valuation

It is worth noting that progress on these issues has been made both in relation to medicine/healthcare and the arts. In both these areas there are markets which are potentially amenable to valuation:

- In relation to medicine/healthcare, tangible economic benefits from research are reflected in lower costs of healthcare provision and higher productivity from a healthy workforce. There are also grounds for believing that individuals, and their families, may attribute values to good health over and above these and significant effort has gone into the methodological and practical issues of valuing benefits. Funding First (2000) summarises some US research in this area
- In relation to the arts, direct economic benefits result from, for example, the staging of exhibitions. Again though, arts research brings broader benefits (social, cultural and economic) - such as supporting the growth of creative industries. This raises new measurement issues which are currently being tackled.[35]

3.2 Methodological basis of this study

This study is based on 18 case studies undertaken during a 3 month period (May to July 2007), supported by analysis from existing literature relating to economic impact of research and consideration of other performance related data, such as the Output Framework[36]. The use of this methodology has been shaped primarily by the scope of the objective and the timescale over which this needs to be achieved - Research Councils fund thousands of different projects across a vast array of research fields and with a myriad of objectives. Getting a truly comprehensive understanding of this complexity is not possible, certainly in the short time period over which the study has been undertaken. Similarly large-scale beneficiary surveys and longitudinal studies, which might give a deeper understanding of certain aspects of Research Council activity were not practicable within the timescales or resource constraints of this study. Beyond this study these (and other) approaches could well become more important in the continued effort to understand economic impact .

In this context, the methodology we used was the best available to us to achieve the objectives set out in section 1.2. In the sections below we set out the logic of the methodology and then the process we used in applying it.

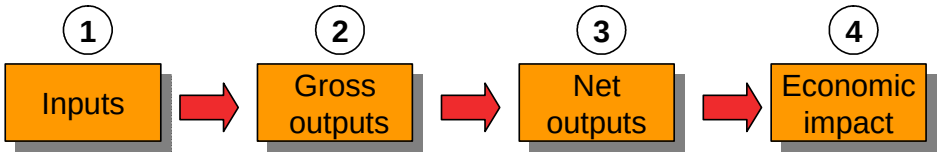
[35] See http://artscouncil.org.uk/documents/publications/340.pdf for an overview of these issues.

[36] See Office of Science and innovation (2006).

3.2.1 Understanding the economic impact of Research Councils: the logic of moving from inputs to impact

In order to develop the case studies within this context, we used a version of the logic chain employed to evaluate the impact of government investment which is presented in Figure 6. [37]

Figure 6: Simplified logic chain from inputs to impact



Each Research Council deploys resources to meet its specific objectives (inputs), and in doing so, in theory, generates a chain of outputs and impacts. Given the constraints on time, our case study research therefore took a simple view of the different stages of the logic chain based on an understanding of the process by which research outputs translate into impact[38]:

- Inputs to the research within the scope of the case study - both the funding and associated activities
- Gross outputs - generally stated in terms of codified and published knowledge; qualifications and skills development; instrumentation/resources and methodologies; networks and intellectual property
- Net outputs - in a simple sense, to what extent were these outputs likely to be 'additional' (i.e. would the activity have been undertaken without Research Council funding) and what other effects such as leakage, leverage and multipliers are likely to be present[39]
- Economic impact - we focused on: new businesses; new products, processes or services; more highly skilled people; inward investment; new or improved policy & services (collectively known as the 'innovation outcomes'); and broader quality of life, social or cultural impacts.

3.2.2 Undertaking the case study process

We used a staged process to undertake the case studies in that we:

- Agreed with the Project Board to undertake a number of case studies per council with a further group dedicated to cross-council activities

[37] Adapted from DTI Occasional Paper No. 2, "Evaluating the impact of England's Regional Development Agencies", http://www.berr.gov.uk/files/file21900.pdf

[38] See section 2.3 for an explanation of how research translates into impacts

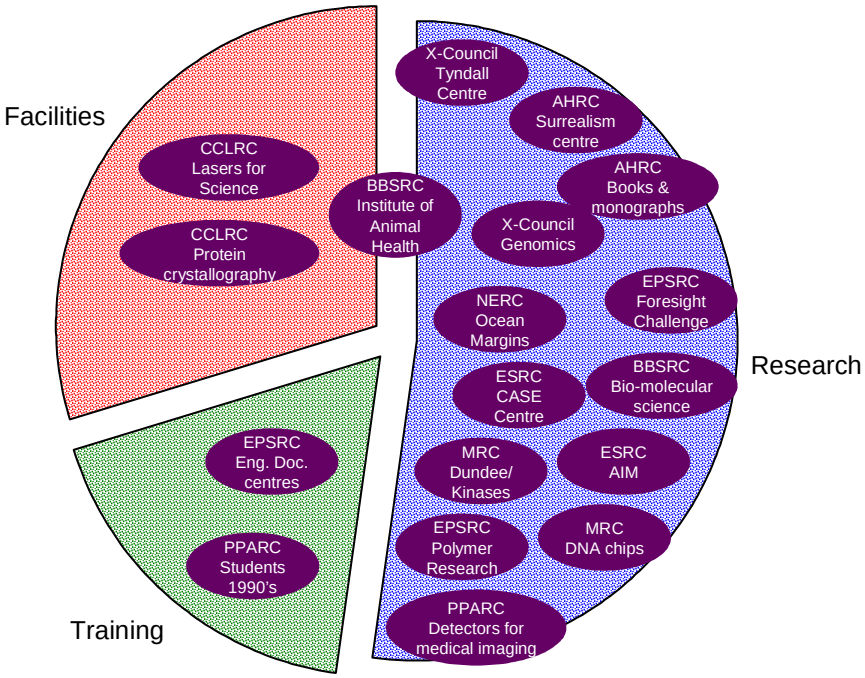
[39] The treatment of net outputs is described in more detail in section 4.5

- Categorised the funding landscape; using characteristics developed with the Research Councils (see Part III: Appendix D) and selected case studies using these characteristics as major determinants[40]. The resulting case study map is set out in Figure 7 below
- Defined the scope of each of the case studies based on a number of criteria to ensure both achievability and appropriateness (for example availability of data) and, in consultation with Research Councils selected a number of stakeholders to interview
- Identified the inputs and outputs for the scope of these case studies by:
  - Undertaking analysis of existing data (e.g. the project records from Research Councils and any past evaluations)
  - Consulting with stakeholders (interviews were held with between 4 and 10 stakeholders for each case study. In total over 130 interviews were held - see Part III, Appendix A for list of interviewees)[41]
- Undertook a wider literature review and identified findings from that literature which were relevant to understanding impact within the case study
- Estimated, at a high-level, net outputs, using interview evidence and existing research to focus on whether the outputs were 'additional' to that which would have otherwise been produced without Research Council funding
- Identified, described and where possible quantified and valued economic impacts arising from the research. In some cases, where it was difficult to prove a causal link between inputs and impact, we used assumptions to provide an illustration of potential impact.

[40] Given the small sample size it was accepted that extrapolation from their results would not be possible. The sampling therefore would become a more important determinant if, at a future time, a larger case study sample is selected.

[41] Interviewees' comments are, in general, anonymised so as to enhance the objectivity of the interview process

Figure 7: Case studies mapped onto Research Council expenditure divided into its three component parts, Research, Facilities and Training. Segments are approximately proportional to budgets (Other non monetary accounting and non grant expenditure is excluded)



Due to the limitations of the case study-based methodology, we were guided by the Project Board in the following ways:

- Understanding ranges of impact is more important and less misleading than producing precise figures
- Given the need to test methodology it was important to stick to a well defined process even where this was not strictly necessary for the development of the case studies (for example, rigorous selection of case studies, even through the small sample size precluded extrapolation)
- Do not ignore results simply because they do not show an impact. In a sampling methodology and given the nature of Research Council activities, one is likely to pick activities which have led more or less successfully to impacts. The rigorous methodology supported the deliberate strategy of not 'cherry picking' high impact studies.

The findings from this methodology are reported in the following chapters.

3.3 Drawing on other evidence of outputs and impact

In order to produce this report we have drawn on three sources of data other than the case studies:

- The Research Council Output Framework[42] and wider data sets
- Existing case studies of Research Council activities
- A wider literature review.

We have used the first two of these to illustrate impact where appropriate and have called on the literature review to provide a wider picture of the impact of research beyond the Research Councils. In drawing together all these sources of evidence across the Research Councils we are breaking new ground.

3.3.1 Research Council Output Framework and wider data sets

All the Research Councils currently collect output indicators which are reported to DIUS. The purpose is to provide information on progress towards the objectives set out in their delivery plans and is one component of the management framework which DIUS uses to show the contribution that Research Councils are making towards achieving government targets. These are high level indicators covering, for example, the number of PhDs supported by the Research Councils, publications and interactions with business and other research users. We have also used related data sets to contextualise.

3.3.2 Existing Research Council case studies

Most of the Research Councils have undertaken other case studies, usually on a project or programme basis. Although a number of these have attempted to assess economic impact, many have been descriptive in nature. A review of these is set out in section 4.3.

3.3.3 Wider literature review

There is a wealth of existing literature on the impact of research and the methodologies used to quantify and value economic impacts. We have undertaken a comprehensive literature review to understand and present more rigorously within the report:

- How research translates into impacts
- General estimates for the impact of research
- Challenges involved in estimating impact.

A full list of references for the literature reviewed is set out in Part III, Appendix B.

[42] See Office of Science and innovation (2006). DIUS is introducing a new Output Framework from 2007 , but the indicators provided by the research councils will not change in the next report.

4 Evidence for the economic impact of the Research Councils

This chapter brings together evidence we have for the economic impact of the Research Councils. We summarise the range of impacts that we have identified: first looking at research outputs and PhDs since, to varying degrees, these are present in all the case studies; we then look at business and commercial impacts, then policy and finally quality of life. Each of these types of impact is illustrated with real examples found during the research. Subsequent sections set out: a summary of findings from the case studies undertaken; a summary of a review of impacts from existing case studies; relevant data from the Research Council Output Framework and then look at the impact of publicly funded research in general. The final section of the chapter discusses what has been achieved by Research Council funding over and above what might otherwise have occurred.

4.1 The range of impacts identified

The case studies reveal many ways in which Research Council funded activities translate research to impacts and these are discussed in this section. We have grouped examples of these impacts under four impact headings: development of human capital'; business and commercial; policy and quality of life.

4.1.1 Development of human capital

The training, and migration, of skilled graduates, post-graduate and post-doctoral researchers is a major impact channel from investment in research. Impacts can be gained through the movement of skilled researchers into industry - raising absorptive capacity and assisting the dissemination and deployment of research results - and also the movement of skilled researchers to other research organisations.

Two of the case studies (EPSRC's Engineering Doctorate (EngD) programme and PPARC studentships) were specifically concerned with PhD outputs:

- We found that EngD graduates, relative to other PhD graduates in similar disciplines, enjoyed significantly higher salaries (between £100,000 and £300,000 over their careers) as a result of their training. This is a direct indicator of the value which employers place on EngD graduates and, therefore, their contribution to the economy. The aggregate salary benefit resulting from

EngD over the case study period therefore could be as much as £80 million, if all achieve the highest salary benefit, for an EPSRC investment of around £12 million

- PPARC PhDs follow a more standard training programme with a concentration on research in PPARC areas[43]. The evidence suggests that average career salaries are around £70,000 higher than equivalent individuals with a first degree which is broadly comparable to the cost of their training even before consideration of broader research outputs.

4.1.2 Business and commercial impacts

Impacts from the innovation process arise in three ways and our case studies produced clear examples of business and commercial impacts from each:

- Knowledge transfer through collaboration (primarily between businesses and academics)
- Generation and exploitation of intellectual property and related outputs
- Creation of clusters and the impact that has on, for example, inward investment.

Knowledge transfer through collaboration

Several of the case studies involve direct collaboration between businesses and academics. These obviously include the LINK programmes, but also others such as Advanced Institute of Management (AIM), the EngD programme and the Protein Phosphorylation Unit (PPU) at the University of Dundee. These programmes have (to different degrees) supported business capabilities to undertake R&D through:

- Ensuring research is relevant to end users and keeping researchers up to date with issues affecting the user community. The EngD programme, for example, ensures that the training of skilled graduates is focused on the real-world challenges that businesses face
- Transfer of knowledge through interactions between academics and businesses. The knowledge transferred is both new techniques and research outputs. The AIM programme interacted with 36 of the FTSE 100 companies. The LINK programme case studies leveraged more than 50% of funding from private sector contributors as part of the scheme's conditions. Commitments have often continued, with more than 30 businesses, many international, participating in membership based schemes arising from the Foresight Challenge and the Polymer Interdisciplinary Research Centre (IRC)
- The development of expertise or insight through the use of instrumentation and scientific facilities (most pronounced in relation to the Synchrotron Radiation Source (SRS) and Lasers for Science Facility (LSF) within the cases we studied).

Intellectual property and other commercial outputs

[43] All PhD students now have the opportunity to develop personal and transferable skills as well as their research capabilities

Many of the case studies have generated, or are expecting to generate, Intellectual Property (IP) and other forms of direct commercial outputs. There is a very wide variation between them, in part reflecting subject area, and also timescales from completion of research, but the general picture is as follows:

- There have been a number of significant licensing deals (Bio-molecular Science Committee (BMS), Polymer Research and the PPU case studies)
- BMS, Polymer Research, Foresight Challenge and the PPU have generated spinouts which have raised substantial external investments
- One of the main outcomes of the AHRC Surrealism Centre was a major exhibition at London's Hayward Gallery which has generated significant expenditure impacts
- Similarly, books funded under the AHRC's Research Leave Scheme have seen direct commercial returns
- Of a rather different nature is the use of scientific facilities by industry. The SRS, for example, sells beam time to businesses. The direct revenue to SRS is likely to be dwarfed, however, by the wider impact arising from businesses' exploitation of knowledge that is developed by using the facilities.

Clusters and inward investment

Research Council funding has helped to create, improve or sustain a number of clusters of research excellence. More generally, many of the case studies describe researchers working with multinational companies and these contacts will help to ensure that the UK is recognised as a centre of scientific excellence and considered in investment decisions as appropriate. For example:

- MRC funding of the PPU at Dundee has contributed to a Biotech cluster in Dundee area which received £50 million joint private-public sector investment
- The Foresight Challenge projects led to sustained centres of which at least one attracts inward investment on an ongoing membership basis from around 20 major companies; the EngD centres have resulted in other research centres with industry support
- A Science and Innovation Campus, which encompasses the SRS, is being developed and has successfully attracted over 40 firms to co-locate on the Campus. The Daresbury Laboratory has collaborated with around two thirds of those.[44]

4.1.3 Policy impacts

The impacts of research on policy arise in two ways:

- Production of a body of research over a period of time which influences ‘received wisdom’ (the 'General Enlightenment' model)

[44] A similar development is planned adjacent to the Rutherford Appleton Laboratory; the location of Diamond and ISIS.

- Direct responses to specific requests for policy inputs, either through commissioned research or advice from individuals (the 'Direct Influence' model).

Two of the studies (Centre for the Analysis of Social Exclusion (CASE)[45] and the Tyndall Centre) are specifically targeted on policy issues and two more (AIM and the Institute of Animal Health (IAH)) have important policy dimensions to their work. More specifically we can identify impacts in the case studies:

- There are frequent references to the work of the Tyndall Centre in Hansard which suggest it is having policy influence both in the UK and internationally. In addition, its consultancy activities are self-sustaining indicating a demand for its specialist expertise
- Interviewees report that "CASE research work enabled government to make better policy, and faster than would otherwise have been produced" and its contribution to the Sure Start programme is used as an illustration of the potential scale of impact
- AIM contributed to the DTI's innovation review[46] in 2003, and during the early stages of the review organised a strategic research forum around some of the innovation issues, which helped to flesh out the thinking and formulate ideas. AIM was also cited has having done important work on the subjects of 'ownership and productivity, research and development (private and university), the benefits of university collaboration and the impact of engagement in Far East economies.' Such work was regarded as influential in forming a much more sophisticated understanding of the factors holding back UK productivity growth
- The IAH is a reference laboratory for several diseases and receives samples of all new strains as they are encountered. IAH is central to surveillance and diagnostic duties, as well as research into the development of faster and more efficient ways of overcoming the challenges to animal health posed by infectious diseases which have a potentially huge cost to the UK economy.

4.1.4 Quality of life impacts

Research Council outputs, as described above, have improved the delivery of public services and this gives rise to a direct economic benefit in the form of cost savings to the exchequer and others. However, Research Council outputs also contribute directly to the quality of life and this generates social benefits over and above efficiency savings. They can often be the most difficult to value but are relatively easily identified.

They can be described in the following ways:

- Healthcare benefits which improve the quality of life for patients and carers[47]

[45] CASE is also a form of studentship sponsored by the Research Councils. To avoid confusion throughout the report "CASE studentship" is used to describe those and CASE refers the Centre.

[46] http://www.berr.gov.uk/files/file12093.pdf

[47] We note that methodologies for valuing these quality of life enhancements are more developed in the medical area than in most others

- Prediction of environmental impacts and how they might be addressed
- Social welfare benefits such as cohesion or enhanced security. These may often be the result of achieving policy goals
- Cultural advances. It is widely argued that improvements in cultural life generate benefits to society over and above those which are measured by willingness to pay. This is perhaps evident both in relation to arts and also humanities, and also in relation to research which improves our understanding of the fundamental laws of nature.

The case studies have produced examples of all four types of quality of life impact:

- Many of the case studies (particularly those of BBSRC, MRC and PPARC) are targeted, ultimately, at biomedical improvements which will enhance health care and potentially longevity of life
- The Tyndall Centre's objective is to focused on 'seeking, evaluating and facilitating sustainable solutions to climate change'. In addition, Foresight Challenge led to development of new materials that help reduce CO2 emissions in aero-engines and the EngD programme led to improvements in ways of reducing nuclear waste and other pollutants reduction
- The ESRC's CASE centre which led to a better understanding of social exclusion and how to address it and books produced under the AHRC Research Leave Scheme which were felt to have contributed to bringing the communities in Northern Ireland closer together and improving the understanding of the plight of children in conflict situations
- The Surrealism Centre which added new dimensions to the study of one of the most important art forms of the 20th Century.

4.2 Impacts from Research Council funding identified through the case studies

The case studies and an estimation of the impacts resulting from them are set out in Figure 8. Because of the methodological challenges outlined in previous sections, we do not claim the same level of robustness for estimation of all impacts. There are four types of impact we set out:

- Past or current impacts where we have reasonable confidence that the research outputs have led (directly or indirectly) to an impact which can be valued. This is labelled as an **actual impact** and we provide an estimation of its value or range of values
- Potential future impacts where we have reasonable confidence that research outputs will lead (directly or indirectly) to an impact which can be valued. This is labelled a **potential impact** and we provide an estimation of its potential value or range of values
- Past, current or future impacts where we have reasonable confidence that the research process has led or could lead (directly or indirectly) to an impact, but this impact can only be valued using assumptions for which we have limited empirical evidence. In this case we label this an

illustrative impact and provide an estimation of its value or range of values based on a set of assumptions which are stated within the case study chapters

- Impacts (whether actual or potential) which are not open to quantification are identified, without a range of values being provided.

The summary table below presents only impacts - rather than listing the significant research outputs which we found in each of the case studies which are reported in Part II of this report. Publications are the most obvious research output and they remain a vital means of communicating new knowledge to other researchers and user communities. All the cases we have explored have led to publications, in some cases in substantial numbers. We are not able to evaluate the quality of these outputs but we would note that a significant proportion of the output is published in leading journals and members of the research teams are highly cited in the literature.

As well as disseminating knowledge they can play an important role in developing perceptions of the UK as the best place to do research (one of the stated aims of the 10 year Investment Framework)[48].

[48] Science & innovation investment framework 2004-2014 HM Treasury www.hm-treasury.gov.uk/spending_review/spend_sr04/associated_documents/spending_sr04_science.cfm

Figure 8: Examples of impacts resulting from case studies

Research Council	Case study	Key characteristics	Impact
AHRC	Centre for Surrealism	Funding for group of universities to undertake research in surrealism. The Centre has, inter alia, organised a number of exhibitions. AHRC input ~ £0.9 million (total).	Actual impacts include: 'Undercover Surrealism' exhibition generated economic impact of ~ £1 million (conservative estimate) Potential impacts include restoration of credibility of surrealism research and contribution to development of creative industries.
AHRC	Books and monographs (Research Leave Scheme)	Funding which provides time for researchers to write up research findings in book or monograph format. AHRC input < £50,000 (total).	Illustrative impacts may include: Savings from lower security costs in Northern Ireland ~ contribution to saving of £200 million annually Increased inward investment to Northern Ireland ~ contribution to increase of £150 million annually from US alone.
BBSRC	Institute for Animal Health	IAH undertakes basic research into animal diseases. It is also a reference laboratory for several diseases and undertakes tests and diagnoses. BBSRC input ~ £3.8 million (2005/06).	Actual impacts to which IAH has contributed include the eradication of Rinderpest, with a net economic benefit to Africa > $1,000 million annually and thereby supporting UK development policy goals.
BBSRC	Bimolecular Sciences Committee	Basic research across the boundaries of physical sciences and biology. BBSRC input ~ £22.5 million (2005/06). EPSRC contribution of 1/3rd of budget (1994 - 2002)	Actual impacts include early stage direct benefits arising from software licensing and establishment of new companies, including: External investment in companies of at least $600 million. Some were in part sponsored through the Applied Genomics programme Software licensing revenue ~£1 million (includes some SRS activity)

Research Council	Case study	Key characteristics	Impact
			Sales revenue ~ £15 million annually for the start up companies.
CCLRC	Lasers for Science Facility	Central resource for researchers. CCLRC input ~ Part of £8 million funding for whole Central Laser Facility of which LSF received ~£1 million (2005/6).	Actual impacts include: £0.25 million funding attracted for an early stage spin out £1 million total investment leveraged from EU and private sector sources. Illustrative impact from realising improvements in healthcare through new drug discovery could realise £multi-millions.
CCLRC	Protein crystallography at the SRS Daresbury	Use of the Synchrotron radiation source by academics and businesses. CCLRC input ~ £12.6 million (1995-2004).	Actual impacts include, for one new business user of SRS, the raising of ~ £50 million in funding. Software developed from SRS (and BBSRC funding) generates licensing revenue ~ £1 million annually. Illustrative impact on drug product revenues could range from $15-200 million annually.
EPSRC	Engineering Doctorates	Doctoral training programme designed to produce engineers with management skills. EPRSC input ~ £12 million (1992/3-1997/8).	Actual impacts include: Leverage around £30,000 per student from private sector Market capitalisation of company founded by EngD during studies >£100 million Contribution to innovations from EngD students including: a new test method estimated to have saved £ millions by reducing warranty returns; • a premium product with lower manufacturing overheads realising a total margin of £ tens of millions annually; a new lower environmental impact product that has become the world

Research Council	Case study	Key characteristics	Impact
			leader; • novel engine management techniques yielding significant fuel and cost savings, and lowervolumes of persistent pollutants with implications for climate change Salary benefits for cohort ~ £80 million (maximum) a proxy for economic impact.
EPSRC	Foresight Challenge	Collaborative research with businesses in the broad area of applications of ICT. EPSRC input ~ £8.6 million (1997-2000).	Actual impacts include: Leverage ~ £8-10 million funding from private sector Creation of new business, of which one, Parc Technologies was sold to a multinational, Cisco for $9 million in 2005 Impact of Mobile VCE estimated at many £ millions and has contributed to retaining multi-national telecommunications research capability in the UK, Potential benefits include a cost savings of ~ £5 million from more effective aero-engine development process due to improved insight into materials Illustrative benefit of new materials from potential contribution to more fuel efficient aviation ~ $828 million.
EPSRC	Basic research in polymer science	Mixture of responsive and directed mode funding. The case study sampled universities attracting around £16 million of funding from a total EPSRC input of around ~ £49 million (1992 - 1996).	Identified actual impacts include: New polymer licensed with an investment of ~ £10 million by the company exploiting the technology Cost savings through improved modelling processes ~ £0.1 million per product development project (products not specified)

Research Council	Case study	Key characteristics	Impact
			Spin-out company (CDT) recently merged with Sumitomo in a deal valued at $285m.
ESRC	Centre for Analysis of Social Exclusion	A focus on one area of CASE's work: Generational and Life Course dynamics. ESRC input ~ £1.2 million (97/98-05/06).	Contribution to development of evidence-based policy for Sure Start programme where Government currently spends £1,000 million per year. Potential broader impact from better, faster policy making in sphere of social exclusion.
ESRC	Advanced Institute of Management	AIM is a network of research fellows designed to address key management issues and to develop relationships between business schools and businesses. ESRC input ~ £21.8 million (2002-2007). EPSRC input ~ £3.2 million (2002-2007)	Illustrative impact of potential increase in turnover growth in AIM-associated companies ~ £4 - 20 million (current year). Potential to raise the impact of management theory on industry practice - including through high quality publications and associated activities.
MRC	Protein Phosphorylation Unit (Kinases research)	Protein Phosphorylation Unit at the University of Dundee, founded in 1990 MRC input ~ £16 million (total).	Actual impacts identified include: Leverage ~ £23.4 million (1999 - 2008) from private sector 22 licenses (undisclosed amount) Royalties ~ $1.1 million annually Biotech cluster in Dundee area received £50 million joint private-public sector investment (1997). Illustrative impact from accelerating drug discovery process ~ £ multi-millions.

Research Council	Case study	Key characteristics	Impact
MRC	DNA Technology	Aspects of DNA technology research. MRC input ~ £12.5 million (estimated) since 1974.	Actual impacts include two major spin-outs ~ $160 million market capitalisation for one. The other is a key contributor to the $600 million DNA micro-array market. Wider benefits include a contribution to the $2,000 million global biochip market. Illustrative impacts include a potential £47 million benefit from earlier detection and conviction through DNA fingerprinting.
NERC	Ocean Margins LINK programme	A LINK programme with the objective of developing a scientific understanding of effects in deep water oceans. NERC input ~ £9 million (2000 - 2007).	Actual impacts include leverage ~ £9 million from private sector. Potential impact expected in the short to medium term include improved risk mitigation and site prediction in oil drilling in Atlantic margins ~ £100 million. Illustrative wider impact includes the application of analytical techniques to drugs testing in sport ~ £10 million annually.
PPARC	PhD students	The subsequent career paths of PPARC funded PhD students. PPARC input ~ £65,000 per student.	Actual impacts include returns to individual ~ £70,000 average return per student (relative to those without a PhD), a proxy for econoic impact. A large spread of salary benefit identified, including a significant minority (~20%) with financial services salaries substantially more than double the average.
PPARC	Detectors research and its use for medical imaging	PPARC supports the development of leading edge detectors for use in major facilities. This case study looked at the transfer of these technologies to medical imaging devices. PPARC input ~ £2 million (but difficult to differentiate	Nature of the dissemination of the codified knowledge from the research is such that direct impacts are difficult to identify. An illustration suggests that leading edge detectors have potential to contribute towards impact of improved medical applications, including ~ £1,000 - 10,000 million annually in avoidance of

Research Council	Case study	Key characteristics	Impact
		funding).	premature deaths
Cross-Councils	Tyndall Centre	Virtual Centre for interdisciplinary research into climate change. Centre established with core funding of £10m provided 50% NERC, 37.5% EPSRC, and 12.5% ESRC.	Actual impacts identified include: Leverage of ~ 40% of funding from mix of private, public and charity sectors Self sustaining consultancy services Potential contribution to influence on UK and global policy- making addressing £310,000 million global warming challenge.
Cross-Council	Applied genomics research	A LINK programme sponsored by BBSRC, MRC and the DTI. Research Council inputs ~ £14 million (total).	Actual impacts identified include: Leverage ~ £14 million from private sector Six companies received further investment > £500 million. Some were in part sponsored by the work shown in the Biomolecular Sciences Committee case study. Illustrative impact from accelerating drug discovery process ~ £ multi-millions.

4.3 Impacts from existing Research Council case studies

A number of studies have looked at Research Council activities, although few provide measures of economic impact (and were not generally intended to do so). The key points from those we have reviewed are summarised in the executive summary and are set out in Figure 9 below.

Figure 9: Research Council and related impact studies

Research Council	Case study	Key characteristics
AHRC	Polynesian visual arts: 'meanings and histories in Pacific and European cultural contexts' Pricewaterhouse Coopers LLP January 2007	To bring Polynesian artworks to greater public attention through exhibitions at the Sainsbury Centre (University of East Anglia) and British Museum. This exhibition brought together craft, culture, history and people. The exhibitions attracted some 23,000 visitors to the Sainsbury centre and an estimated 120,000 visitors to the British Museum. ACTUAL IMPACT: Tourist and visitor expenditures valued at £0.27 million for the Norwich region, extending to £3.9 million for London and £8.1 million on the UK economy (estimated at 90% additionality from support).
AHRC	'The AHRC Centre for Research in Intellectual Property and Technology' Pricewaterhouse Coopers LLP January 2007	The centre works in such areas as IP, IT law, ethics and regulation of virtual societies, with a strong influence on policy. To create a strong interaction between academics, regulators and industry as a consultancy centre. The Centre attracted £0.6 million of external funding from its research and extra funds from its e-learning programmes. ACTUAL IMPACT: This is a difficult case to unpack, but it was estimated that £190,000 was attributed solely to additionality in the 3 years to 2005. POTENTIAL IMPACT:

Research Council	Case study	Key characteristics
		Estimates from its education courses indicate additionality for net economic impact (as NPV) of £8.3-£11 million between 2002-2031.
AHRC	'Are translucent / transparent architectural structures possible?' Pricewaterhouse Coopers LLP January 2007	A link of two projects, firstly investigating recycled glass and research into new composite materials (e.g. TTURA). Secondly, to investigate the viability of transparent/ translucent 'buildings'. ACTUAL IMPACT: Current net GVA of £190,000 and IP royalties of £15,000. POTENTIAL IMPACT: Projected Gross Value Added of £2-3 million and IP royalties of c.£0.5-1 million over 25 years from new companies selling TTURA (Additionality of GVA estimated at 70%) Reductions to landfill NPV c.£22-34,000 over this period.
AHRC	'The past, present and future of flexible housing' Pricewaterhouse Coopers LLP January 2007	Links physical design of housing with social issues to adapt accommodation to suite changing lifestyles (e.g. children, ageing or disability). Such as adding or removing 'units' dividing or opening internal areas. ACTUAL IMPACT: This research led directly to external funding for production of the manual, in turn setting industry standards. The range of low-high estimates on housing maintenance savings is between £105,289 and £4,211,567. Similarly for gross rental income through reduced vacancy rates, between £33,670 and £1,262,607 (Figures cited for 2004-05).
AHRC	Archaeological research at Avebury, Wiltshire and the 'Longstones Project' Pricewaterhouse Coopers LLP 2007	Archaeological research in Wiltshire which has contributed to local historic understandings and its economy. ACTUAL IMPACT: Additionality between the research and designation of World Heritage site is linked. The estimate of additionality (50%) is suggested to be £87,500 due to the extra visitors attracted from the research which

Research Council	Case study	Key characteristics
		enabled World Heritage status. All archaeological research at the site is estimated to have generated a net additional £13million in visitor expenditure in the twenty year period 1986-2006
AHRC	Raphael economic impact survey Winter 2004-05 Draft Commentary Report MEW Research: London	ACTUAL IMPACT: Economic impact estimated at ~£30 million excluding admission charges. Incidental charges of £1 million in consumables and gifts (etc) were generated (£10 million from day visitors and £9 million for visitors staying away from home. Treasury approved multiplier of 1.5 applied).
BBSRC	Evaluation of BBSRC Modular Training for Industry (MTI) Programme. 2005	ACTUAL IMPACT: A third of the modules run, secured external support (funding, in-kind) ranging from £5,000-£26,000.
BBSRC	Life is too short to remain unnoticed Biotechnology Young Entrepreneurs Scheme (YES). Celebrating 10 years. 2006	ACTUAL IMPACT: 3 entrepreneurs raised over £5 million of equity investment for their ventures. Example case study: A participant founded the spin-out of Cybersense Biosystems Ltd (2001) from the University of Surrey based on Biosensor technologies. Contestant also won the DTI Smart award (2001) and raised over £0.7 million R&D funding with global customers of products.
BBSRC	Making a difference – the past and future and societal impact of Rothamsted research Rothamsted Research Impact Document September 2006	Rothamsted is the oldest active agricultural research station in the world. It is now a multi-disciplinary research site contributing to best practices and policy objectives through scientific applications ACTUAL IMPACT: Implementing farming practices for maize production in Kenya & Uganda have increased yield 20-50% for 1,500 farms Sugarbeet production – average output 3rd most dense and a 50% reduction of agrichemicals and 96% labour reduction

Research Council	Case study	Key characteristics
		POTENTIAL IMPACT: Natural repellents could replace the synthetic repellent market of +$350 million GM Nutraceuticals could capture part of the $10,000 million p.a. market Wheat crop improvements could reduce the £400 million (pa) loss from grain quality Reduction of the £12 million UK expenditure on fungicide spraying from forecasting disease patterns.
BBSRC	Report on the evaluation of outcomes from BBSRC supported knowledge transfer partnerships (KTP) Momenta, Managing Agents of the Knowledge Transfer Partnerships	ACTUAL IMPACT: 78% organisations benefited from partnership 38% companies benefited from partnership 50% companies cited no increased profitability from KTP 23% companies cited increased profitability from KTP 50% of partners have continued partnership.
BBSRC/MRC	Bioscience Business Plan Competition: report on commercial activity of participating teams. Presented to the BBSRC by Critical I Ltd 2003	Reporting on the BBSRC/MRC's first two business plan competitions: ACTUAL IMPACT: 10 spin-out companies formed which have raised £2.3 million in investment, creating 27 FTE jobs. Also spent £1 million in R&D and generated £2.1 million revenues. Companies projected to employ 200 people and spend £25 million p.a. on R&D and generate annual revenues of £39 million 8 licence agreements have been completed generating £0.46 million in initial income and a potential lifetime value of £10.5 million 32 contracts awarded generating over £1.2 million initial income. POTENTIAL IMPACT:

Research Council	Case study	Key characteristics
		From these 32 contracts there exists a potential lifetime value of £36.6 million.
BBSRC/MRC	Tracking progress – a report on the commercial activities of bioscience participants in the 1999, 2001 and 2003 Business Plan Competition Presented to the BBSRC by Critical I Ltd, October 2006	An update(to 2006) of the business plan competitions: ACTUAL IMPACT: Total R&D spend of 13 active respondents was £5.34 million which secured a further £5.66 million in funding Proportion of investment by regionally-based venture funds and RDAs has doubled since 2003 to 26% of total investment, with grant funding at 17%.
EPSRC	Connecting with business: The impact of EPSRC research on society and the economy, May 2007 Knowledge Transfer in Action: Spin-outs in ICT: EPSRC International review of ICT, December 2006 Knowledge Transfer Challenge 2006	A brief summary of EPSRC industrial links and knowledge transfer activities. The EPSRC supports research projects with £2,600 million in funds and collaborates with some 2,000 companies. ACTUAL IMPACT: Spin-out companies have raised £1,500 million on the stock market in the last 3 years; examples are: SPI lasers (est.2000 Southampton) with 140 employees. Novel research for laser applications in medical, aerospace, defence, electronics and other manufacturing industries. Annual turnover £3 million Tissue Regenix (Leeds) raised £0.69 million in seed-corn funding to commercialise bio-engineering products Progressive sports (Loughborough) a keep-fit innovation derived from an EPSRC PhD has been licensed to Reebok, with 30,000 (Reebok Deck) units sold and forecast to reach £50 million by 2009 Surrey Satellite Technology Ltd (est.1985 Surrey) manufactures small satellites with 230 staff, have launched 27 satellites with export sales of £150 million, and revenues forecast of £30 million for 2006-07 Nanoinstruments (est.2005 Cambridge) from the Dept of Engineering construct carbon nano-products to serve the nanotechnology industry. Turnover in first year £0.2 million. POTENTIAL IMPACT:

Research Council	Case study	Key characteristics
		Buildings are responsible for 45% carbon emissions in the UK. Research is underway to construct 0% carbon buildings by 2016.
EPSRC	Impact study of the EPSRC Life Science Interface (LSI) Programme November 2005	40% of EPSRC grants have links with industry, LSI acts as a link with the Life Science sector. ACTUAL IMPACT: BioNEt (North east post-genomics network) is a regional network funded by LSI established in 2001 which has held 19 workshops, 10 industrial seminars and 11 research seminars with 150 speakers collectively with 20% from industry. Has attracted £6,000 through sponsorship and able to attract £145,000 income from these activities in its first three years.
EPSRC	EPSRC Collaborator Satisfaction Survey October 2006	45% of respondents thought the collaborative project they had supported would lead to a moderate, high or very high impact on their business within 5 years, while over 80% thought the project had medium, high or very high value to their business.
ESRC	Policy & practice impacts of research funded by the Economic and Social Research Council: A case study of the Future of Work programme, approach and analysis. Technical Report. Wooding, S., Nason, E., Klautzer, L., Rubin, J., Hanney, S. & Grant, J. (2007) Rand publications: London	Technical Report for the Future of Work programme (FoW), summarised from case-study analyses. ACTUAL IMPACT: Interaction between governmental and non-governmental organisations and private sector. Utilised seminars and secondments. Over 75% Principal investigators felt FoW formed networks with researchers, policy makers and practitioners. Publication of 11 books, 69 chapters, 4 special issue journals, over 100 peer-reviewed articles and over 200 conference presentations.. Policy debate included 60 working papers. Contributed to the promotion of 20 academics and includes nine secondments to government Principal investigators cited 50 policy impacts from national government, political parties, employers and unions Changes to employment legislation, families bill and maternity-paternity leave

4. Evidence for the economic impact of the Research Councils

Research Council	Case study	Key characteristics
ESRC	Policy and Practice Impacts of ESRC Funded Research: Case Study of the ESRC Centre for Business Research SPRU, Ingenio March 2007	Identifies a non linear view of relationship between academics, potential users and beneficiaries of academic research. Boundaries between "users" and "producers" become blurred. Development of formal policy responsibilities is a major way in which the research agenda was influenced by policy needs. Social networks established and sustained by the centre emerged as one of the most important channels for policy and practice application.
ESRC	Centre for the Analysis of Risk and Regulation (CARR) British Academy (2004). 'That full complement of riches': the contributions of the arts, humanities and social sciences to the nation's wealth.	CARR draws upon the expertise of those working in law, sociology, political science, accounting, economics, geography and environment and operational research. It pursues academic research into risk management and regulation and provides partners (including BP; PwC; Deutsche Bank and Aon) with a stream of knowledge transfer on operational, environmental and compliance risk management in both the public and private sector. Staff at the Centre engage actively with policy makers and practitioners both in the UK and abroad. In the UK, staff have advised policy makers in the Cabinet Office, DTI, Environment Agency, Health and Safety Executive and Treasury. They have also engaged with the Committee for Standards of Public Life, National Audit Office, Commission for Health Improvement, Strategic Rail Authority, Railtrack and so on. Engagements abroad include government organisations and policy-makers in Canada, Italy, Japan and Jordan and the World Bank.
ESRC	Econometric modelling British Academy (2004). 'That full complement of riches': the contributions of the arts, humanities and social sciences to the nation's wealth.	Of all the fields of public policy, macro-economic management is probably unique in the sophistication of the theory sustaining it. The theory has been operationalised in a number of econometric models for analysis, forecasting and evaluation of policy options, including models developed by HMT, the Bank of England and academic centres at the National Institute of Economic and Social Research, the London Business School, and the Universities of Cambridge, Warwick, Liverpool and Glasgow. The Economic and Social Research Council invested heavily and over a long period in the development of macro-economic modelling and put the UK at the forefront in this field.
MRC	Laboratory for Molecular Biology	Invention of a technology to create antibodies outside the body. By administering the antibodies as a drug,

Research Council	Case study	Key characteristics
	UNICO, UUK, RCUK 2007 IMPACTS: Successes from UK Research	they can be used to support the body's natural response. MRC's patent formed the basis of a new biotechnology company, Cambridge Antibody Technology (CAT) in 1990. ACTUAL IMPACT: MRC sold its royalty stream on one drug (Humira®) to Abbott for $265 million, one of the biggest industry/academia biotechnology deals of all time. In June 2006, AstraZeneca bought CAT for £750 million.
MRC/BBSRC	MRC laboratories in The Gambia Science and Innovation: Making the most of UK Research DTI December 2006	The MRC laboratories in The Gambia first demonstrated the effectiveness of mosquito nets treated with biodegradable insecticides and research funded by BBSRC research led to the discovery of a whole new class of less toxic insecticides The MRC's work triggered large-scale trials in northern Ghana, Kenya and The Gambia. This led the Tropical Diseases Research Programme of the UN, World Bank and World Health Organization (WHO) to fund research to improve methods for treating nets and since 1998 they have been used in the WHO's Global Malaria Programme. ACTUAL IMPACT: In Vietnam, insecticide-treated nets were introduced in 1991 and deaths from malaria were virtually eradicated by 2003. The costs of providing treated nets for 1000 people for one year are less than half of the cost of spraying. The cost of free nets, including insecticide, labour and transport, for the 350 million people in lowland tropical Africa is £189 million a year. This is 17 per cent of the amount spent on 'de-fleaing'cats in Europe and the US. POTENTIAL IMPACT: Malaria's direct and indirect costs have been shown to be a major constraint to economic development. Annual economic growth between 1965 and 1990 in countries with severe malaria averaged 0.4 per cent of GDP per capita, compared with 2.3 per cent in the rest of the world.

4. Evidence for the economic impact of the Research Councils

Research Council	Case study	Key characteristics
NERC	Economic benefits of environmental science. A study of the economic impacts of research funded by the Natural Environment Research Council Pricewaterhouse Coopers LLP November 2006	ACTUAL IMPACT: Rapid Climate Change Programme attracted £1.72 million from European partners and £3.93 million from the USA. POTENTIAL IMPACT: Helping develop a UK marine biotechnology industry £224-1,222 million Geological survey Providing subsidence and ground instability data to insurers, developers and local authorities £70-270 million Reducing the cost of gritting and salting icy roads £20 million Discovering the hole in the ozone layer £8-40 million Flood Estimation Handbook £7-34 million Lowland Catchment Research Programme £2-9 million
PPARC	"Maths leading to better computer games" UNICO, UUK, RCUK 2007 IMPACTS: Successes from UK Research	Gamers demand ever-increasing realism but often it takes too long for computers to work out exactly how light and shade should fall on objects as they move. Researchers found their way of doing the calculations was 10-100 times faster and decided to set up Geomerics in 2005 to exploit the opportunity. (Note that two researchers were astrophysicists, one an engineer and one an EPSRC advanced research fellow, demonstrating cross-cutting nature of much of the investment of Research Councils.) POTENTIAL IMPACT: Share of a $1,000 million a year market.

4.4 Existing output data

There is some data available on aggregate Research Council activity which is reported to DIUS as part of the Output Framework. We have classified this, where possible, to reflect some of the impact channels described in this report and discussed in the case studies. Relevant examples have been summarised below. Note that data from the 2006 Output Framework report has been used as the 2007 report will not be published until after the finalisation of this report. It should also be noted that there are differences between the Councils in reporting definitions and that some of the indicators relate to UK-wide activity (notably publications) rather than relating solely to Research Council Programmes.

The majority of Research Council spend, and in some cases all, is allocated through universities. We were unable to identify studies which specifically considered the impacts of Research Council spend through the universities[49]. However, the HEBCI survey does provide information relevant to economic impacts of the universities, some of which we would expect to be relatively closely associated with Research Council spend and we also report analysis of this below[50].

4.4.1 Output data relating to publication of research

Analysis published in the Output Framework report includes the following:

- In world rankings, the UK was 2nd to the USA in terms of national share of global citations for 2004, with about 12% of global citations. It was 2nd to the USA on citation count in 6 of 9 research fields, and 7 out of 10 research fields including the newly added humanities field
- The UK led the G8 in 2004 on citations/GDP (0.12), with Canada the nearest competitor
- The UK was ranked 2nd to the USA in terms of national share of global publications for 2004, with about 9% of global publications
- In 2004, the UK had around 13% of the most cited 1% of papers, (ranked 2nd in the world)
- In 2003, the UK was ranked 2nd to Italy in the G8 for publications/researcher, and 4th overall in the world.

4.4.2 Output data relating to development of human capital

Analysis published in the Output Framework report includes the following:

- In 2004/5, there were 119,450 higher degrees obtained in the UK, 15,775 of which were doctorates. Of these, 59,185 higher degrees and 9,640 doctorates were UK domiciled

[49] We are aware that the BBSRC has commissioned case studies of the 10 universities which receive the highest levels of BBSRC funding, but this study has not reported at the time of writing.

[50] The analysis has been undertaken by SQW using 2005-06 data (http://www.hefce.ac.uk/pubs/hefce/2007/07_17/)

- In 2004/5, of the 42,375 former full time postgraduate students with UK domicile whose destination was known, 4% were assumed to be unemployed. Of the 29,075 former part time postgraduate students, 1.7% were assumed to be unemployed
- In 2003, the UK was ranked 2nd among G8 nations for the number of PhDs awarded per researcher
- In 2003, the UK was ranked 6th equal in the G8 with 5.92 researchers per thousand workforce.

4.4.3 Output data relating to business and commercial impacts

Analysis published in the Output Framework report includes the following:

- Total funding for R&D performed in the Research Base in 2003-2004 was £5,486 million of which:
  - 72% came from Government
  - 14% from charities
  - 8% from overseas (including 4% from the EU)
  - 5% from UK industry
- Data covering 2003-04 for UK HEIs indicate an 18% increase in income from contract research as compared to 1999-00. For Public Sector Research Establishments (PSREs) the second annual survey indicates a rise of 47% in income from business from 2003-04 to 2004-05
- Data covering 2003-04 for the UK indicates the overall value of collaborative research has risen by 13% in the UK, to £541 million and consultancy income to £211 million. 2005/6 HEBCI data suggests that 31% (by cost) of all collaborative research undertaken by the universities is funded by the Research Councils
- Data covering 2003-04 for UK HEIs indicate an 86% increase in number of patent applications and 146% increase in number of patents granted annually as compared to 1999-00
- Whilst the numbers of new spin-outs for UK HEIs have declined in 2003/04 (down from 197 to 167) this can still be attributed to the impact of schedule 22 of the 2003 Finance Act. However there seems to be more flexibility in HEIs approaches to marketing the fruits of their research. There has been an increase in the numbers of employees (up from 12,800 to 15,200) while aggregate turnover has increased from £358 million to £448 million. For PSREs the second annual survey indicates a fall of 4% in the number of spin-outs from 2003-04 to 2004-05
- Data covering 2003-04 for UK HEIs indicate a 288% increase in number of licenses and options granted and 64% increase in gross income from IP since 1999-00. For PSREs the second annual survey indicates a fall of 53% in the number of licenses executed but a rise of 32% in the income from licensing from 2003-04 to 2004-05. Research Council data suggests that £36.5 million in licensing income from the RCIs was generated in 2005-06.

4.5 Net outputs: What would have happened without Research Council funding?

In all cases we have tried to assess the extent to which the research, and ensuing outputs, would have occurred in the absence of Research Council funding. This is our simplified definition of 'net outputs'.

The factors which we would ideally consider individually and in aggregate are defined as follows:

- **Additionality** - What are the outputs which would not have been secured without Research Council funding (also known as the counter-factual)
- **Displacement/substitution** - The extent to which Research Council funding causes a reduction in outputs elsewhere in the target area or otherwise causes a firm to substitute one activity for another
- **Multipliers** - Further economic activity (e.g. jobs, expenditure or income) associated with the inputs to or outputs from the project
- **Leakage** - The number or proportion of outputs/outcomes that benefit those outside the target area of the investment[51]
- **Leverage** - The extent to which other (private or public sector) resources are attracted.[52]

In practice, this detailed consideration is unlikely to be feasible in the current context:

- Identifying what the Research Councils might have supported if they had not devoted resources to a specific programme/facility is unlikely to be feasible. This would involve an exploration of corporate decision making processes which cannot be undertaken during the current project (and is unlikely to provide definitive results in any case). In addition, the financial settlement for the Research Councils, in part, reflects intended programmes which would further complicate any analysis
- The project is not structured to identify in any depth what businesses might have done in the absence of RC support, much less displacement and substitution effects within companies.

Given these challenges we instead pose three broad questions:

- Whether some other (private sector) organisation might have funded the research in any case or whether the outputs could have been obtained from publicly funded research abroad (offering a simplified proxy for complex additionality, displacement and substitution effects)
- The extent to which additional funding has been attracted from public or private sector sources given the Research Council investment (leverage)

[51] It is important to distinguish between 'leakage' and 'dissemination' of outputs. The first is a technical term relating to the capture of benefits - and significant leakage results in lower impacts for the UK. The second is central to the research process and is considered a positive effect.

[52] This is often treated as a separate effect, but for ease of reference we have included at this stage.

- The extent to which outputs from the research may have been exploited outside the UK and the UK has therefore not benefited fully from the investment (leakage).

In general, it is worth noting the following factors which impact our understanding of net outputs.

In relation to the first question, the charities are of course an alternative source of funding for many researchers but, with the exception of the Wellcome Trust, are much smaller than the Research Councils and do not invest in basic research to the same extent. If we take any single programme in isolation, then one of the charities might have supported it, indeed there are many examples of joint funding in the case studies, but this would inevitably have been at the expense of some other area, and in aggregate the charities cannot be considered a substitute for the Research Councils[53]. The other potential source is industry, but the fundamental nature of most of the activities we have examined means that in most cases, Research Council funding is genuinely additional.

The collaborative programmes do raise some other issues in that industry has demonstrated an interest in the research. However, the consultations undertaken during the case studies indicate that they would not be willing to pay the full costs of the research and, in some cases, that a consortium of firms would be unlikely to emerge unless there was a public programme to organise the collaboration and undertake research. The requirements to publish research also ensure that the outputs have more of the characteristics of a public good.

4.6 General economic studies of research impacts

In the 1980s and 1990s economic returns of basic research were commonly cited for the social rate of return for R&D investment (Griliches, 1995), especially under the assumption of the linear innovation model. These social rates of return typically ranged from 0% to near 70% (Martin & Salter, 1996), but levels over 100% have been recorded (Jones & Williams, 1998). The social rate of return to R&D can be disaggregated to an effect of productivity through innovation, and also the potential to imitate (especially for laggard countries to increase productivity through R&D re-engineering). However, with the complexity of the innovation process becoming better understood, this form of quantification has been subject to widespread criticism. More recently analyses by partial-indicator elasticities have estimated rates of return as cited by Scott et al. (2002) (Figure 10).

[53] There is, of course, also the point that most would withdraw if they believed they were simply substituting for public funding.

Research has also focused specifically on the economic benefits arising from improvements in health. For instance, the US Exceptional Returns[54] report published in 2000, summarised work commissioned from a number of leading US economists. This work suggested that the total economic value of reductions in US cardiovascular disease alone might be worth 20 times the amount the US spends on medical research in the area. Subsequent studies have also found large rates of return.[55] [56] However, some of the assumptions made have been questioned.[57] There is also uncertainty about the degree to which the results can be extrapolated to countries such as the UK, where spill-over benefits to the UK from research in other countries are larger than might be the case in the US. The MRC, the Wellcome Trust and the Academy of Medical Sciences are therefore sponsoring a programme of research to estimate the economic value to the UK of health benefits arising from UK-funded medical research. Two projects have been funded. One will look in detail at the economic benefits arising from UK research in cardiovascular research and in mental illness. The other will take a more global approach to UK health as a whole.

Figure 10: Estimates of partial indicator elasticities for public basic research

Author	Sector	Finding
Toole (2000)	Pharmaceuticals	~1% increase in stock of public basic research leads to 2-2.4% increase in commercially available new compounds
Guellec & Van Pottelsberghe (2000)	All sectors	Each $US of public funding for R&D (inc. defence) leads to additional business R&D of: +$0.70 when allocated to business -$0.44 when allocated to government labs[58] -$0.18 when allocated to universities
Beise & Stahl (1999)	Manufacturing	10% of manufacturing firm's products or processes were only possible through complementary public research, this equated to 5% of new product sales.
Tijssen (2001)	All sectors	20% of private sector innovations were partially based on public sector research

The figures presented by Beise & Stahl (1999) are analogous to the study of Mansfield (1991) citing that the development of 11% new products and 9% new processes were accelerated due to the presence of academic research. This equated to 2.1% of sales for new products and 1.6% for new processes.

54 http://www.laskerfoundation.org/reports/pdf/exceptional.pdf

55 See for instance www.researchaustralia.com.au/files/Access_Economics_Exceptional_Returns.pdf

56 See also Murphy K.M and Topel R.H. The value of health and longevity *J Political Economy 2006* **114**, 871-904

57 Medical research: assessing the benefits to society. Report of an international symposium organised by the UK Evaluation Forum and published in 2006 by the Academy of Medical Sciences, MRC and the Wellcome Trust. See pages 26 and 27.

58 A negative elasticity implies some crowding out of private sector R&D, but the estimates indicate a net gain to the economy.

More recent OECD work as focused on the impacts of R&D on total factor productivity (TFP)[59]. Investigations over nearly two decades (1980 -1998) and across 16 OECD countries which included the UK, indicated[60]:

- The impact of public R&D on productivity is positively affected by the share of universities in public research.
- The impact of public research diminishes with the share of industry funding of Higher Education, whereby increasing business sector finances for university research, lowers the impact on growth
- 1% increase in business R&D increases Total Factor Productivity by 0.13%
- 1% increase in public R&D increases Total Factor Productivity by 0.17%.

Furthermore, a similar OECD study (Guellec & Van Pottelsberghe, 2004) concluded that no evidence existed for crowding out of private investment by public investment in R&D; in fact they may complement each other.

A less direct, but interesting, indicator of returns to R&D has been derived by comparing publications and economic prosperity. Figure 11 (King, 2004) shows a comparison between a measure of citation intensity and GDP per head for 31 countries. This strongly indicates a positive relationship between the two, although it is clearly non-linear and abstracts from many complex interrelationships.

Figure 11: Comparing economic and scientific wealth

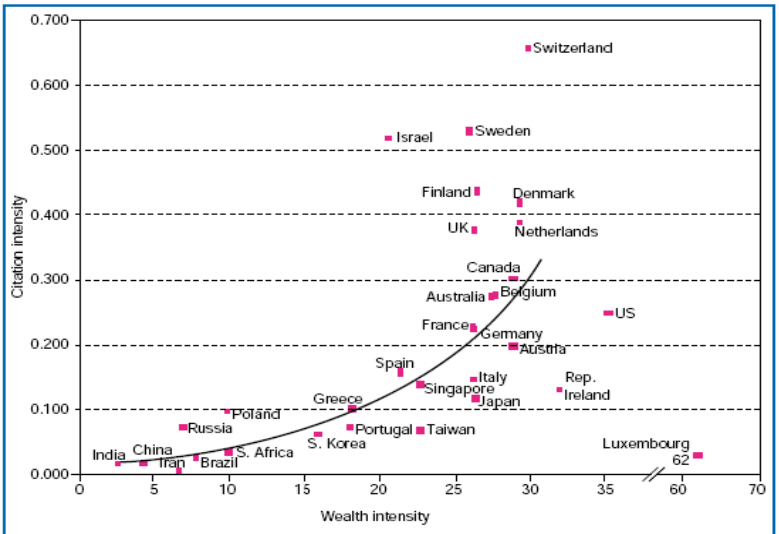


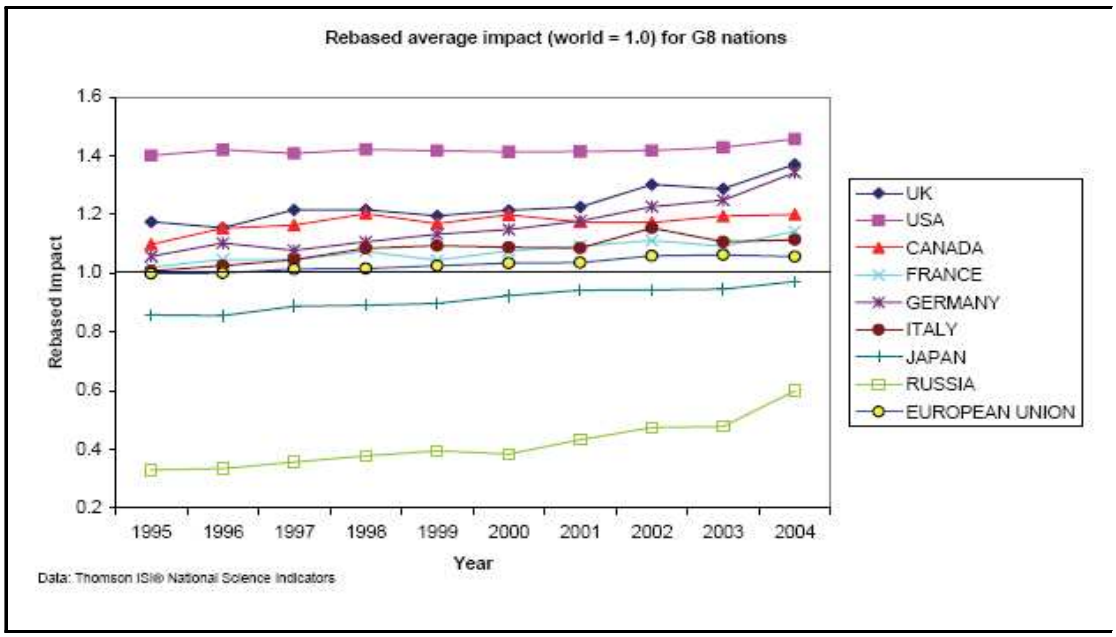
Figure 2 **Comparing economic and scientific wealth. National science citation intensity, measured as the ratio of the citations to all papers to the national GDP, shown as a function of the national wealth intensity, or GDP per person, for the 31 nations in the comparator group. GDP and wealth intensity are given in thousands of US dollars at 1995 purchasing-power parity. Sources: Thomson ISI, OECD and the World Bank.**

[59] An attempt to measure outputs per unit of aggregate inputs as opposed to outputs per unit of labour or per unit of capital.

[60] Guellec & Van Pottelsberghe, 2004

Note that the UK is 'above the line' suggesting wealth is lower than citation intensity would suggest. This almost certainly reflects the high productivity of UK research as measured by citations. Figure 12 shows that the UK is second only to the USA amongst G8 nations for publication impacts. Additional analysis (not shown) indicates that the UK leads in terms of citations per unit of public expenditure on R&D.

Figure 12: Impact factors for publications- G8 comparison (%)



There is a considerable literature measuring the private and social returns to education, including higher education. The starting point for this work is that salary differentials reflect productivity differentials and are therefore are indicators of contributions to national output. A recent study (O'Leary & Sloan 2005) examined various levels of education and also distinguished between disciplines. Figure 13 shows the returns for masters and PhD degrees relative to an undergraduate degree, i.e. they show the increase in returns for the additional study A blank cell indicates that although a difference was detected it was not 'statistically significant' (it was small enough to have arisen by chance rather than because of systematic differences).

Figure 13: Returns to higher degrees compared with undergraduate degrees - by discipline, gender and level of qualification (%)

	Masters		PhD	
	Men	**Women**	**Men**	**Women**
Medicine		9	18	15
Sciences		9	8	14
Maths/computing			14	12
Engineering & technology	8		16	
Architecture & related	13			

	Masters		PhD	
Social sciences	8	18	8	14
Business and finance	14	20	20	11
Arts	9	8		9
Education	12	8		12

Source: Based on O'Leary & Sloan 2005

5 Developing a baseline for assessing economic impact

5.1 Does this report provide a baseline?

As noted in section 1.2, this report was intended to form a baseline 'in producing a repeatable methodology that will result in a description and broad assessment of the economic impact of the Councils' activities, against which future achievements can be assessed. It is anticipated that the baseline will be a descriptive baseline supported by metrics where possible and relevant (which will most likely vary between the Research Councils)'.

While a further report will address this issue in detail following further analysis, here we provide an analysis of the extent to which this report can and does provide a baseline in the sense intended above.

This report provides a baseline to the extent that we have followed a methodology which is codified and repeatable. For example:

- Case studies were selected on the basis of an understanding of their input characteristics in a structured process
- Case study interviews were carried out using a standard set of initial questions and write ups follow a standard structure
- We have designed a framework for understanding impacts which captures a comprehensive range of impacts in a simple way.

As a result, the snapshot of impact we have produced can be repeated and over time it will be possible to build up a more comprehensive and detailed picture of impact of Research Council funding both on an aggregate and on an individual basis.

Ideally though, a baseline would enable Research Councils to assess current impacts, on a range of indicators, and revisit these indicators in the future in order to evaluate changes in performance. The case study work, both that undertaken during this study and previously, does not, however, enable such a baseline to be defined for the following reasons:

- The number of case studies is small both in relation to the number of Research Council 'activities' and in relation to total spend. We estimate that the 18 case studies account for less than 2% of total spend

- They cover differing periods, both in relation to when research was undertaken and when impacts occurred (and given challenges with impact time lags it would be difficult to make these periods consistent)
- The case studies were selected to reflect a wide range of activities in order to provide a full description of the ways in which impacts arise as was required by the terms of reference. There were also practical considerations of data availability in the time allocated to this study and the need to cover all of the Research Councils as well as some cross council programmes. They were not selected with a view to extrapolation of the results to other programmes
- The input devoted to each was limited and the studies have focused on subsets of stakeholders and impacts within each case study area. They therefore provide a partial analysis of impact in each case.

5.1.1 Does output monitoring data help in establishing a baseline of impact?

As noted previously, all the research councils currently collect output indicators which are reported to DIUS. These output indicators are able to illustrate the various channels by which impacts are realised (as outlined in section 4.4) and how Research Council outputs contribute to the UK science and innovation system which delivers economic impacts. (We note that Research Councils have been asked to re-categorise their data according to the new UK economic impact reporting framework.)

However, there are a number of methodological reasons why we were not able to use the data currently collected in combination with the case studies undertaken in this study to derive an impact baseline. More specifically:

- The output indicators cannot, in general, be mapped onto specific activities or expenditure by the research councils
- The outputs cannot always be attributed to research council activities, for example, some councils report all publications in the subject areas for which they are responsible, whether or not the research was supported by the council; the data on commercialisation of IP reflects in part inputs from university commercialisation offices and other organisations
- There are differences between the councils in the ways in which indicators are defined, although this is probably the least important factor
- And, as already mentioned, the sample of case studies is small so that even without these problems extrapolation of the impacts identified in the case studies to total spend via the output indicators could not be justified. Existing case studies could not be simply be 'added' to the current case studies to form a baseline due to familiar problems of different methodologies, inconsistent study periods and reliance on illustrative or potential impacts.

Taken together, these factors mean that we cannot extrapolate from the case study findings to total spend and are therefore unable to provide a baseline against which future performance can be assessed.[61]

5.2 Implications for future work on impact assessment

The second phase of this study will be concerned with recommendations for future assessments of Research Council impact. Substantive work on this further report has yet to begin, but work on the current report has identified clearly some of the major issues which will need to be addressed. Two are particularly important:

- In this study we have assembled direct evidence of economic impact which is valuable in demonstrating, describing and assessing research council impacts. However, they account for a small proportion of total spend and expanding the volume of case study information to encompass a substantial proportion of total expenditure is not feasible. As such, the further report needs to consider what sort of information needs to be collected, and how, to enable robust extrapolations to be made
- For the reasons discussed earlier in this chapter, this report has not generated a baseline against which impacts in the future might be judged. The further report will address this issue and also consider the extent to which a baseline might be established retrospectively. That is to say it will consider the feasibility of establishing a basket of impact related indicators relating to (for example) 2007.

We also expect to make some more specific recommendations in the further report, including:

- Further studies which address key methodological issues such as how do certain impacts arise and how might they be evaluated. We are not thinking of a funded programme of research policy studies but there may be specific areas which are of significance to several councils and relate closely to activities where the Research Councils are the primary funders
- Further studies of specific programmes/activities which are representative of a significant share of expenditure (either for a single Council or across several) but for which there is limited impact information available. The results of these studies might then be generalised to similar programmes
- Required data related to the monitoring of programmes/projects and post-programme outputs. The report will also consider implications for MIS(s). It will not be possible to explore these in any depth, but we would expect to comment on issues such as consistency between Councils and the ability/need to link data sets.

[61] This issue will be addressed in the further report